Perspectives on the Problem of Alternative Conceptions

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Abstract: Perspectives on the Problem of Alternative Conceptions

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Alternative conceptions present an ongoing problem that has proven difficult to address. Much research into the alternative conceptions of various groups of learners, including pre-service science teachers (PSSTs), has been undertaken. This research study adopts two perspectives to the problem of alternative conceptions in chemistry: one founded upon postpositivism and constructivism, and one founded upon Edith Stein’s phenomenology of empathy and community, using Leslie Baxter’s Relational Dialectics Theory (RDT) as a sensitising theory. Both perspectives lend insight into this problem, with the latter presenting a new perspective not previously adopted in Science Education Research (SER). The postpositivism-constructivism perspective was adopted to examine the role of the model of Science Teacher Education (STE) on PSSTs’ alternative conceptions in chemistry, and PSSTs’ approaches to answering diagnostic instruments, such as that developed as part of this study. The Stein-RDT perspective was taken to investigate the lived experience of PSSTs as they attempted to develop their conceptual understanding, and encountered alternative conceptions, in the context of the community-oriented blended learning programme, which was developed as part of this research study. This approach reframed the problem of alternative conceptions from one which viewed it as a primarily cognitive issue, to one which considered it a problem of persons relating to one another.

The postpositivism-constructivism approach to investigating the role of STE on PSSTs’ alternative conceptions involved the creation of an alternative conceptions diagnostic instrument which was administered to PSSTs following the concurrent and consecutive models of STE across Ireland. The results indicated that, in general, the most important predictor of the prevalence of alternative conceptions was a factor unrelated to any aspect of third-level education: it was PSSTs’ upper-second-level educational experience of chemistry. However, PSSTs’ model of STE was an important predictor in the area of chemical bonding, with those following the concurrent model having fewer alternative conceptions than those following the consecutive model. This was interpreted as being due to the complexity of the topic and differences in perceptions of future roles at the outset of third-level chemistry/science education. The investigation into PSSTs’ approaches to diagnostic items led to unexpected findings which formed a bridge between the two perspectives in this study. PSSTs experienced shame, embarrassment and self-recrimination when discussing their conceptual understanding. This led to a re-evaluation of alternative conceptions as a problem solely within learners’ cognitive structures and a new perspective was sought out which could respond to this aspect of the research. This led to the Stein-RDT approach in which the problem was reframed as one of persons relating to one another.

The Stein-RDT perspective taken to investigate PSSTs’ lived experience of attempting to address their alternative conceptions revealed the presence of three main dialectical tensions: a tension between the denial and acceptance of barriers to conceptual understanding, a tension between expression and non-expression, and a tension between perspectives as a learner and as a teacher. The interplays upon which these dialectics were constituted were central to PSSTs’ experience of conceptual discussions and the behaviours of the community-oriented groups. Direct, antagonist interplays between alternatively-conceived and scientifically-conceived conceptual discourses were observed to lend themselves to more favourable educational outcomes in the groups observed in the study. The engagement of the community-oriented groups with metacognitive experiences was also associated with more favourable outcomes. This engagement and the interplays between conceptual discourses were founded upon the relational dialectics experienced by the community-oriented groups. This thesis presents the research and background relating to the postpositivism-constructivism and Stein-RDT perspectives and discusses the implications of this research for STE and the value of the Stein-RDT perspective for future research.
Declaration

This thesis is presented in fulfilment of the requirements for the degree of Doctor of Philosophy. I, Muireann Sheehan, declare that this thesis is my original work. Where the work of others has been drawn from, this has been fully acknowledged and referenced. This work has not been submitted to any other third-level institution or for any other academic award at this university. This work has been funded by the Irish Research Council.

Signature: __________________________    Sept. 2017

Muireann Sheehan
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Chapter 1 Introduction

Alternative conceptions (aka misconceptions, preconceptions, naïve conceptions, etc.) refer to the phenomenon of learners possessing ideas with a meaning that is not consistent with the commonly accepted scientific consensus. A large body of research has been carried out in this area to date (Duit 2009). Often the focus has been on cataloguing the alternative conceptions of learners in various topics, but research has investigated the impact of teaching strategies and methodologies in remediating alternative conceptions amongst learners. Much of this research is founded upon branches of constructivism and postpositivism. There has been a tendency to investigate this issue in terms of the minutia of specific alternative conceptions or upon fixing the problem of their existence. Although these perspectives are necessary, and are certainly important, the limited success in addressing alternative conceptions amongst learners suggests that other perspectives are needed to capitalise on the knowledge already gleaned about alternative conceptions.

Two areas have been identified in this research that are, as yet, poorly understood. The first of these is the relative impact of various educational factors – particularly in relation to Science Teacher Education (STE) models – upon the conceptual understanding of pre-service science teachers (PSSTs). These have proved an important group in the research area, given that their understanding will impact upon that of their future students. Although research has been carried out on the impact of subject specialisation on PSSTs’ conceptual understanding, the impact of the model of STE used by teacher training programmes has not been thoroughly investigated. One might reasonably think that those following the consecutive model (i.e. the study of science in a degree, followed by the study of pedagogy, education, etc. in a postgraduate diploma) should have a better understanding of fundamental concepts than their peers following the concurrent model (i.e. the study of science, pedagogy, etc. in a single degree programme), given the greater depth of treatment in their subject area.

The second area which is poorly understood in relation to alternative conceptions, is PSSTs’ experience of having alternative conceptions and whether the experience itself may impact upon their ability to replace alternative conceptions with those that are scientifically-conceived. It is widely acknowledged that alternative conceptions are deeply held and difficult to address, but it is not yet understood how learners experience this issue when it comes to the fore in their learning. Understanding more about the communicative practices of learners as they develop or address alternative conceptions can aid researchers in the development of learning strategies that are better suited to learners’ needs. Further to this, a learner does not exist in a bubble of isolation, but is part of a community of learners (in the
form of a class group, a third-level year of study, a study group, etc.) and this communal experience may impact upon learners’ perspectives and ideas (be they scientifically- or alternatively-conceived). An understanding of the role and impact of community in the learning experience can lend further insight into learners’ experience of the problem of alternative conceptions. The identification of this second area as one suitable for investigation in this research study, arose organically from the experiences of the researcher with the PSSTs involved in Phase 1 of the study.

This two-phase study took a mixed methods approach to extend understanding of these areas. The first phase focused primarily upon investigating the relative impact of various educational factors on PSSTs’ understanding of fundamental chemistry concepts. This phase was founded upon postpositivist and constructivist philosophies and the major quantitative strand of research made use of a quantitative research tool. The second-phase of the study investigated PSSTs’ experience of developing their conceptual understanding in a community-oriented, blended learning environment. This was primarily based upon Edith Stein’s philosophy of empathy and community (1989; 2000) and Leslie Baxter’s (2011) Relational Dialectics Theory (RDT). The major strand of this research was qualitative, and Stein’s and Baxter’s perspectives were tools to analyse and interpret the collected data.

The design of this research study moved from a constructivist – postpositivist perspective, which treated alternative conceptions as a problem within PSSTs’ cognitive structures, to a Stein – RDT perspective which reframed the problem as one of persons relating to one another. This shift in focus arose over the course of the research study and the research strands in this study are best framed within this organic process. At the outset, the entirety of the study was designed based on the perspective of alternative conceptions as a problem within learners’ cognitive structures, with the design of the study being adapted at a later date in the study. Therefore, the research process will first be presented in this chapter in order to give the reader an overview of the research strands and their connection to one another. Each research perspective, along with a brief summary of the rationale, methods, and findings of the research strands, will then be presented. This layout of this thesis is intended to reflect the research process and this chapter is an advanced organiser for how the thesis is laid out and why it has been laid out in this way.
1.1 OVERVIEW OF THE RESEARCH PROCESS

The original intention of this research study was to investigate the impact of STE and other educational factors on PSSTs’ conceptual understanding and, based on the findings of this investigation, create a learning programme or strategy that would target the most problematic areas for a group of PSSTs. Based on a review of the literature, blended learning was identified as an under-utilised style of learning programme for the purpose of addressing alternative conceptions. It was intended to be designed to directly target a number of alternative conceptions. The overall investigation was to be founded upon a constructivist – postpositivist perspective in which alternative conceptions were considered a problem related to learners’ cognitive structures. As such the original research questions were:

- Does the model of STE on which PSSTs are enrolled have an effect on the prevalence of alternative conceptions about fundamental chemistry concepts, taking into account other variables such as subject specialism, year of study, degree classification, and previous second-level school experiences?
- Does a blended learning programme improve PSSTs’ understanding of fundamental chemistry concepts?
- How do PSSTs approach conceptual questions in a quantitative alternative conceptions diagnostic instrument?

The first two of these research questions were to be investigated using quantitative research methods. The first was to be the central research question and major strand of research in Phase 1 of the study, with the second research question being addressed by a major quantitative strand of research in Phase 2. A quantitative alternative conceptions diagnostic instrument was to be used to investigate these research questions. The last research question was intended to lend insight into the PSSTs’ approaches towards the types of conceptual diagnostic questions used to collect data within the quantitative research strands and their reasoning about the concepts included in the instrument. It was to be investigated in a minor strand of qualitative research during Phase 1 of the study, with the intention of using insights about PSSTs’ reasoning to design the content of the blended learning programme as well as provide insight into the quantitative research strands.

Phase 1 of the research study proceeded in accordance with this plan. However, the minor qualitative strand of research produced some unexpected findings. PSSTs’ experience of discussing their conceptual understanding and reasoning about various concepts appeared to relate to their non-cognitive capacities as much as to their cognitive capacities. Behaviours and utterances that suggested the presence of shame, embarrassment, self-recrimination and blame appeared to be central to their ability to discuss their conceptual understanding and
possibly even to engage in reasoning about various chemistry concepts. These unexpected findings led to a re-evaluation of the entire foundations of the study as well as the planned research for Phase 2 of the study. This led to the adoption of a new perspective, based on Edith Stein’s phenomenology of empathy and community and Leslie Baxter’s (2011) RDT, which reframed the problem of alternative conceptions as one related to holistic human persons relating to one another. This led to the intended major research question for Phase 2 (i.e. Does a blended programme improve PSSTs’ understanding of fundamental chemistry concepts?) being downgraded to a minor research question in deference to the original research design, and the introduction of a new research question, to be investigated in a major qualitative strand of research, which became the focus of Phase 2:

- How do PSSTs experience the issue of alternative conceptions in chemistry in a community-oriented, blended learning environment?

As a result of this new research question, the blended learning programme was not designed with the goal of directly targeting the particular alternative conceptions found to be problematic in Phase 1, but was instead designed with the goal of creating a community-oriented learning environment in which PSSTs would discuss their conceptual understanding.

![Figure 1.1 Relationship between research strands in the final research design](image)
Therefore, the research strands in the study became related to one another as shown in Figure 1.1. The major quantitative strand in Phase 1 (denoted Phase 1 QUAN in Figure 1.1) was the initial primary focus. This was connected to the minor quantitative strand in Phase 2 (denoted Phase 2 quan) through the original research design as previously described. Therefore, in this thesis the quantitative strands of research are presented first with Phase 2 quan following on from Phase 1 QUAN. The minor qualitative strand of research in Phase 1 (Phase 1 qual) was also related to Phase 1 QUAN via the original research design – this strand of research lent insight into the findings of Phase 1 QUAN by providing a more in-depth analysis of why PSSTs adhered to particular alternative conceptions in Phase 1 QUAN. The findings of Phase 1 qual led to a re-evaluation of the entire perspective which had been adopted by the study and so the major qualitative research strand in Phase 2 (Phase 2 QUAL) arose from the Phase 1 qual research strand. The major quantitative and minor qualitative research strands in Phase 1 and the minor quantitative research strand in Phase 2 are founded upon the constructivist – postpositivist perspective, while the major qualitative research strand in Phase 2 is founded upon the Stein – RDT perspective. This latter strand of research led to some very interesting findings and represents a research approach not previously adopted in the alternative conceptions and conceptual learning research to date.

In order to reflect the fact that the quantitative research strands are related to one another largely through the original research design, these strands of research are the first that will be presented in this thesis. The qualitative strands of research are then presented, starting with the minor strand from Phase 1 as it forms the bridge between the two perspectives adopted in this research study: this research strand was undertaken from the constructivist – postpositivist perspective and the resulting findings were the catalyst for a re-evaluation of the foundations and design of the study leading to the Stein – RDT perspective.

1.2 RESEARCH BASED ON THE CONSTRUCTIVIST – POSTPOSITIVIST PERSPECTIVE

In this portion of the research study, constructivism was combined with postpositivism in order to allow for a perspective that valued subjective experiences while also providing for the existence of objective knowledge. Postpositivism seeks to predict behaviour based on causal explanations, while also maintaining that subjective and objective views are not mutually exclusive (Allison and Pomeroy 2000; Racher and Robinson 2002). Human experience is recognised as valuable and as dependent on an individual’s cognitive structures (Bentley and Garrison 1991). Therefore, this philosophy allows for the existence of objective knowledge but posits that human beings cannot ever attain such knowledge – being confined within their own cognitive structures. Constructivism posits that all learning is an active
process in which knowledge is actively constructed rather than innate or absorbed (Fox 2001). Learning is about making sense of the world and it requires meaningful problems for learners to solve (Fox 2001). These two philosophies lent a focus on individual cognitive structures as the primary issue when considering alternative conceptions while also providing a valid foundation for both quantitative and qualitative research strategies.

The research area of interest within this perspective was the current level of PSSTs’ conceptual understanding, the impact of past education upon their understanding, and on identifying a useful and viable strategy to improve their conceptual understanding.

(a) Rationale

The education of teachers is a continuous process beginning with initial TE and continuing during their teaching career. Although the area of interest in this study was PSSTs’ subject matter knowledge (SMK), Shulman (1987) identified a number of categories that are important for professional knowledge for teaching and which TE should address. Successive researchers have made further refinements to the categories he identified. Grossman (1990), Carlsen (1999) and Magnusson et al. (1999) identified four main areas that they considered to be the cornerstones of professional knowledge for teaching: general pedagogical knowledge, knowledge of context, SMK and pedagogical content knowledge (PCK). Many researchers have taken a special interest in PCK given that this category, in particular, distinguishes the professional knowledge for teaching from that for content specialists (Shulman 1987; Gess-Newsome 1999a). PCK was defined by Shulman (1986) as “subject matter knowledge for teaching” and described as “the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted… for instruction” (Shulman 1987). This blending of content and pedagogy involves the transformation of SMK into forms that are “pedagogically powerful” (Shulman 1987). Knowledge of common student alternative conceptions, and appropriate strategies and explanations to address them, were identified as important elements of PCK (Shulman 1986). Researchers who have since adapted and extended Shulman’s model continue to identify these elements as an integral part of PCK (Grossman 1990; Van Driel et al. 1998; Magnusson et al. 1999; Loughran et al. 2001). Teachers’ SMK (which some authors have subsumed into the category of PCK\(^1\)) should consist of scientifically-acceptable concepts.

\(^1\) Cochran et al. (1993) and Fernandez-Balboa and Stiehl (1995) consider SMK to be a component of PCK while Shulman (1987), Tamir (1988), Grossman (1990), Magnusson et al. (1999) and Carlsen (1999) consider SMK to be a separate but related domain in teachers’ professional knowledge.
and alternative conceptions should not be present (Brickhouse and Bodner 1992). Therefore, TE, whether initial or continuing, must ensure that teachers have a sound understanding of the concepts which they will teach and provide them with the skills to access and understand up-to-date information about promoting understanding among students.

Models of TE are diverse across Europe and the World (Buchberger 1998). STE programmes may follow the consecutive, concurrent, integrated or modularised models, to name a few. The length of STE programmes for second-level teachers ranges from three to seven years in Europe (Eurydice 2012). As a result of the Bologna process (1999), countries in Europe have introduced the consecutive model in addition to other models already in place (Ingvarson et al. 2006). While concurrent programmes should provide a more integrative approach to TE, given that PSSTs study education, pedagogy and scientific discipline subjects in parallel for the duration of the programme, it is widely acknowledged that in reality the approach is fragmented and without coherence between the academic disciplines and educational aspects of the programmes (Coolahan 2001; Sultana 2005). Pre-service teachers on consecutive courses spend three to four years studying solely the academic disciplines and, therefore, study their disciplines in greater depth compared to those following the concurrent model. Both the concurrent and consecutive models are well-established in Ireland.

The effect of one to two year TE programmes following the consecutive model on PCK (Van Driel et al. 2002; De Jong et al. 2005; Hume and Berry 2011), Nature of Science2 (NoS) concepts (Akerson et al. 2006), teaching self-efficacy (Cakiroglu and Boone 2002) and SMK (Kind and Kind 2011; Taber and Tan 2011) of PSSTs has been investigated. The effect of concurrent STE programmes on these areas of professional knowledge for teaching has also been investigated (Czerniak and Haney 1998; Ali and Ismail 2005; Çalik and Ayas 2005; Beyer et al. 2009; Halim et al. 2014). Gansle et al. (2012) have noted an absence of literature regarding the effect of differences in TE programmes, although some research in this area has taken place in the United States (U.S.). The focus of many of these U.S. studies is the effect of alternative pathways to apply for certification (or the lack of certification) on teacher quality and student performance, rather than on the effect of differences between university-based

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1 Which is generally considered to be a component of PCK (Grossman 1990; Magnusson et al. 1999; Fernandez-Balbou and Stiehl 1995) but has also been considered a separate domain of professional knowledge for teaching (Shulman 1987).

2 Which is generally considered to be a component of PCK (Grossman 1990; Magnusson et al. 1999; Fernandez-Balbou and Stiehl 1995) but has also been considered a separate domain of professional knowledge for teaching (Shulman 1987).
There is little research about the effect of different STE models on PSSTs’ professional knowledge for teaching.

SMK has been shown to impact upon the instructional practices of teachers (Hashweh 1987; Carlsen 1993; Baumert et al. 2010) and it may indirectly impact on PCK (Rollnick et al. 2008; Kaya 2009; Baumert et al. 2010; Chai et al. 2013). This is not surprising as Cochran et al. (1991) described PCK as “the synthesis of teachers’ pedagogical knowledge and their subject matter knowledge”. Teachers with poor SMK have a greater number of alternative conceptions and knowledge inaccuracies compared with those with good SMK (Hashweh 1987): they have difficulty identifying alternative conceptions in textbooks and are more likely to include alternative conceptions in their lesson plans (Hashweh 1987); they employ highly routinised activities such as prescriptive individual work and scripted student behaviours (Hacker and Rowe 1985; Carlsen 1993; Sanders et al. 1993; Lee 1995), permit little student engagement with each other or with the teacher (Lee 1995) and are less open-ended with students (Hashweh 1987; Carlsen 1993). Teachers with poor SMK also have difficulty detecting alternative conceptions in students’ answers, correcting alternative conceptions and may, in fact, reinforce alternative conceptions (Hashweh 1987).

SMK is an important component of teachers’ professional knowledge (although there are also other, arguably more important, components), yet research studies have shown that alternative conceptions in chemistry remain prevalent among PSSTs. A number of factors such as subject specialisation and year of study on STE programmes have been analysed for their impact on the alternative conceptions of PSSTs (Kahveci 2009; Kind and Kind 2011). However, few studies have investigated the impact of the model of STE, and the relative impact of external factors – the factors outside of the learner’s own cognition, learning style, etc. – in contributing to predicting performance on an alternative conceptions diagnostic instrument. Such an analysis could inform the research community which, if any, of these factors has the greatest potential to impact upon conceptual understanding in chemistry and, therefore, which areas, if improved, could provide the greatest benefit to PSSTs.

Past research studies have carried out various types of learning programmes/strategies (aka “learning interventions”) with learners in an attempt to improve their conceptual understanding and remediate their alternative conceptions (Barker and Millar 2000; Slocum et al. 2004; Ekici et al. 2007; Beerenwinkel et al. 2011; Ozmen et al. 2012). Some of these learning interventions have involved the use of conceptual change texts (Atasoy et al. 2009), cooperative learning (Slocum et al. 2004), context-based learning (Parchmann et al. 2006), and
concept cartoons (Dalacosta et al. 2009). These attempts to address the alternative conceptions of learners are typically associated with moderate or small effect sizes on conceptual understanding (Bowen 2000; Gutwill-Wise 2001; Lewis and Lewis 2008; Beerenwinkel et al. 2011), although in some cases large effect sizes have been observed (Ozmen 2007; Atasoy et al. 2009; Dalacosta et al. 2009). Blended learning is the integration of face-to-face and technologically-mediated interactions between students, teachers and learning resources (Bluić et al. 2007). It has been used as a way to change the delivery of third-level chemistry modules to learners. This strategy has been found to improve students’ performance in end-of-module examinations (Williams et al. 2008; Antonoglu et al. 2011). However, this strategy does not appear to have been utilised in the context of alternative conceptions and/or conceptual understanding in chemistry. A blended learning approach is likely to be of value to the delivery of science teacher education for PSSTs given that there are many important issues of which PSSTs need to be aware, e.g. Nature of Science, inquiry-based learning, and so on (Abd-El-Khalick et al. 2004; Akerson et al. 2006). A blended learning programme may be a viable way of providing PSSTs with the interactions and learning resources which they require to aid them in revising their conceptual understanding, without a radical reduction in the time given to other important science education issues. Furthermore, the technologically-mediated component of blended learning allows for the multimedia capabilities of Web 2.0 and, potentially, more effective learning resources for addressing conceptual understanding (Sanger and Badger 2001; Kocakaya and Gonen 2010).

Based on this rationale the following research questions were identified as suitable for investigation in the current research study:

- Does the model of STE (concurrent or consecutive) on which PSSTs are enrolled have an effect on the prevalence of alternative conceptions about fundamental chemistry concepts, taking into account other variables such as subject specialism, year of study (for those on the concurrent model), degree classification (for those on the consecutive model), and previous second-level school experiences?
- Does a blended learning programme improve PSSTs’ understanding of fundamental chemistry concepts?

Diagnostic instruments containing multiple-choice items are a regular feature of studies investigating learners’ conceptual understanding. Such a research instrument was to be used in investigating PSSTs’ conceptual understanding in the current research study and the relationships between this understanding and the model of STE and impact of a blended learning programme. These instruments often use multiple-choice style items and past research has questioned the extent to which learners adopt sense-making approaches or
choice-making approaches when responding to these items (Nyachwaya et al. 2011). Research has been carried out on the approaches of learners to answering traditional multiple-choice items (Kitsantas 2002; Harlow and Jones 2004). Some research has also been carried out on learners’ approaches to alternative conception diagnostic items in chemistry (Sanger 2000; Tan et al. 2005). However, these studies tend to focus on approaches to small numbers of items or on approaches to a single conceptual area. Insight into the approaches used by PSSTs in addressing multiple-choice style diagnostic items can add to the discussion within the research community on the value of diagnostic items and may be of use to teachers that wish to use diagnostic items as teaching tools; knowledge of the types of approaches could allow them to assist students in using strategies that can best elicit the understanding specific to the conceptual problem under discussion. More importantly, a better understanding of PSSTs’ approaches and reasoning strategies would provide insight into why PSSTs have the conceptual understanding identified in the quantitative strands of research for this study. Therefore, the following research question was considered worth investigating and formed the basis for the minor qualitative research strand in Phase 1 of this research study:

- How do PSSTs approach conceptual questions in a quantitative alternative conceptions diagnostic instrument?

(b) Target Population and Sample Groups
The target population in this research were PSSTs engaged in STE at the time of the study in Ireland. It was decided that the major quantitative research in Phase 1 of the study (in which the impact of the model of STE was investigated) should target PSSTs across both the Republic of Ireland (ROI) and Northern Ireland (NI). The rationale behind the decision to include PSSTs from two educational systems was that the findings should have relevance for educational systems outside of ROI. Had PSSTs in the ROI system been the target population then the results may have been exclusively relevant to the characteristics of this single educational system. It was also initially intended to include the educational systems as part of the analysis as this may impact on the conceptual understanding of PSSTs. However, this may have unintentionally revealed the results from the few STE programmes in NI which would be an ethical breach with the relevant Higher Education Institutions (HEIs) and as a result this work was not undertaken. The lack of inclusion of the educational system as a variable during the analysis may also pose a confounding factor for the results. Therefore, a brief summary of the educational systems will be provided. An outline of the primary-level and second-level education systems in place in ROI and NI may be seen in Figure 1.2.
Primary-level schooling begins at the ages of 4 or 5 years across Ireland. Science is part of the curriculum in both education systems and the chemistry content is focused on the topic of materials. Second-level schooling begins between the ages of 11 and 12 years. The lower-second-level education systems in Ireland are of three years’ duration and the study of science is optional in ROI. However, approximately 90% of lower-second-level students do study science and sit the Junior Certificate Examination in science in ROI \(^3\) (State Examinations Commission 2014). The proportion studying science in NI is more difficult to assess as there

\(^3\) This is often because science may be made compulsory by individual schools.
is no state examination in lower-second-level education in NI. The syllabus in both systems is similar. The syllabi combine chemistry, physics and biology in a single subject. The chemistry portions of the syllabi have an emphasis on particulate nature of matter concepts. For example, both systems include the following conceptual areas in their lower-second-level syllabi (i.e. Junior Certificate Science in ROI and Key Stage 3 in NI):

- Particle model;
- Behaviour of matter;
- Elements, compounds and mixtures;
- Acids and bases;
- Metals and non-metals;

Therefore, all of the participants in the current research study will need to understand these fundamental chemistry concepts for their roles as future teachers of the lower-second-level syllabus in either education system.

The study of a science discipline is optional at upper-second-level in both systems. Both systems offer biology, chemistry and physics as subjects in upper-second-level or combinations of these subjects. Approximately 15% of upper-second-level students in ROI study chemistry and take the Leaving Certificate Examination (LCE) in chemistry. In addition to the main educational levels shown in Figure 1.2, there may also be, depending on school policy, an optional year between lower- and upper-second-level offered to students in ROI. The purpose of this year is to give students an opportunity to experience a wider-range of educational experiences, including work experience, and there is no set curriculum (Department of Education and Skills 2015). State examinations take place at slightly different points in the educational systems, as may be seen in Figure 1.2. The LCE and the A-Levels are high-stakes examinations that determine entry to third-level institutions based on a points system. In both cases, two levels of science study are offered: Higher Level and Ordinary Level in ROI, and AS Level and A1 Level in NI. Chemistry (and other subjects) is given a greater depth of treatment in NI A-Levels than in the ROI LCE owing to the fact that those

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4 Comparisons are often drawn between the Junior Certificate Examination and the General Certificate of Secondary Education (GCSEs) in NI. However, the GCSEs take place at a later stage in a student’s education than the Junior Certificate Examinations. Given that the majority of participants in this study are enrolled in programmes in the ROI, it was decided to map the NI system to the ROI system and, as such, the GCSEs are considered to be part of upper-second-level education for the purposes of this study.

5 This is limited to a physics-chemistry combination in ROI but the NI system offers more flexibility.

6 The percentage of students studying upper-level chemistry in NI cannot be directly calculated as the figures provided by the examination boards are related to the total number of subject entries to GCSEs and A-Levels and not to the total number of students.
in ROI study more subjects and obtain a broader education, while those in NI study fewer subjects but in greater depth. LCE chemistry in ROI is considered to account for two-thirds of A-Level chemistry in NI (Qualifax 2017).

The consecutive and concurrent models of STE are offered in NI and ROI. Teaching in both regions is an all-graduate profession. STE programmes may follow the concurrent or consecutive models, as shown in Figure 1.3. PSSTs on consecutive programmes have previously studied science to degree level. They then study education, pedagogy and subject-specific pedagogy on a one-year STE programme, known as the Postgraduate Certificate of Education (PGCE) in NI and the Professional Diploma in Education (PDE) in ROI. The PDE is now of two years’ duration (Trinity College Dublin 2015). This was not the case at the time of the study. There are seven institutions with consecutive STE programmes (six in ROI and one in NI). The programme of study for the PGCE and the PDE is similar, with a strong focus on TP (Queen’s University Belfast 2015; University College Dublin 2015). The level of competition for places on STE programmes is high and the ROI system is one of the most competitive in Europe (Heinz 2008).

![Figure 1.3: The consecutive and concurrent models of STE (* The study of science disciplines in the consecutive model is shown here as of four years’ duration but may also be of three years’ duration)](image)

PSSTs following the concurrent model of STE study science, education and pedagogy simultaneously over the course of their four-year concurrent STE degree programme. There are seven institutions in Ireland offering concurrent STE programmes (five in ROI and two in NI). In ROI, places on concurrent programmes are offered based solely on the points systems resulting from the LCE. In NI, places are offered based on a combination of the NI

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7 Although the concurrent model is shown as being an equal split between Science Disciplines, and Education and Pedagogy, this is not the case. There is actually more study of the Science Disciplines than Education and Pedagogy. The diagram in Figure 1.3 is intended to be a model that displays the concurrency of these studies rather than the specific amount.
points systems and information about extracurricular activities and previous employment. Again, the competition for places in concurrent STE programmes is high in ROI, and those that pursue these programmes must be in the top 30% of LCE performers and most are in the top 10% of LCE performers (State Examinations Commission 2014). Therefore, the participants in this study are high performers in both educational systems.

Table 1.1 shows the number of HEIs participating in NI and ROI and the number of PSSTs participating in each STE model in each region. Although the educational system was not included in the analysis for this strand of research, it is important to cognisant that the composition of the sample group did include PSSTs from both educational system and this may be a factor influencing the results.

<table>
<thead>
<tr>
<th>Table 1.1 Higher Education Institutions (HEIs) involved in the study</th>
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<tbody>
<tr>
<td>HEIs in NI (No. PSSTS)</td>
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<tr>
<td>Concurrent STE Model</td>
</tr>
<tr>
<td>Consecutive STE Model</td>
</tr>
<tr>
<td>Total HEI in Region</td>
</tr>
</tbody>
</table>

* One HEI ran a concurrent STE programme and a consecutive STE programme.

The target population for the other two research strands undertaken using the constructivist – postpositivist perspective (i.e. the minor quantitative strand in Phase 2 investigating the impact of a blended learning programme on conceptual understanding, and the minor qualitative research strand in Phase 1 in which PSSTs’ reasoning approaches were investigated) were PSSTs in a single HEI in the ROI. This HEI provided concurrent STE programmes. This decision was taken for two reasons: 1) the researcher had more access to PSSTs in this HEI, and 2) the ethical issues already identified (i.e. unintentionally identifying the results/findings of PSSTs from the two participating HEIs in NI) remained.

The minor qualitative strand of research in Phase 1 engaged with seven PSSTs in a single HEI in ROI. These PSSTs had taken part in piloting the alternative conceptions diagnostic instrument used in the quantitative research strands. The minor quantitative strand of research in Phase 2 also involved PSSTs from this HEI. 52 PSSTs participated and they were divided into a Blended Learning Group (30 PSSTs) and a control group, named the Conventional Group (22 PSSTs). All the PSSTs in this sample were studying on their STE programme and the Blended Learning Group additionally took part in the blended learning programme designed for this research study.
(c) Methods and Findings
The major and minor quantitative strands of research in Phases 1 and 2 involved the design and development of an alternative conceptions diagnostic instrument. This instrument included the most fundamental concepts in the areas of particulate nature of matter (PNM), chemical bonding, stoichiometry, and equilibrium. Half of the concepts in the instrument were either included in the lower-second-level syllabi in the NI and ROI educational systems or were necessary to create solutions in order to teach these topics at this level. The other half of the concepts were included in the upper-second-level syllabi in both educational systems, which are also taught in third-level science degrees (typically, in introductory chemistry modules). A demographic survey was also used to collect data for the independent variables being investigated in the quantitative research strands. These were not the only quantitative research instruments utilised in this study, with additional instruments being used in the minor quantitative research strand to ensure the comparability of the Blended Learning and Conventional Groups.

In analysing the data associated with both research strands, a descriptive analysis and inferential testing by means of t-tests, Mann Whitney tests, etc. was carried out. The descriptive analysis involved exploring the measures of central tendency, location and dispersion. The inferential testing involved comparing these measures between different groups arising from the independent variables (e.g. comparing PSSTs specialising and not specialising in chemistry). This type of inferential testing has been labelled ‘Comparison Testing’ in this thesis. In determining the impact of the model of STE on PSSTs’ conceptual understanding, further inferential testing by means of a regression analysis was carried. This involves fitting the data to a straight-line model for the purposes of predicting PSSTs’ performance in the diagnostic instrument. The advantage of this method is that one can determine which variables contribute to the model when all other variables are held constant.

The investigation into the impact of the model of STE on PSSTs’ conceptual understanding revealed a number of interesting findings. Previous experience of upper-second-level chemistry was identified as the most important of all educational variables in contributing to PSSTs’ understanding. It contributed significantly to their performance in PNM, stoichiometry, equilibrium, and total scores on the diagnostic instrument. Previous upper-second-level experience of mathematics was also a significant predictor of performance in the PNM portion of the diagnostic instrument. This finding is interesting given that PSSTs’ subject specialism did not contribute significantly to their performance in any area of the instrument. In fact, it was generally one of the poorest predictors of performance. Those with a chemistry specialism have experienced far more extensive study in chemistry than
those who do not have a specialism in the subject. This suggests that third-level chemistry in not impacting on PSSTs’ conceptual understanding.

Among those PSSTs following the concurrent model of STE, their year of study was not associated with any difference in performance in the areas of stoichiometry and equilibrium, and the impact was counterintuitive for PNM, chemical bonding, and total scores on the diagnostic instrument. PSSTs in their first year of study outperformed those in subsequent years of study. Finally, the model of STE being followed by PSSTs was the most powerful predictor of performance in chemical bonding, and it was also a significant predictor of performance in total scores in the instrument, with the latter likely arising from the former. PSSTs on concurrent STE programmes are predicted to have fewer alternative conceptions about fundamental chemical bonding concepts than those on consecutive STE programmes.

Another important finding from this strand of research was that large amounts of variance in the data remained unaccounted for by the regression models. Other variables which may account for this variance include the cognitive level, reasoning ability, field dependence, and goal setting strategies of the PSSTs included in the study. The educational system of the PSSTs (i.e. ROI or NI) may also be a confounding factor. One might expect that those from the NI system would outperform those from the ROI system, given that upper-second-level chemistry is taught in more detail in NI than in ROI. This is likely to have an impact on the conceptual understanding of PSSTs who studied the subject, given the long-lasting impact of upper-second-level study of this subject that was identified in this strand of research.

The minor quantitative research strand involved investigating the understanding of a group of PSSTs who had experienced a blended learning programme, compared to their peers who did not participate in it. The blended learning programme, called SuBATOMIC (Supporting Better Activities To Overcome Misconceptions In Chemistry) involved a combination of face-to-face sessions and online learning and communication using a website and social media platform. The programme focused on the topics of PNM and chemical bonding. The Comparison Testing revealed that there was no statistically significant difference between the Blended Learning Group and the Conventional Group. However, the size of the sample meant that there was only sufficient statistical power to detect large effect sizes but not medium or small effect sizes. There was a medium effect size associated with PNM, in favour of the Blended Learning Group, and a small effect size associated with the area of chemical bonding, also in favour of the Blended Learning Group. Examining the data more closely suggested that the blended learning programme may have primarily benefitted those with the lowest initial conceptual understanding. The outcome in relation to PNM was better than
that in chemical bonding. This was likely due in part to the structure of the blended learning programme itself – with differences between the PNM-focused and chemical bonding-focused portions of the programme – but the difference in the complexity of these two conceptual areas was also undoubtedly a factor in the different outcomes. The more abstract and complex nature of chemical bonding compared with PNM is well-acknowledged in the research literature and the findings from the previous quantitative research strand also reinforce this: chemical bonding was a consistently problematic area and it was in this area that the year of study for concurrent PSSTs, and the model of STE which PSSTs were following had the greatest impact on performance. Furthermore, it was the only conceptual area in which previous upper-second-level study of chemistry was not a significant predictor of PSSTs’ performance in the diagnostic instrument.

The minor qualitative research strand in Phase 1 of the study investigated PSSTs’ reasoning approaches to alternative conception diagnostic items. This strand of research forms the bridge between the quantitative strands of research and the constructivist – postpositivist perspective, and the major qualitative strand of research in Phase 2 and the Stein – RDT perspective. Semi-structured interviews were carried out with seven PSSTs in which the alternative conceptions diagnostic instrument formed the protocol for the body of the interview. The interviews were audio-recorded and then transcribed. The transcribed interviews were then analysed using the method of inductive thematic analysis outlined by Braun and Clarke (2000). In addressing the researching question, five rational reasoning approaches were identified as follows:

- **Balancing of Factors:** this involved introducing a number of concepts/factors considered to be relevant and weighing them against one another to select a response.
- **Pure Algorithm:** this referred to the application of an algorithm, with either no ability to discuss or no attempt to discuss the underlying concepts.
- **Concept Consideration and Immediate Consistent Response:** PSSTs discussed their concepts and then, often almost immediately, selected a response that was consistent with these concepts. This was the most common approach used by PSSTs.
- **Elimination:** this involved considering multiple response options in an attempt to discern which were false and which were true.
- **Concept Consideration and Algorithm:** PSSTs considered concepts which they believed to be relevant and also applied an algorithm to select a response option. This is distinct from the Pure Algorithm approach in that PSSTs were able to connect the algorithm to underlying chemistry concepts.
In most cases, the approach taken by PSSTs was a careful and considered approach in which they engaged in a lot of sense-making. Balancing of Factors, Concept Consideration and Immediate Consistent Response, and Concept Consideration and Algorithm, were all found to involve sense-making. Even the Elimination approach was, occasionally, observed to be a carefully considered approach combining sense-making with choice-making. However, some approaches were less considered and appeared to be devoid of sense-making. Elimination sometimes presented as an entirely ‘choice-making’ approach. The Pure Algorithm approach was observed to be one devoid of any sense-making; the algorithm was sufficient for them to make a choice.

The PSSTs that were interviewed relied on an Elimination approach more often in chemical bonding and equilibrium diagnostic items than in the other conceptual areas. The Pure Algorithm approach was used more often in equilibrium and stoichiometry than in the other areas. Equilibrium was very poorly understood and the issue in this area appeared to be less one of alternative conceptions than one of a total lack of any kind of understanding leading to an inability to discuss concepts in this area. This is likely the reason for the greater use of the choice-making approaches in this conceptual area. The use of less-considered Elimination approaches in the area of chemical bonding may also be a reflection of the low conceptual understanding in this area – PSSTs relied upon alternatively-conceived ideas far more than scientifically-conceived ideas in this conceptual area. In the area of PNM, PSSTs relied upon alternatively-conceived ideas only slightly more than scientifically-conceived ideas in responding to diagnostic items. PSSTs also used more of the sense-making approaches in the area of PNM, suggesting that they have better conceptual understanding in this area. This finding again reflects the higher degree of complexity associated with the conceptual area of chemical bonding when compared with the area of PNM. The higher tendency to use less considered approaches in the area of chemical bonding may have been the reason for the difficulty observed in these areas in the quantitative research strands, and the use of these approaches is likely to reflect the lack of clarity among PSSTs about this conceptual area as much it reflects upon their alternative conceptions.

This strand of the research also led to some unexpected findings, which impacted upon the design of the research study. Throughout the interviews, PSSTs engaged in mannerisms and statements that were indicative of a negative experience such as nervous laughter, repeatedly apologising, admitting that they lacked understanding, and making other negative statements about their attitudes or emotional states. During the interviews, PSSTs also spontaneously introduced reflections upon previous educational experiences. These reflections usually had a negative connotation in which the previous experience was being suggested as, or implied
to be, the cause of the PSST’s poor understanding. It was interesting, in light of the earlier results about the importance of previous upper-second-level chemistry, that this level of education was most often reflected upon, despite the fact that PSSTs had studied several chemistry models in their STE programme. The negative affective behaviours and comments just described underpinned the entire discussion with PSSTs as they attempted to reason about the meaning of concepts and reveal their own conceptual understanding. This suggested that the problem of alternative conceptions was linked to far more than PSSTs’ cognitive structures and led to a re-evaluation of the constructivist – postpositivist perspective, in which the researcher had adopted this view of the problem. These unexpected findings were the catalyst for a review of the foundations and design of the research study.

1.3 RESEARCH BASED ON THE STEIN – RELATIONAL DIALECTICS THEORY PERSPECTIVE

(a) Rationale

The unexpected findings arising from the Phase 1 qualitative strand of research suggested that the issue of alternative conceptions may be best examined with a more holistic perspective on the nature of the human person. PSSTs appeared to be affected by experiences such as shame and embarrassment while discussing their conceptual understanding. PSSTs discussion of their conceptual understanding appeared to be impacted upon by their interaction with the researcher during the interview process: feelings of embarrassment and a lack of confidence in their own capabilities sometimes appeared to be linked to their anticipation of the interviewer’s reaction to their understanding. These unexpected findings led to a review of the entire foundations of the research study. The constructivist – postpositivist perspective was re-evaluated to determine the weaknesses of the perspective: namely, the focus on individual cognition and also the treatment of objectivity within this perspective. The focus on individual cognition led to strands of research that took a narrow view of the nature of the human person and the problem of alternative conceptions. The treatment of objectivity in this perspective was also problematic: at worst, the question of objective knowledge is not considered at all because this can never be verified and, at best, objective knowledge is considered to exist but is inaccessible to human beings who filter all experience through their own cognitive structures, i.e. I do not come to know the world, but only the world as I perceive it. Such a view is problematic for science and science education, given that science can be characterised as “the pursuit of truthful understanding, honestly, openly and forcefully conducted” (Matthews 2009, p.17).

A review of the literature was undertaken to identify a philosophical foundation that was more appropriate as a foundation for science education research (i.e. in relation to the
treatment of objectivity) and that viewed the human person in a more holistic way. This ultimately led to Edith Stein’s phenomenology of empathy and community (Stein 1989, 2000). Stein applies the phenomenological method to the phenomenon of empathy, which refers not only to empathetic experiences related to emotional content (the common modern day meaning) but also to experiences based on ideation, sensory observation and affective acts, such as attitudes and values. Her phenomenological study develops a perspective in which empathy is central to the constitution of the human person – that is, the empathetic experiences of a person allows them to come to know themselves as a psycho-physical person like others but also distinct from them. Such a perspective allows for a very holistic view of the human person in which mind, body, emotion, and expression are all deeply connected, and these connections are founded upon empathy. Stein’s work also allows for the existence of objective knowledge and a person’s ability to access it. Within the confines of one’s own mind, one is always restricted to ‘the world as I perceive it’, however, in acts of empathy we gain views of the world that are not based on our own perception. We can attain as many views of the world as we have people with which to empathise, thus freeing us from the confines of our own minds. As such, Stein posits that objectivity is constituted through intersubjectivity (i.e. experiences accessible to a plurality of persons).

From this new foundation, the research study was re-designed such that the purpose of the planned blended learning programme changed and a new research question was introduced and given primacy in the second phase of the study (with the pre-existing research question for Phase 2 downgraded to a minor research question). There has been little research carried out on PSSTs’ experience of addressing alternative conceptions and attempting to improve their conceptual understanding. Furthermore, based on the work of Stein, environments which encourage and accept the empathetic and communal nature of human beings may be more appropriate for obtaining an orientation on PSSTs’ learning experiences. Therefore, the new research question was as follows: How do PSSTs experience the issue of alternative conceptions in chemistry in a community-oriented, blended learning environment? As a result, the learning programme did not focus on targeting a few problematic alternative conceptions, but was instead a vehicle for encouraging a sense of community to develop in order to observe PSSTs’ experience of alternative conceptions in community-oriented groups. The blended learning programme was developed with this research question in mind.

During the analysis of the data in this research strand, Leslie Baxter’s RDT (2011) was identified as a valuable framework to combine with Stein’s phenomenology of empathy and community. RDT is a branch of dialectics first conceived of by Baxter and Montgomery (1996) and later refined by Baxter (2011). It is a sensitising theory representing a collection
of concepts for the purpose of sensitising and appropriately orienting researchers to important characteristics and processes of the problem at hand (Turner 1986, p. 11). In this case, RDT sensitises the researcher to the interplay of dialectical tensions in people’s relating to each other. It focuses upon these tensions and seeks to uncover the idiosyncratic presentation of these tensions in different contexts and environments. (Baxter 2004). It also orients the researcher to identify the interplay upon which these tensions are constituted. Baxter has identified two forms of communicative interplay in which contradictions are constituted: synchronic and diachronic (Baxter 2011, pp.130-138). Diachronic communicative activities are characterised by the domination of a single discourse at a particular time or space and, therefore, competing voices are isolated from one another in an attempt to evade the contradiction inherent in the dialectical tension. Communicative activities categorised as synchronic are characterised by the co-occurrence of opposing discourses at a given point in time. These synchronic communicative activities have been conceptualised as potentially occurring across four dimensions, three of which are relevant to this particular study: antagonistic – non-antagonistic struggle, direct – indirect struggle, and polemical – transformative struggle (Baxter 2011, p. 131). The antagonistic – non-antagonistic struggle refers to the extent to which a discourse or system of meaning is at stake, with the stakes being higher closer to the antagonistic end of the dimension. The direct – indirect dimension refers to the extent to which speech is open or hidden (Baxter 2011, p. 134). Indirectness in the interplay between discourses allows for ambiguity of meaning, while directness does not. The polemical – transformative dimension, refers to the potential for discourses to remain entirely negating of one another or for there to be a profound recalibration of the discourses such that they become complementary.

RDT is one of the most prominent theories in communications research (Halliwell 2015), yet its use within educational research is quite limited. Within educational research, studies using RDT as a sensitising theory have typically focused upon students’ experience of attending third-level educational institutions and differences between the culture and status of lecturers and third-level students (Lowery-Hart et al. 2011; Simmons et al. 2013; O’Boyle 2014). The literature review carried out as part of the current research study identified no research within the alternative conceptions literature, or within the body of science education literature, which has adopted this theoretical lens to examine learners’ experiences while engaged in learning. The adoption of this lens can shed new light on the experience of alternative conceptions, the barriers to addressing alternative conceptions, and how alternative conceptions come to be held by a plurality of individuals rather than presenting idiosyncratically for every individual.
(b) Methods and Findings

Thirty PSSTs took part in the blended-learning programme and four small-groups were selected from the face-to-face component to form the basis of four case studies. Audio-visual data of each community-oriented group in a face-to-face session was collected, as well as social media contributions and reflective journal entries about the session-in-question for each member of the group. The audio-visual data was the primary data source, with social media and reflective journal data acting as a secondary data source which could lend insight into observations made about the audio-visual data. Two of these case studies were selected for inclusion in this thesis. The audio-visual data collected was of each community-oriented group in a face-to-face session as they worked on completing some task, e.g. as they attempted to create a concept cartoon for use with their future students on the topic of elements, compounds and mixtures. For each case study, the audio-visual data was analysed in order to identify patterns in the flow of experience, e.g. how one experience precipitated the next and so on. At these stage, certain tensions between mutually negating discourses were observed. For example, a tension between a desire to express one’s thoughts and understanding, and a desire to maintain the privacy of one’s own thoughts and understanding. Another review of the literature was undertaken and Leslie Baxter’s RDT (2011) was identified as the most appropriate to explore tensions in the data, while also being very complementary with Stein’s phenomenology of empathy and community.

Contrapuntal analysis, as described by Baxter (2011), was used to analyse the data in an attempt to identify the dialectical tensions experienced by each community-oriented group and the interplay upon which these tensions were constituted. This analysis was carried out at two levels: 1) the discourses within the experience of the community-oriented group, and 2) the discourses about specific chemistry concepts. This approach resulted in the identification of a number of dialectical tensions and a number of interplays between conceptual tensions – some of which were favourable to group learning outcomes and some of which were unfavourable. The interplays between conceptual discourses were founded upon the interplay between the discourses within the community-oriented group experience.

The discourses identified within the community-oriented group experience were:

- Denial – Acceptance; this was a tension surrounding PSSTs’ awareness of barriers to conceptual discussions. There was a tension between the acceptance of these barriers and the denial of these barriers.

- Expression – Non-Expression; this was a tension with regard to the extent to which PSSTs desire to share their personal thoughts, understanding, etc. and their desire to withhold this kind of information.
• Learner – Teacher; this tension related to the differing perspectives adopting by
groups: they sometimes saw themselves as learners of chemistry, and at other times
saw themselves as teachers of chemistry.

These tensions presented themselves in ways that were idiosyncratic to each case study. In
one community-oriented group, expression – non-expression presented as a tension between
openness (i.e. the desire to open with one another about their thoughts, understanding,
perceived-failures, etc.) and closedness (i.e. a desire to withhold this type of information).
However in another community-oriented group, it presented as a tension between an expert
resource discourse (i.e. a discourse in which the task should be approached by finding external
‘expert’ resources and simply using these resources to complete the task) and a community
resource discourse (i.e. a discourse in which the task should be approached by using the group’s
resources, such as their own thoughts, words, prior learning, etc.).

These relational dialectics identified in the experience of the community-oriented groups
were the foundation upon which the interplay between conceptual discourses arose. A direct,
antagonistic interplay between alternatively-conceived and scientifically-conceived
discourses was observed to lead to more favourable group outcomes in these case studies
than an indirect interplay between discourses. The general lack of discursive contact between
opposing discourses associated with indirect interplays was observed as a tendency to focus
upon a single discourse for which further support was then sought out. This single discourse
could be alternatively- or scientifically-conceived. Some discursive contact with another
discourse, regardless of its accuracy, provided the community-oriented groups with an
opportunity to deepen their conceptual understanding as they refuted or defended the
discourses. The more direct antagonistic interplays between conceptual discourses were
founded upon the interplay between relational dialectics within the experience of the
community-oriented groups. Where the discourses of expression and acceptance were dominant
over their discursive counterparts, this tended to be associated with direct, antagonistic
interplays between conceptual discourses. However, these were not the only interplays which
supported directed antagonistic conceptual discussion. For example, a reframing interplay
between expression and non-expression, such that the non-expression discourse complemented the
expression discourse, was also observe to support direct, antagonistic interplays between
conceptual discourses. Non-expression was an opportunity to revise understanding, reflect on
discussion and provide respite from conceptually-heavy discussion and this allowed for
better and higher quality contributions in the context of the expression discourse.
RDT as a sensitising theory with which to investigate PSSTs’ experience of addressing alternative conceptions proved to be a fruitful area in which to gain insight into the problem of alternative conceptions. This area requires future research to continue this investigation into the dialectical tensions experienced by PSSTs (and indeed other types of learners) and the interplays upon which these tensions are constituted. The Stein – RDT perspective may also be a useful perspective for science education researchers: it allows for a different orientation not only towards the design of future research on alternative conceptions, but also towards science education issues in general.

1.4 STRUCTURE OF THESIS
This thesis is not laid out in the traditional quantitative style and does not present the various aspects of the study in chronological order. It is separated into three parts: Part I focuses on the background information such as the relevant literature, philosophical and theoretical considerations, and nature of the SuBATOMIC programme; Part II provides all things quantitative: the quantitative methodology, results of both phases, and discussion; Part III presents the qualitative methodology, findings of both phases and discussion. The thesis finishes with a concluding chapter which ties the results and findings together and examines the potential for future research based on this study. This layout has been selected to reflect the organic development of the research study. The writing style within the thesis also reflects the subject matter. For example, when discussing quantitative results, the passive voice is used, while I use the first-person voice when discussing qualitative findings.

(a) Part I: Background to the Study
This section comprises two chapters: Alternative Conceptions in Chemistry, and Foundations of the Study. Alternative Conceptions in Chemistry presents a systematic review of the literature in relation to: the conceptions identified in a number of conceptual areas in chemistry, research approaches and methodologies, and instructional and pedagogical approaches to addressing alternative conceptions. This chapter provides the literature review upon which the initial research design was founded. Foundations of the Study presents the philosophical considerations for each phase of research. Given that the philosophy of Edith Stein has not been previously used in the science education literature, it is likely to be unfamiliar to many readers and has been given a depth of treatment. This chapter also presents the relevant literature available on Baxter’s RDT. As such, it provides the literature background for the Stein – RDT perspective. The design and implementation of the blended learning programme, SuBATOMIC, during Phase 2 of the research study is also presented. The chapter concludes with a description of the study including the research questions and approach, sample groups, data collection methods, and an overview of the project.
(b) Part II: Quantitative Strands
Four chapters compose this section, which addresses all quantitative aspects of the study. The traditional quantitative style is followed in presenting these research strands. Methodology describes the quantitative research tools, development of the primary quantitative research tool and data analysis procedures. The chapters Results of Phase 1 and Results of Phase 2 present the quantitative results of the respective phases of research. This layout is reflective of the connection between these two stands of research as previously outlined in Figure 1.1. Finally, a discussion of the results in relation to the previous literature and relevant research questions is provided in Discussion.

(c) Part III: Qualitative Strands
This section uses a more qualitative style to present the qualitative research strands. Qualitative reports often describe the methods used and discuss the findings as part of a presentation of the analysis as these are intrinsic to any qualitative data analysis. This format has been used and, as a result, this section comprises two chapters entitled Findings of Phase 1 and Findings of Phase 2 which present the qualitative findings of the respective phases of research. This layout has been selected, with Findings of Phase 1 presented after both quantitative research strands and before the qualitative research strand in Phase, to reflect the bridging nature of Findings of Phase 1. The associated research strand was founded upon the constructivist – post-positivist perspective, but the findings led to the Stein – RDT perspective. These chapters use the first-person voice to make explicit the role of the researcher in the interpretation of the findings.

The thesis finishes with Conclusion, a chapter which reviews the main results and findings, discusses them in relation to each other, and highlights potential future research which could arise from this research study. This thesis has a number of associated appendices but only the most essential of these have been included in the printed version while the remainder are available on the associated CD-ROM.
Part I
Background to the Study
Chapter 2 Alternative Conceptions in Chemistry

There is a large body of published research investigating the alternative conceptions of learners and the effect of various instructional methods on learners’ conceptions (Duit 2009). For this study a method was required which would allow for a representative selection of research studies to be reviewed and details of this will first be provided. The alternative conceptions documented in the literature arising from the use of this review method will then be discussed. The current research study focuses on pre-service science teachers (PSSTs). PSSTs have been found to have many of the same alternative conceptions as learners in other levels of education (Mulford and Robinson 2002; Kruse and Roehrig 2005). Therefore, the alternative conceptions of different types of learners are not differentiated from each other throughout this review. However, where studies have involved PSSTs, this will be highlighted. The methods used to determine the alternative conceptions of learners and the instructional approaches implemented to address and remediate these conceptions will be discussed. The epistemological and theoretical considerations informing research in these areas will be introduced. This chapter does not provide an in-depth review regarding these considerations but merely summarises them. Chapter 3 will examine these issues in greater detail, as they relate to the current study. Finally, the findings of a number of relevant doctoral research studies in the Irish context will be reported.

The main purposes of this chapter are to:

- highlight the main findings of research carried out in the area of learners’ alternative conceptions in chemistry,
- outline the research approaches and methods used in these studies, and
- report on the level of success of a number of instructional approaches in improving learners’ performance in chemistry and in stimulating a change from alternative towards scientifically-acceptable conceptions among learners.

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8 Note that when referring to the study that is the subject of this thesis, the term ‘current study’ will be used and the author of this thesis will be referred to as the ‘current author’.

9 The term learner is used as a generic term throughout this review to refer to any group whose conceptual understanding has been investigated in the research literature.
2.1 METHOD OF REVIEW
The upper-second-level chemistry syllabus in the Republic of Ireland was used as a framework in order to select the conceptual areas in chemistry for inclusion in the literature review. The conceptual areas were placed in a flowchart in order of increasing complexity, shown in Figure 2.1. The most fundamental conceptual areas were related to the particulate nature of matter (PNM), chemical bonding, and stoichiometry. Each of these areas was included in the literature review. The most complex conceptual areas included equilibrium, rates of reactions, organic chemistry and electrochemistry. Of these areas, equilibrium was selected for inclusion in the review.

The identification of journal articles involved three stages: the primary, secondary and tertiary searches. The primary search was intended to locate articles reporting on studies identifying alternative conceptions in the selected conceptual areas. It involved the combination of common terms for alternative conceptions, the terms shown in Table 2.1, and appropriate Boolean logic (i.e. the use of logical AND and/or logical OR in the search phrases). The secondary search combined the common terms for alternative conceptions with the terms shown in Table 2.2 and Boolean logic. The purpose was to identify studies that used various instructional strategies to address the alternative conceptions of learners. The terms used to retrieve journal articles were expanded, where necessary, to retrieve a larger return. Every article returned from the primary and secondary searches was not included in the literature review as some involved concepts that were at too high a conceptual level or were not relevant to the topic. In a minority of cases, the author had no access to the journal article. The tertiary search concerned the identification of relevant articles in the reference lists of articles already located. The databases used to conduct the primary and secondary searches included (but were not limited to): Academic Search Complete, Education Full Text, British Education Index, and Education Resources Information Centre (ERIC). All searches using these databases were limited to scholarly articles in the English language and the terms were sought in the abstracts of articles. The common terms for alternative conceptions were: misconception, alternative conception, alternative framework, conceptual understanding, preconception, pre-conception, and naïve conception.

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10 Note that although Conceptual Change Texts are also a strategy reviewed, an additional search was not carried out for papers on this topic as there were sufficient journal articles from other searches.

11 This decision was made given that searching the title may overlook important papers while searching the full text would return too many irrelevant papers.
Figure 2.1 Flow chart of conceptual areas in the upper-second-level chemistry syllabus
Table 2.1 Details of the primary search for alternative conceptions literature

<table>
<thead>
<tr>
<th>Conceptual Area</th>
<th>Search Terms</th>
<th>Unique Records Returned</th>
<th>Number Reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate Nature of Matter</td>
<td>(Particle OR Particulate) AND Matter</td>
<td>88</td>
<td>79</td>
</tr>
<tr>
<td>Chemical Bonding</td>
<td>(Bond OR Bonding) AND (Chemistry OR Chemical)</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>Mole OR Molar OR Stoichiometry OR Stoichiometric</td>
<td>27</td>
<td>23</td>
</tr>
<tr>
<td>Chemical Equilibrium</td>
<td>Equilibrium AND (Chemical OR Chemistry)</td>
<td>52</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 2.2 Details of the secondary search for instructional strategies literature

<table>
<thead>
<tr>
<th>Instructional Strategy</th>
<th>Search Terms</th>
<th>Unique Records Returned</th>
<th>Number Reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Mapping</td>
<td>(Chemical OR Chemistry) AND (Concept Map OR Concept Mapping) AND (Conceptual Understanding OR Performance)</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>Concept Cartoons</td>
<td>(Chemical OR Chemistry OR Science) AND (Concept Cartoon)</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Cooperative Learning</td>
<td>(Chemical OR Chemistry) AND (Cooperative Learning) AND (Conceptual Understanding OR Performance)</td>
<td>38</td>
<td>27</td>
</tr>
<tr>
<td>Blended Learning</td>
<td>(Chemical OR Chemistry OR Science) AND (Blended Learning) AND (Conceptual Understanding OR Performance)</td>
<td>21</td>
<td>14</td>
</tr>
</tbody>
</table>

This method resulted in a total of 352 scholarly articles upon which this literature review is based. These were imported into NVivo Qualitative Data Analysis Software where they were coded according to the following general areas: alternative conceptions reported, study participants, data collection methods, data analysis procedures, instructional strategy (where relevant), and research design. Within NVivo, codes were gradually collated until a small number of distinct categories for each general area were created. For example, the various alternative conceptions reported in the area of PNM became collated into five categories: composition of matter, properties of matter, arrangement and movement of particles, effect of physical changes on composition and properties, and effect of chemical changes on composition and properties. This literature review also involved reporting on effect sizes, where possible, for studies which focus on the effect of instructional approaches. Where effect sizes were not reported in the article, they have been calculated by the current author, provided that sufficient data was provided to do so. Details of the statistical procedures used to calculate and interpret effect sizes are provided in Section 4.3.

This literature review encompassed a significant number of journal articles; this was considered to be necessary given the size of the body of literature. The use of NVivo was considered essential to allow for an overview and coherent view of this body of literature. It is hoped that this is reflected in the remainder of this chapter.
2.2 POTENTIAL ORIGINS AND IMPACTS OF ALTERNATIVE CONCEPTIONS

(a) Terminology
There is a variety of terminology concerning this area of research. Terms such as misconceptions (Doran 1972), alternative conceptions (Gilbert and Watts 1983), alternative frameworks (Driver and Easley 1978), naïve beliefs (Caramazza et al. 1981), children’s science (Gilbert et al. 1982), and preconceptions (Clement 1982) are used to refer to a similar phenomenon: that learners often have ideas with a meaning that is not consistent with the commonly accepted scientific consensus. However, each of these terms presents a slightly different aspect of this phenomenon. Throughout this thesis, the term alternative conception is used and defined as any conceptual idea that differs from scientific consensus. These alternative conceptions interfere with subsequent learning (Clement 1982) and are resistant to change through traditional teaching methods (Driver and Easley 1978).

(b) Contributions from Educational Psychology
Educational psychology has produced a body of influential work related to the process and nature of learning. This body of research is relevant in considering the problem of alternative conceptions given that these conceptions arise as a result of learning and can interfere with new learning, thus, causing further learning difficulties. The work of three educational psychologists will be considered briefly: Jean Piaget, Lev Vygotsky and David Ausubel.

Piaget’s Theory of Cognitive Development was developed based on his view of cognitive development as resulting from the biological development that occurs as a function of nature (Inhelder and Piaget 1958). This theory proposes that cognitive development takes place in four pre-determined stages. In each of these four stages, the individual exhibits particular behaviours and thought-processes. For example, the ability to reason about abstract concepts is only possible in the last of the four stages (Inhelder and Piaget 1958). Piaget postulated that learning occurs via Operative Intelligence: part of which includes the cognitive processes of assimilation and adaptation. Assimilation occurs when the learner encounters new information to which a pre-existing cognitive structure or scheme is applied; certain information is ignored in order to fit the new data into the pre-existing scheme. The learner is said to be in a state of equilibration if he/she is satisfied that the new information ‘fits’ the pre-existing scheme. Disequilibration occurs when the learner cannot assimilate new

12 Piaget identified age ranges at which all individuals are in each of these pre-determined stages. This has not been reported here as these generalisations have since been shown to be incorrect (Shayer and Adey 1981).
information into a pre-existing scheme. He/she returns to a state of equilibration by the process of accommodation, in which the scheme must be altered to encompass the new information (Piaget 1950). According to Piaget, this constructive process is the means by which learning occurs throughout life.

Vygotsky was a contemporary of Piaget and his work also became influential after it was translated from Russian to English (Vygotsky 1986). Vygotsky’s work may be seen in some contrast to Piaget’s work. Where Piaget placed little consideration on social factors in the process of learning, Vygotsky viewed these factors as instrumental in the process. In ‘Thought and Language’, he explores the relationship between the two (Vygotsky 1986). He links both internal (self-talk) and external (a means for social interactions) speech with the development of mental concepts. Therefore, thought, understanding, and learning develop socially (Vygotsky 1986). Vygotsky also postulated about a Zone of Proximal Development (Vygotsky 1986). The lower limit of the zone is the level of learning which can be achieved when the learner is working independently. The upper limit of the zone is the maximum level of learning and understanding which could be achieved with assistance from a peer or a teacher (assuming that they have a higher level of understanding than the learner). As a result, learning can occur that exceeds the learner’s particular level of cognitive development when assisted by a more capable person.

The final educational psychologist to be considered here is Ausubel, a successor of Piaget and Vygotsky. Ausubel identified two types of instructional strategies which could be placed at opposite ends of a continuum: reception-instruction (in which the entire content to be learned is presented in its final form) and discovery-instruction (in which the content is discovered by the learner). All instructional strategies can be placed somewhere on this continuum. Both reception-instruction and discovery-instruction can potentially lead to meaningful learning or rote learning, as shown in Figure 2.2. Meaningful learning takes place when the learner can relate the content to his/her prior knowledge or cognitive structure (Ausubel et al. 1978, p.27). Ausubel developed a theory of cognitive learning called Assimilation Theory that described how meaningful learning and the acquisition of new meanings takes place. The basis of the theory is that in order for meaningful learning to occur, new information must be linked to relevant pre-existing ideas in a learner’s cognitive structure and, as a result, both the new information and the pre-existing cognitive structure are modified. Ausubel paid particular attention to meaningful reception learning, given that this is a common strategy used in the classroom.
He drew a distinction between the formation of concepts and the utilisation of concepts. Concepts can be acquired either by a process of concept formation or concept assimilation. The former is a deductive process in which the learner experiences numerous exemplars of a concept and as a result determines the essential criteria of the concept (for example, the concept of ‘dog’ is formed by observation of many different types of dogs). The latter involves the presentation of the essential criteria of a concept to the learner and then relating this concept to other exemplars of the concept already within the learner’s cognitive structure. Ausubel also makes reference to stages of cognitive development (Ausubel et al. 1978). As children advance in years, they become capable of higher order abstractions which tend to be more precise and well-differentiated. They also acquire new concepts mainly through the process of concept assimilation rather than the process of concept formation. Concepts which have been acquired can be used in perceptual categorisation or may be used cognitively. Perceptual categorisation refers to the influence of concepts within the cognitive structure on the perception of objects, events or phenomena related to that concept e.g. the perception of an exemplar of a concept. The cognitive use of concepts occurs when learning newer concepts that must be related to the pre-existing concept or when engaging in problem-solving which requires the extension, elaboration or qualification of pre-existing concepts (Ausubel et al. 1978). Ausubel, in contrast to Piaget, views language as an integral facilitator in the process of meaningful learning and the acquisition of concepts (Ausubel et

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13 Although he acknowledged that the distinction between the formation and utilisation of concepts was arbitrary and served only to allow for a closer examination of the nature of concept acquisition and the use of these concepts (Ausubel et al. 1978).
Words and propositions can represent a concept and allow the learner to clarify the meaning of a concept, to refine and differentiate the concept, and to manipulate and apply the concept.

Ausubel was aware of the available research literature on alternative conceptions in science among young children and he attributed this phenomenon to several factors (Ausubel et al. 1978, pp. 372-373). These include:

- the lack of cognitive development among children in addition to the lack of experiences necessary for the development of robust conceptions,
- the classroom pressure which results in children concealing their lack of understanding by rote-learning key terms and phrases without the implied conceptual understanding,
- the discomfort which some children feel when they experience a sense of ambiguity about the meaning of a concept, which leads to them to premature conceptual closure in order to alleviate this discomfort, and,
- the confusion between words with different meanings that may sound similar.

(c) Insights from Educational Psychology on Alternative Conceptions

How does the work of the educational psychologists shed light on the problem of alternative conceptions? Piaget’s work on the processes of assimilation and adaptation could provide an explanation for the effect of alternative conceptions on future learning. A pre-existing cognitive schema, which is based on alternative conceptions, interferes with new learning if new information is assimilated into said schema. In this instance, information which does not fit the schema is ignored in order to fit the new information to the pre-existing schema. There is some evidence to support this, as learners with alternative conceptions about the content they are learning can misperceive laboratory events which contradict their existing conceptions (Resnick 1983; Johnstone et al. 1994). Ausubel’s views of instruction and learning are also based on the importance of prior knowledge and the learner’s internalisation of new information in a way that connects the new information to the prior knowledge. In this case, the potential for alternative conceptions to interfere with future learning is similar to that applied to Piaget’s work. Piaget’s theory of cognitive development may potentially account for the original development of alternative conceptions (and not just the effect of alternative conceptions discussed thus far). In the case of science and chemistry education, the concepts to be learned are abstract and often complex. According to Piaget, only learners in the last stage of cognitive development (which he calls the Formal Operational Stage) are capable of processing these ideas. A learner who has not yet reached this stage will, therefore,
be unable to process these ideas and may erroneously simplify them leading to the development of alternative conceptions. A similar explanatory model may be developed based on Ausubel’s work on the cognitive factors affecting learning.

Vygotsky’s work provides an alternative viewpoint for the development of alternative conceptions based on his socially-oriented theory of learning. His views on the link between language and learning and the Zone of Proximal Development may also present an explanatory model for alternative conceptions. When learners engage with either their peers or their teacher they can develop understanding which they would not be capable of developing if they worked independently. However, it is conceivable that one way the learner could adopt alternative conceptions is in cases where the peer or the teacher has alternative conceptions regarding the content.

While there is overlap between Ausubel’s work and that of Piaget and Vygotsky, he includes other elements not found in their work, which are of relevance for the problem of alternative conceptions. For example, he acknowledges the influence of instructional materials on learning (Ausubel et al. 1978). The effect which such materials can have on learners’ understanding has been well-documented in the research literature. Textbooks may encourage or reinforce alternative conceptions in biology (Barman and Mayer 1994; Rees 2007; Cook 2008), physics (McClelland 1993; Stylianidou et al. 2001) and chemistry (Sanger and Greenbowe 1999; Pedrosa and Dias 2002) and they are sometimes written by authors with inadequate understanding of the topic (Cervellati et al. 1982; Gunstone et al. 2005). Also, the manner in which teachers present material to their students can reinforce and encourage alternative conceptions (Bodner 1991; Taber 2000; Van Driel and Verloop 2002; Nakiboglu 2003). The use of simplified models to explain concepts, such as atomic structure and bonding, creates difficulty as learners continue to use these models long after their usefulness has been outgrown (Taber 2002, p.90; Tsaparlis and Papaphotis 2002).

The work of these educational psychologists, and the contribution of those utilising their methods and theories to the issue of alternative conceptions, will be discussed in greater depth in Chapter 3.
2.3 DOCUMENTED ALTERNATIVE CONCEPTIONS IN CHEMISTRY

(a) Particulate Nature of Matter
An understanding of the particulate nature of matter (PNM) is fundamental for the development of sound understanding of all conceptual areas within the discipline of chemistry (Adbo and Taber 2009) and particularly to the understanding of more complex concepts such as dissolution, chemical reactions and equilibrium (Nakhleh 1992).

There is significant overlap between the areas of PNM and chemical bonding. Therefore, for the purposes of a literature review, there was a need to delimit the concept of PNM. Snir et al. (2003) highlight a number of salient features of the particulate model of matter:

- matter is made up of discrete particles which have a complex internal structure,
- there are a variety of forces included in the particulate model,
- elements of the microscopic world are in constant motion at many levels (intraparticulate and inter-particulate, for example),
- the mass of matter is an invariant of any system in all its transformations, and,
- there is a distinction between the additive properties of matter, such as mass, and the intensive properties, such as density.

Based on these features, this study, for the purposes of reviewing the literature, utilised the following definition of the particulate model of matter: *matter is made up of discrete particles with a complex internal structure that determines its structure and properties; these particles are in constant motion due to the forces acting upon, between and within them.* Based on this definition, a review of the literature on the understanding and alternative conceptions of learners in the area of PNM was undertaken. This review revealed that research has taken place in five main conceptual areas: the composition of matter, the properties of matter, the arrangement and movement of particles in matter, the effect of physical changes on the composition and properties of matter, and, the effect of chemical changes on the composition and properties of matter. These conceptual areas and their meaning are shown in Table 2.3. The main findings of the literature review in each of these areas follows, as does a summary of the types of learners with whom research in the area of PNM has been carried out.
Table 2.3 Meaning of the conceptual areas used to organise documented PNM alternative conceptions

<table>
<thead>
<tr>
<th>Conceptual Area</th>
<th>Includes learners' understanding related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition of Matter</td>
<td>the homogeneous and heterogeneous composition of substances, including concepts such as: molecule, atom, compound, element, mixture, and pure substance.</td>
</tr>
<tr>
<td>Properties of Matter</td>
<td>intensive and additive properties of matter resulting from its particulate nature.</td>
</tr>
<tr>
<td>Arrangement and Movement of Particles</td>
<td>the arrangement and movement of particles in the three classical states of matter.</td>
</tr>
<tr>
<td>Effect of Physical Changes on Composition and Properties</td>
<td>changes in the composition and properties of matter, as defined above, due to phase changes, mixing, etc.</td>
</tr>
<tr>
<td>Effect of Chemical Changes on Composition and Properties</td>
<td>changes in the composition and properties of matter, as defined above, due to chemical reactions.</td>
</tr>
</tbody>
</table>

**COMPOSITION OF MATTER**

Alternative conceptions in this area largely stem from mental associations between the following pairs of concepts: compound and mixture, element and pure substance, molecule and compound, and, element and atom. Conceptions include ideas such as 'mixtures are compounds' (Papageorgiou and Sakka 2000; Sanger 2000; Kahveci 2009) or 'compounds are mixtures' (Onwu and Randall 2006; Stains and Talanquer 2007). Pure substances are often only considered to be pure elements and not pure compounds (Sanger 2000; Onwu and Randall 2006). The association between molecule and compound, and, between element and atom can lead to the development of conceptions such as 'every molecule is a compound' (Stains and Talanquer 2007; Kahveci 2009) and 'element is a synonym for atom' (Papageorgio and Sakka 2000). The composition of particles is an abstract area that also causes confusion.

![Figure 2.3: Three ways that learners may visualise ethane (C₂H₆): a) a collection of free atoms, b) elemental fragments, and c) rows of connected atoms](image_url)
As depicted in Figure 2.3, compound molecules may be represented as a collection of free atoms (Eylon et al. 1982; Williamson and Abraham 1995), elemental fragments (Kern et al. 2010) or rows of connected atoms (Eylon et al. 1982; Kelly and Jones 2007; Kern et al. 2010). An understanding that the space between atoms is a vacuum is difficult to develop. Alternative conceptions that can arise in place of this idea are related to the presence of impurities (Adadan et al. 2009), air, or other gases between particles (Williamson and Abraham 1995; Tsitsipis et al. 2012; Adadan 2013).

**Properties of Matter**

The most prevalent alternative conception related to the properties of matter is that the particles of a substance have all (or some of) the macroscopic properties of that substance (Ben-Zvi et al. 1982; de Vos and Verdonk 1987; Johnson 1998a; Ardac and Akaygun 2005; Othman et al. 2008; Franco and Taber 2009). This may be connected to the view that matter is continuous or granular (i.e. particles are like granules of the substance), which has been documented in many studies (Novick and Nussbaum 1978; Nakhleh and Samarapungavan 1999; Boz 2006; Beerenwinkel et al. 2011). Another related idea is that the size or mass of particles is a property that is dependent on the state of matter (Stavy 1988; Lee et al. 1993; Vassiliki et al. 1997; Tatar 2011); the belief that a gas has no mass or volume (Çalik and Ayas 2005), for example. Other properties, particularly those with periodic trends, can cause difficulties and result in alternative conceptions. This is particularly the case in the areas of ionisation energies (Tan et al. 2005; Ozmen 2010; Wheeldon 2012), atomic or ionic radii (Taber 1998a; Nyachwaya et al. 2011), atomic mass (Griffiths and Preston 1992), or, the oxidation numbers of ionic species (Nyachwaya et al. 2011).

**Arrangement and Movement of Particles in Matter**

The arrangement of the particles of a gas has been reported as an area of difficulty. Some common alternative conceptions include ideas such as an orderly rather than a disorderly arrangement of particles of a gas (Gabel et al. 1987; Çalik and Ayas 2005), or that gases do not occupy the entire volume of a container but are clustered in some part of the container (Nurrenbern and Pickering 1987). The representation of molecular gases as monatomic is also a common conception (Çalik and Ayas 2005). Çalik and Ayas (2005) highlight the invisible nature of gases as the probable reason for the development of alternative views. The relative distance and spacing between particles in different substances and states is an area in which confusion can arise. Alternative conceptions include that: liquids have an intermediate spacing compared to solids and gases (Adadan et al. 2009), and there are no spaces between solid particles (Ozmen 2011a; Tatar 2011). The conception that there is no
movement of particles in solids has also been reported (Pozo and Gomez Crespo 2005; Adbo and Taber 2009; Gustafson *et al.* 2010; Tsitsipis *et al.* 2012), as has the notion that particles are pushed externally to keep them in motion (Novick and Nussbaum 1978; Lee *et al.* 1993; Williamson and Abraham 1995; Pozo and Gomez Crespo 2005).

**Effect of Physical Changes on Composition and Properties of Matter**
The most common alternative conceptions in this area are related to molecules being altered chemically or physically as a result of a phase change. Conceptions which have been reported include that: intramolecular bonds break and may recombine on boiling (Osborne and Cosgrove 1983; Bodner 1991; Valanides 2000; Kirbulut and Beeth 2013), evaporating (Ben-Zvi *et al.* 1982; Mulford and Robinson 2002; Othman *et al.* 2008) and/or condensing (Osborne and Cosgrove 1983; Bar and Travis 1991; Kirbulut and Beeth 2013). The physical changes which may be alternatively-conceived as having occurred as a result of phase change are changes in mass (Griffiths and Preston 1992; Othman *et al.* 2008; Aydeniz and Kotowski 2012), size (Griffiths and Preston 1992; Banda *et al.* 2011), shape (Pereira *et al.* 1992; Griffiths and Preston 1992) or temperature (Lee *et al.* 1993; Boz 2006). In other words, particles of the same substance in different states are said to have fundamentally different properties. Similar alternative conceptions about the changes in chemical or physical properties of matter have been documented in relation to other physical changes such as crushing, mixing and dissolving (Ebenezer and Erickson 1996; Kabapinar *et al.* 2004; Kelly and Jones 2007; Taber and Garcia-Franco 2010).

**Effect of Chemical Changes on Composition and Properties of Matter**
Conservation ideas are a source of difficulty when learning about chemical changes and can result in alternative conceptions in which atoms and mass are not conserved (Yarrock 1985; Abraham *et al.* 1994; Haidar 1997; Mulford and Robinson 2002; Çalik and Ayas 2005). Chemical changes may be alternatively-conceived as not resulting in a change in the composition of particles and, as a result, products and reactants may be given representations that are identical to each other (Ardac and Akaygun 2005). The properties of matter may also be considered to be identical before and after a chemical change (Çalik and Ayas 2005). When chemical changes are represented using chemical equations, confusion very often arises about the concept of coefficient. Coefficients may be considered to represent a kind of multiplier of subscripts and, thus, the concept is linked to determining the number of atoms in a molecule (Yarrock 1985; Mulford and Robinson 2002; Kern *et al.* 2010; Nyachwaya *et al.* 2011). Subscripts or coefficients may also be ignored (Abraham *et al.* 1994; Haidar 1997). The properties of a compound have been reported in the literature as being the same as the
properties of the compound’s constituent elements. For example, sodium chloride may be considered reactive because sodium is reactive (Boo 1998). Similarly, potassium sulfate may be considered reactive as potassium is reactive or potassium chloride may be considered to be 'clear' because the chlorine bleaches it (Taber 1993).

Study Participants

In the area of PNM, the majority of studies have involved lower-second-level learners (Bar and Galili 1994; Johnson 1998; Othman et al. 2008; Ayas et al. 2010; Aydeniz and Kotowski 2012), followed by upper-second-level learners (Griffiths and Preston 1992; Chandrasegaran et al. 2007; Bridle and Yezierski 2012) and third-level learners (Mulford and Robinson 2002; Gopal et al. 2004; Heredia et al. 2012; Becker et al. 2013). Comparatively fewer studies have been published that have carried out investigations about the understanding of PNM among primary-level learners (Osborne and Cosgrove 1983; Bar and Galili 1994), pre-service teachers (Chang 1999; Valanides, 2000; Kahveci 2009; Kind and Kind 2011), in-service science teachers (Kruse and Roehrig 2005; Williamson and Jose 2008) or graduate students (Treagust et al. 2011). Of those studies carried out with pre-service teachers, the majority of these involve pre-service primary teachers (Gabel et al. 1987; Kokkotas et al. 1998; Valanides 2000; Tatar 2011; Subramanium and Harrell 2013).

Comparative Studies

Many studies have compared the understanding of groups of learners. These studies have compared lower-second-level with upper-second-level learners (Harrison and Treagust 1996; Boz 2006; Franco and Taber 2009; Aydeniz and Kotowski 2012) and in some cases also with third-level learners (Abraham et al. 1994; Hwang 1995; Ayas et al. 2010; Stains et al. 2011). Primary-level learners have been compared with lower-second-level learners (Bar and Travis 1991; Bar and Galili 1994; Paik et al. 2004; Krnel et al. 2005) and, in some cases, also with upper-second-level learners (Osborne and Cosgrove 1983; Liu and Lesniak 2005). Understanding of PNM is, generally, found to improve from primary-level through to lower-second-level and upper-second-level education (Abraham et al. 1994; Liu and Lesniak 2005; Boz 2006). However, some studies have observed that understanding of these concepts does not improve between lower-second- and upper-second-levels (Franco and Taber 2009). Aydeniz and Kotowski (2012) found mixed results between these two levels with some concepts being more fully understood by upper-second-level learners while others were better understood by lower-second-level learners.

PSSTs have been included in some of these comparison studies (Çalik and Ayas 2005; Kahveci 2009; Kind and Kind 2011). Çalik and Ayas (2005) found that PSSTs in their final
year of a concurrent STE programme had a much better overall understanding about PNM than lower-second-level learners. However, both the PSSTs and the lower-second-level learners had difficulty in representing the arrangement of particles in a gas. Kahveci (2009) found that PSSTs in their fifth-year of a five-year concurrent STE programme had a better understanding of elements, compounds and mixtures than those in either their fourth-year or first-year. Those in their fourth year had a better understanding than those in their first-year. Among all groups, the following alternative conceptions were observed: ‘all molecules are compounds’, ‘a mixture is a compound’, and ‘macroscopic properties can be attributed to microscopic particles’. This latter conception was prevalent among all three groups. Kind and Kind (2011) compared PSSTs of different specialisms following a consecutive STE programme. They noted the alternative conceptions that: ‘macroscopic properties can be attributed to microscopic particles’, ‘there is air between particles’, and ‘bubbles in boiling water are a mixture of hydrogen and oxygen gases’. The chemistry specialists outperformed the biology specialists and the physics specialists. A similar result, with regard to subject specialism, was obtained by Chang (1999).

Kruse and Roehrig (2005) compared chemistry specialist and non-specialist in-service teachers. The authors utilised the same instrument as Mulford and Robinson (2002), thus, allowing for comparison between teachers and third-level-learners in their first year studying a general chemistry module. Teachers were less likely to have alternative conceptions than students. Alternative conceptions did arise for teachers; however, they were much more likely to have resolved their understanding to scientifically-acceptable conceptions. Some conceptions found among teachers and students were that ‘atoms are not conserved as a result of chemical change’, ‘confusion between subscripts and coefficients’, and ‘macroscopic properties can be attributed to microscopic particles’. Kruse and Roehrig (2005) also found that chemistry specialists performed significantly better than non-specialists.

(b) Chemical Bonding

An understanding of chemical bonding is fundamental for further study in areas such as chemical equilibrium, thermodynamics, organic chemistry and chemical reactions (Taber and Coll 2003; Pabuccu and Geban 2006). It is widely acknowledged as one of the most difficult areas in chemistry for learners to gain a sound conceptual understanding (Unal et al. 2006; Kind and Kind 2011). Chemical bonding is a complex and abstract topic which requires

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14 The authors found that 36% of PSSTs and 24% of lower-second-level learners could draw accurate representations of the gas particles.
15 The authors included only these three groups of PSSTs in their study.
learners to create complex mental models (Taagepera et al. 2002). In an investigation with PSSTs about their conceptions in several topic areas (including PNM, mole calculations and combustion reactions), Kind and Kind (2011) discovered that PSSTs had the most difficulty with concepts related to chemical bonding. Several researchers have noted that the current chemical bonding educational methods do not support the development of conceptual understanding among learners (Nicoll 2001; Taber 2002). As a result, alternative methods for the teaching and learning of chemical bonding have been proposed (Harrison and Treagust 2000; Taber 2002; Levy-Nahum et al. 2010).

The research carried out in relation to learners' alternative conceptions of chemical bonding has been broken down into three main conceptual areas: the process of bonding, the resulting structures and the resulting properties. Table 2.4 shows the meaning of each of these conceptual areas for the purpose of this literature review.

### Table 2.4 Meaning of conceptual areas used to organise alternative conceptions in chemical bonding

<table>
<thead>
<tr>
<th>Conceptual Area</th>
<th>Includes learners' understanding related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process of Bonding</td>
<td>the energetics of bonding, impetus for bonding, meaning of bonding and the bond types, and particles involved in bonding.</td>
</tr>
<tr>
<td>Resulting Structures</td>
<td>the structure of ionic, metallic, covalent intermolecular, covalent network structures, etc.</td>
</tr>
<tr>
<td>Resulting Properties</td>
<td>the properties of bonds (polarity, strength, etc.) and the properties resulting from the type of bonding (boiling points, electrical conductivity, etc.)</td>
</tr>
</tbody>
</table>

#### PROCESS OF BONDING

**Energetics of Bonding**

In the area of energetics of bonding, the most common alternative conception reported is that the breaking of bonds releases energy and/or that energy is stored in bonds (Boo 1998; Barker and Millar 2000; Teichert and Stacy 2002; Kind and Kind 2011). This particular conception has been linked with the treatment of adenosine triphosphate (ATP) hydrolysis in the discipline of biology (Galley 2004). Another common alternative conception related to the energetics of bonding is that the release of energy in an exothermic reaction is due to the presence of some entity (such as air, oxygen, heat, etc.) (Barker and Millar 2000; Nicoll 2001; Kind and Kind 2011). The difficulties associated with the concepts of energy and stability have been documented. Confusion may exist about the link between energy and stability (Wang and Barrow 2013; Luxford and Bretz 2014) or the link between the two concepts may be entirely lacking (Nicoll 2001).
Impetus for Bonding

The literature revealed several alternative conceptions about the impetus for bonding. The octet rule and electrostatic attractions cause the most difficulty for learners. The obtaining of an outer shell with eight electrons for atoms and ions is often considered the dominant factor in bond formation (Taber 1998b; Tan and Treagust 1999; Toplis 2008; Kind and Kind 2011; Taber et al. 2012). Alternative conceptions that can arise and/or interfere with learning include the conception that bonding occurs to neutralise charge (Boo 1998; Tan and Treagust 1999; Luxford and Bretz 2013). When applied to ionic bonding, this conception is linked to the idea that ionic bonding involves an ion-pair molecule, as described by Taber (1993) and noted by other researchers (Tan and Treagust 1999; Othman et al. 2008). It is possible that some teaching and learning difficulties in this area arise from prior learning in the discipline of physics. For example, the conception that 'like charges attract like charges' has been noted in the research literature about learners' understanding of chemical bonding (Nicoll 2001; Luxford and Bretz 2013). It is possible that this conception may have developed over the course of teaching and learning in physics and then transferred over to the chemistry context.

Meaning of Bonding and Bond Types

The distinction between bond types can be a source of confusion for learners. The definitions of ionic and covalent bonds may be confused with each other (Tan and Treagust 1999; Barker and Millar 2000; Coll and Treagust 2002; Toplis 2008; Nyachwaya et al. 2011). Covalent and intermolecular bonds can also be confused with each other (Peterson and Treagust 1989; Tan and Treagust 1999; Taagepera et al. 2002; Othman et al. 2008), and the same has been found to be the case with ionic and metallic bonding (Taber 1993; Ozmen et al. 2009). A notable conception that can be attributed to the idealised ionic bond type is one in which the process of ionic bonding is associated with ion formation rather than with the electrostatic attraction between ions (Taber 1993; Taber 1998; Luxford and Bretz 2013). This conception has implications for developing an understanding of the structure of ionic substances. Alternative conceptions about general bonding concepts have also been documented. Bonds may be conceived of as physical entities (Boo 1998; Wang and Barrow 2013). Research into the interpretations of Lewis structure conventions may indicate that these structures contribute to this conception as the lines between atoms are often interpreted as representative of actual physical bonds (Toplis 2008; Luxford and Bretz 2014). A dualistic understanding of bonding may also develop in which all bonding is viewed as

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16 This will be discussed overleaf in the context of conceptions about ‘Resulting Structures’.
either pure ionic or pure covalent (Taber 1993; Taber 1998; Ozmen et al. 2009; Luxford and Bretz 2013). There is some evidence of an integrative meaning for bonding, in which substances are considered to be either simultaneously involved in both pure ionic and pure covalent bonding, or are capable of forming pure ionic bonds or pure covalent bonds depending upon the circumstances (Luxford and Bretz 2013). A number of researchers have pointed out the flaws in the chemical bonding teaching and learning approaches (Taber 2000; Nicoll 2001; Levy-Nahum et al. 2010). Levy-Nahum et al. (2010) notes that the practice of dichotomously classifying all elements as metals and non-metals "leads to a dichotomous classification of bonding related to compounds, namely covalent (existing between non-metallic elements) or ionic (existing between metallic and non-metallic elements)" (Levy-Nahum et al. 2010). This in turn "may obscure the important notion of a unified rationalisation of all chemical bonds based on underlying principles". These comments would appear to be particularly relevant to the alternative conceptions just discussed, as learning about chemical bonding often does lead to a dichotomous classification of bonding.

**Particles involved in Bonding**

Alternative conceptions regarding the sharing and motion of particles involved in the bonding process have been reported in the research literature. For example, the conception that electrons in all covalent bonds are shared equally (Peterson and Treagust 1989; Birk and Kurtz 1999; Taagepera et al. 2002; Wang and Barrow 2013). Learners’ interpretations of Lewis structure conventions may contribute to this conception as Luxford and Bretz (2014) discovered that the spacing of dots can be taken to mean that equal sharing of electrons is taking place. There are a number of common conceptions associated with the motion of electrons in covalent bonds including that the electrons are: in a fixed and stationary position (Nicoll 2001), moving back and forth between the two atoms (Nicoll 2001; Luxford and Bretz 2013), and moving in a figure eight around the two nuclei (Nicoll 2001).

**RESULTING STRUCTURES**

**Ionic and Metallic Structures**

Ionic compounds are the structures about which alternative conceptions are most often reported. Ionic structures may be alternatively considered to be composed of atoms (Taber 1993; Othman et al. 2008). However, a more prevalent conception is that they are composed of molecules and/or bond together through intermolecular bonding (Butts and Smith 1987; Tan and Treagust 1999; Othman et al. 2008; Nyachwaya et al. 2011; Taber et al. 2012). There are a number of alternative conceptions discussed in the previous section to which this conception may be related. For example, it may be the result of the idea that bonding occurs
in order to neutralise charge resulting in an ion-pair molecule. It is also possible that this conception could be related to confusion between ionic and covalent bond definitions. Metallic substances may also be considered to be composed of molecules that bond together in a lattice structure through intermolecular bonding (Taber 1993; Coll and Treagust 2002; Vaarik et al. 2008). Other reported conceptions about metallic substances are that they are composed of only nuclei (Coll and Taylor 2001; Coll and Treagust 2002).

**Covalent Molecular and Covalent Network Structures**

Alternative conceptions about covalent structures are associated with molecular shape and the type of bonding that occurs in macromolecules. Molecular shape is the result of several factors. However, this shape may be associated with a single factor such as: bond polarity, the effect of bonding pairs of electrons, or the effect of non-bonding electrons (Peterson et al. 1989; Birk and Kurtz 1999; Ozmen et al. 2009). In relation to the structure of macromolecules, the same alternative conception is reported as in the case of ionic and metallic structures: that they are composed of molecules engaged in intermolecular bonding (Tan and Treagust 1999; Ozmen 2008).

**Resulting Properties**

**Bond Strength**

The largest body of research in this area is in relation to bond strength. Certain bonds may be seen as inherently stronger than others (Taber 1998b; Barker and Millar 2000; Coll and Taylor 2001; Toplis 2008; Kind and Kind 2011). Covalent bonding may be viewed as strong bonding and as stronger than ionic bonding (Barker and Millar 2000; Coll and Taylor 2001; Toplis 2008; Kind and Kind 2011) or, vice versa, that ionic bonding is viewed as a strong bond and as stronger than covalent bonding (Barker and Millar 2000; Kind and Kind 2011). Metallic bonds may be considered to be an inherently weak form of bonding (Taber 1998b; Coll and Taylor 2001). These ideas about the strength of bonds are related to the idea that some bond types are not 'real' bonds. It has been reported that intermolecular, ionic and metallic bonds may not be considered 'real' bonds but are considered as 'just forces' (Taber 1993; Barker and Millar 2000; Taber et al. 2012).

**Directionality of Bonds**

Alternative conceptions regarding the directionality of bonds are mostly in relation to ionic bonding. An ion may be thought of as only bonded to an ion to/from which it has transferred/accepted an electron (Taber 1993; Taber et al. 2012; Luxford and Bretz 2014). It was previously mentioned that ionic bonding is often associated with ion formation rather
than electrostatic attraction between ions\(^\text{17}\). This conception appears to be linked with the conception of directional ionic bonds and the two have been reported together (Taber 1998b; Taber et al. 2012). Metallic bonding may also be considered to have an element of directionality (Coll and Taylor 2001), although this is less commonly reported.

**Bond Polarity and Molecular Polarity**

Among the documented alternative conceptions about the causes of bond polarity are: ionic charge or other charged particles (Peterson et al. 1989; Birk and Kurtz 1999; Nicoll 2001), the number of valence electrons (Peterson et al. 1989; Ozmen et al. 2009), or the influence of non-bonding electron pairs on shared electrons (Birk and Kurtz 1999; Ozmen et al. 2009). Generally, bond polarity is not associated with electronegativity (Nicoll 2001). Alternative conceptions of molecular polarity are the result of attributing the polarity to a single one of the following factors: the presence of polar bonds (Birk and Kurtz 1999; Ozmen 2008), non-bonding electrons (Peterson et al. 1989; Birk and Kurtz 1999; Ozmen et al. 2009), or electronegativity (Peterson et al. 1989; Birk and Kurtz 1999; Ozmen et al. 2009). The essential difficulty arises from ignoring the influence of molecular geometry when considering molecular polarity (Birk and Kurtz 1999).

**Boiling Points**

Research has been carried out with learners to investigate their understanding of the prediction of boiling points. Higher boiling points have been attributed to more branching in molecules (Schmidt et al. 2009), rather than less branching. High or low boiling points may be attributed to pKa values (i.e. the logarithmic scale of the acid dissociation constant) or resonance within molecules (Henderleiter et al. 2001), although such conceptions are not widely reported. High boiling points are also connected to molecular instability (Schmidt et al. 2009). This conception may be linked with the idea that covalent bonds break on boiling\(^\text{18}\) (Schmidt et al. 2009). This link is not surprising as concepts within PNM are a pre-requisite for the development of understanding about chemical bonding (Othman et al. 2008).

**Electrical Conductivity and Viscosity**

The electrical conductivity of graphite has been documented as being the result of delocalised carbon atoms that conduct electricity (Tan and Treagust 1999) or layers of carbon atoms that slide over each other and, therefore, conduct electricity (Tan and Treagust 1999; Pabuccu and Geban 2012). Graphite's ability to conduct electricity may be seen as a consequence of

\(^{17}\) This was reported in ‘Meaning of Bonding and Bond Types’ on page 45-46.

\(^{18}\) This was reported in ‘Effect of Physical Changes on Composition and Properties of Matter’ on page 41.
a disordered geometry (Pabuccu and Geban 2012). Layers of covalently bonded atoms can also be associated with higher viscosities in substances (Tan and Treagust 1999) along with 'strong bonds in the covalent lattice' (Peterson et al. 1989). The electrical conductivity of ionic compounds when in the liquid state may be attributed to the ‘melting’ of atoms to form ions or electrons which conduct electricity (Othman et al. 2008). Given that in the study of physics, the conductance of electricity is only explicitly associated with electrons, learners may be under the impression that only free electrons, and not ions, can conduct electricity. It, therefore, logically follows that ionic compounds conduct electricity as a result of the presence of free electrons (Othman et al. 2008; Heredia et al. 2012).

**STUDY PARTICIPANTS**

Coll and Taylor (2001) stated that the "conceptions which tertiary level chemistry students hold about chemical bonding have, in comparison [with second-level students], been researched infrequently". This is no longer the case as the majority of research into alternative conceptions in the area of chemical bonding is spread almost equally between studies involving third-level learners (Birk and Kurtz 1999; Coll and Treagust 2002; Taagepera et al. 2002; Teichert and Stacy 2002; Cooper et al. 2010; Luxford and Bretz 2014) and upper-second-level learners (Peterson and Treagust 1989; Taber 1993; Barker and Millar 2000; Coll and Treagust 2002; Ozmen 2008; Taber et al. 2012). Far fewer studies\(^{19}\) have been carried out in this area with lower-second-level learners (Tan and Treagust 1999; Othman et al. 2008), possibly because many of the concepts just discussed are not addressed in detail at this level of education, and PSSTs (Toplis 2008; Kind and Kind 2011). There are few studies that include learners from among graduate students (Coll and Taylor 2001; Coll and Treagust 2002) or chemistry faculty members (Birk and Kurtz 1999; Cooper et al. 2010). Utilising the literature method discussed in Section 2.1, no studies were found that investigated the understanding of experienced in-service second-level teachers about chemical bonding. Therefore, the current situation is one in which the conceptions of pre-service and in-service science teachers, faculty members, and lower-second-level learners have, in comparison with third-level and upper-second-level learners, been researched infrequently.

\(^{19}\) Four studies involving PSSTs were identified using this literature review method, while nineteen studies involved third-level learners and twenty-one involved upper-second-level learners.
Studies have compared the understanding of learners from a number of the groups mentioned in the previous section (Birk and Kurtz 1999; Coll and Taylor 2001; Coll and Treagust 2003; Vaarik et al. 2008; Cooper et al. 2010; Luxford and Bretz 2013). These studies provide some interesting, though occasionally conflicting, insights into the development of conceptual understanding about chemical bonding among learners as they progress through their education. Learners at more advanced levels of education, such as those at third-level and postgraduate-level, hold at least some of the same alternative conceptions as those in second-level education (Birk and Kurtz 1999; Coll and Taylor 2001; Cooper et al. 2010; Luxford and Bretz 2013). Groups of learners at different educational stages have been compared to ascertain whether those at later stages have a deeper understanding and fewer alternative conceptions than those at earlier stages (Peterson et al. 1989; Birk and Kurtz 1999; Nicoll 2001; Othman et al. 2008). Peterson et al. (1989) and Othman et al. (2008) involved two groups of upper-second-level learners in each of their studies that were one educational year apart. Peterson et al. (1989) noted an improvement in understanding for those a year ahead in their education, while Othman et al. (2008) noted improvements in some areas and diminished understanding in other areas. Birk and Kurtz (1999) involved the widest range of learners in their study. They involved groups of learners from upper-second-level, third-level, postgraduate-level and faculty-level. The authors noted an improvement in understanding with each advance in educational level. Nicoll (2001) included learners at third-level education from junior through to senior level and did not find evidence of an improvement in understanding. However, this study had a small sample size.

Other studies have utilised a longitudinal design, in which a single group is tracked over a period of time, to address the same research issue (Barker and Millar 2000; Taagepera et al. 2002). Naturally, given the time it would take, it is more difficult for these studies to obtain data about a range of educational levels and they tend to collect data from a single group over the course of one-two years. Barker and Millar (2000) found that upper-second-level learners did improve their understanding, as a result of context-based instruction over sixteen months, and were less likely to have alternative conceptions. However, they were more likely to have certain alternative conceptions the further on they were in their studies. Such conceptions include: 'breaking bonds releases energy', 'covalent bonds are weaker than ionic bonds' and 'hydrogen bonding isn't real bonding'. Taagepera et al. (2002) followed a group of third-level learners over an academic year of their studies. Learners’ understanding of chemical bonding had improved at the end compared with the start of the year. However, in a few cases their understanding was diminished and, where understanding had improved.
between the start and end of the year, it was often accompanied by reductions in understanding in the interim tests. One might tentatively conclude based on a review of these studies, that the development of abstract concepts about chemical bonding is a complex and non-linear process that is impacted upon by the specific concepts being addressed and by the span of educational levels which one includes in a research study.

(c) Stoichiometry

Gulacar and Fynewever (2010) investigated the sub-problems which learners encounter in the area of stoichiometry. These ten sub-problems formed a method for categorising past research investigating learners’ alternative conceptions in stoichiometry. The sub-problems have been grouped together under conceptual areas, shown in Table 2.5, along with a description of the meaning of each of these categories. It is important to note that there remains overlap between these categories; this is to be expected given that often one topic is dependent on understanding of other topics (e.g. successful use of stoichiometric ratios involves an understanding of the mole and other topics).

<table>
<thead>
<tr>
<th>Conceptual Areas</th>
<th>Sub-problems identified by Gulacar and Fynewever</th>
<th>Includes learners’ understanding related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE CONCEPT</td>
<td>Mole concept</td>
<td>the mole as a unit of amount of substance, its relationship to molar mass and numbers of particles, and its role in measurements of molarity.</td>
</tr>
<tr>
<td>Stoichiometric Ratio</td>
<td>Stoichiometric ratio Percentage yield</td>
<td>the relative quantities of reactants and products in chemical reactions.</td>
</tr>
<tr>
<td>Chemical Formulae</td>
<td>Empirical formulae Molecular formulae Mass percent</td>
<td>chemical formulae written in their simplest form expressing the composition of a compound, and formulae written for molecular substances expressing their relative molecular mass.</td>
</tr>
<tr>
<td>Reagents</td>
<td>Limiting reagent Excess reagent*</td>
<td>substances consumed or partially consumed during a chemical reaction.</td>
</tr>
<tr>
<td>Chemical Equations</td>
<td>Balancing chemical equations Writing chemical equations</td>
<td>the writing and balancing of chemical equations.</td>
</tr>
<tr>
<td>Conservation of Mass</td>
<td>Conservation of mass</td>
<td>the principle that mass is neither created nor destroyed in a chemical reaction.</td>
</tr>
</tbody>
</table>

*This was not identified as a separate sub-problem by Gulacar and Fynewever (2010) but the alternative conceptions related to this concept in the literature led to its inclusion as a sub-problem.

MOLE CONCEPT

This review has found that the mole concept is the stoichiometric area in which the most alternative conceptions have been documented. The mole is often considered to be a unit of mass (Krishnan and Howe 1994; Case and Fraser 1999) and may be alternatively defined as the number of molecules in a gram of a substance (Cervellati et al. 1982; Dahsah and Coll 2008). Other alternative conceptions relate the mole to the molar mass of a substance. It may
be considered to be the same as molar mass or the result of the molar mass multiplied by Avogadro's number (Haidar 1997). Confusion has also been reported about the concept of mole in relation to molecule, with the mole being used as a synonym for molecule (Case and Fraser 1999; Dahsah and Coll 2008; Davidowitz et al. 2010). Gulacar and Fynnewever (2010) documented the conception that the subscripts in chemical formulae are inappropriately used as moles. Other conceptions include that the mole is: an abstract concept that is not real, and the smallest part of a substance that can take part in a chemical reaction (Haidar 1997).

Molar mass is another integral part of many stoichiometric calculations. Molar mass may be alternatively-conceived as the actual mass of the substance taking part in the chemical reaction (Haidar 1997; Dahsah and Coll 2007). The coefficient of a substance in a chemical equation may be taken into account when calculating molar masses (Boujaoude and Barakat 2003): for example, the molar mass of ammonia in its formation from nitrogen and hydrogen gas \( N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \), may be calculated as \( 2NH_3 \) rather than \( NH_3 \). Dahsah and Coll (2007; 2008) reported some common alternative conceptions related to incorrect definitions of molarity including that it is: a mole of solute in 1 L of water, a mole of solute in 1000 g of solution, a mole of solute in 22.4 L of solution, or a molecule of the solute in 1 L of solution. These difficulties in understanding the concept of the mole and its uses have implications for learners’ ability to solve stoichiometric problems as these concepts are fundamental for all stoichiometric calculations and concepts.

**REAGENTS**

A number of alternative conceptions regarding the concept and use of limiting reagents and excess reagents have been reported (Davidowitz et al. 2010). These two concepts can often be confused with each other (Dahsah and Coll 2008). Alternative conceptions can relate to their effect on the product of a chemical reaction. For example, excess reagents are sometimes considered to contribute to the mass of products (Boujaoude and Barakat 2003; Kind and Kind 2011). Wood and Breyfogle (2006) discovered that some may regard the product as being formed exclusively from the limiting reagent. The limiting reagent itself can take on a multiplicity of meanings including that it is the reagent of the: lowest mass (Boujaoude and Barakat 2003), lowest number of moles (Huddle and Pillay 1996; Boujaoude and Barakat 2003), or lowest molar mass (Dahsah and Coll 2007). Dahsah and Coll (2008) also reported the conception that if one reagent is limiting then the reaction will not proceed. Wood and Breyfogle (2006) found that the concept of limiting reagent may be viewed as a fundamental property of a specific reagent in a particular chemical reaction; in other words, one reagent will be considered to be limiting regardless of the amount of all reagents present.
CONSERVATION OF MASS

While, generally, the concept of conservation of mass is well understood (Kind and Kind, 2011), alternative conceptions can arise in certain contexts. For example, Kind and Kind (2011) found that the conception that the mass of products is greater than the mass of reactants arose when a precipitate was produced by the reaction. The authors also noted that the mass of products may be considered to be less than the mass of reactants when a gas is produced in a closed system\(^{20}\). The most common alternative conception about the conservation of mass in stoichiometry calculations is that moles are conserved rather than mass (Wood and Breyfogle 2006; Davidowitz et al. 2010; Gulacar and Fynewever 2010). Molar mass may also be considered to be conserved rather than mass (Haidar 1997). This latter conception may be related to the idea that molar mass is the same as the actual mass of a substance involved in a reaction\(^{21}\). Stoichiometric problems in closed systems also create difficulty as any reagent present in excess may be disregarded in considerations of conservation of mass (Boujaoude and Barakat 2003).

CHEMICAL FORMULAE

An understanding of empirical and molecular formulae is necessary for learners to be able to write chemical equations, which will be discussed in the next section. Gulacar et al. (2013) found that empirical and molecular formulae can be confused with one another. Gulacar and Fynewever (2010) noted that learners have much less success in the working out of empirical formulae than molecular formulae. Empirical formulae are particularly relevant for writing chemical equations involving ionic compounds. There is little chance of success in this area where learners have no basic knowledge of common oxidation states, as has been reported to sometimes be the case (Dahsah and Coll 2007; Gulacar and Fynewever 2010). Alternative conceptions which interfere with the ability to determine empirical formulae include the idea that these can be constructed based on information about a single element of the compound (Dahsah and Coll 2007) or without reference to the mole concept (Gulacar et al. 2013). Gulacar and Fynewever (2010) also found that the context in which an empirical formula had to be constructed could affect learners’ ability to do so.

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\(^{20}\) These alternative conceptions would appear to have more to do with the PNM concepts previously mentioned in Section 2.3(a) (that gases weigh less than solids, for example) rather than conservation of mass in the context of stoichiometry.

\(^{21}\) This was reported in ‘Mole Concept’ on pages 51-52.
Some of the difficulties in interpreting and constructing molecular formulae relate to confusion about the meaning of subscripts and coefficients (Sanger 2005; Wood and Breyfogle 2006; Davidowitz et al. 2010). A number of researchers have identified alternative conceptions related to the concept and calculation of mass percent (also known as percentage composition) in their studies (Wood and Breyfogle 2006; Dahsah and Coll 2007; Gulacar and Fynewever 2010). Gulacar and Fynewever (2010) found that this concept may be regarded by some to mean the mass per atom, in which the mass percent is calculated by dividing the mass of a compound by the number of atoms in the compound. For example, the subscripts in methane (CH₄) were used in an attempt to find the quantity of matter of carbon in the molecule. In this case, the mass of methane was divided by 5 (i.e. the subscripts 4+1) in order to find the mass of carbon. Mass percent calculations may be confused with limiting reagent calculations (Wood and Breyfogle 2006). Dahsah and Coll (2007) found that where a question presents the mass of an element assessed through quantitative elemental analysis techniques, this may be taken to mean the actual mass of the element in the compound. The ability to construct empirical and molecular formulae directly impacts on success in writing chemical equations.

**CHEMICAL EQUATIONS**

The writing and balancing of chemical equations have formed part of the investigations of a number of studies into the alternative conceptions of learners (Haidar 1997; Sanger 2005; Wood and Breyfogle 2006; Davidowitz et al. 2010; Gulacar and Fynewever 2010). The inclusion of spectator species in the writing of chemical equations, i.e. excess substance that does not participate in the reaction, has been documented as an alternative conception (Sanger 2005; Dahsah and Coll 2008; Davidowitz et al. 2010). Gulacar et al. (2013) noted that learners could find themselves in the predicament of trying to write down a chemical equation with no basic knowledge of common oxidation states or nomenclature. In the balancing of equations, common errors relate to alternative conceptions about the concept of coefficient in chemical equations (Haidar 1997; Wood and Breyfogle 2006). For example, fractions may be used instead of integers (Haidar 1997). In other cases, it may not have been understood that the coefficients in the chemical equation should be the smallest integer ratios (rather than multiples of this) (Dahsah and Coll 2007; Davidowitz et al. 2010). The problem-solving approach taken can also result in unbalanced equations as some learners may not check the balance of the equation upon successive alterations to coefficients (Haidar

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22 This is only considered an alternative conception when the learner is indicating a fraction of a particle rather than a fraction of a mole.
Gulacar and Fynewever (2010) in their investigation of the difficulty of sub-problems associated with stoichiometric problems noted that, of all the sub-problems investigated, learners were least successful in writing chemical equations and most successful in balancing equations. The authors postulate that this is due to a lack of basic knowledge, such as knowledge of nomenclature, interfering with the ability to write chemical equations, while the use of an algorithmic approach can ensure success when balancing equations.

**Stoichiometric Ratio**

Understanding the meaning of coefficients in chemical reactions (Davidowitz et al. 2010; Gulacar et al. 2013), an inability to use ratios (Dahsah and Coll 2007), and the use of 'magic formulae'24 (Boujaoude and Barakat 2003) have been found to cause difficulties in the use of stoichiometric ratios to calculate quantities of reactants and products. The calculation of the mass of the product may be alternatively-conceived as being calculated from the molar masses of the reactants (Dahsah and Coll 2007). Conceptions related to the mole ratio in chemical equations also impact on these mass-of-product calculations. The most common alternative conception in the use of mole ratios is their treatment as mass ratios (Sanger 2005; Dahsah and Coll 2008) and the assumption that all reactants react in a 1:1 ratio (Haidar 1997; Sanger 2005; Dahsah and Coll 2007). In some cases, the mole ratio is thought of as a volume ratio (Dahsah and Coll 2008). A conception that results in incorrect calculations of the volume of the product of a reaction is the association of the volume of product with the volume of one mole of an ideal gas (22.4 L) regardless of the state of matter, temperature, or pressure (Cervellati et al. 1982; Boujaoude and Barakat 2003; Dahsah and Coll 2008). Other alternative conceptions discovered in the use of stoichiometric ratios include the use of the excess reactant in the calculation of the mass of the product (Kind and Kind 2011) and a confusion between the meaning of reactants and products (Sanger 2005).

Alternative conceptions related to percentage yield are largely related to the concept itself rather than to the calculation of percentage yield. The calculation of the yield does cause problems but it would seem to relate back to alternative conceptions in other areas: the use of molar masses as actual masses in the calculation (Dahsah and Coll 2007), for example. The concept of percentage yield may be mistaken to mean the: theoretical yield, mass of the product when 100 g of reactants are used, or the molar mass when 100 g of reactants are used (Dahsah and Coll 2007).

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23 A list of these sub-problems was presented in Table 2.5.
24 These are combinations of formulae that are used instead of working from first principles.
STUDY PARTICIPANTS

Research in the area of stoichiometry has been mainly carried out with third-level (Krishnan and Howe 1994; Huddle and Pillay 1996; Sanger 2005; Gulacar and Fynewever 2010) and upper-second-level learners (Cervellati et al. 1982; Boujaoude and Barakat 2003; Dahsah and Coll 2008). Lower-second-level learners are not represented as stoichiometry is not part of lower-second-level curricula. PSSTs (Haidar 1997; Kind and Kind 2011) are poorly represented in this area. No research studies could be found about the alternative conceptions of in-service science teachers utilising this literature review method.

COMPARATIVE STUDIES

Some of the studies in this area have engaged with different groups of learners to gain an understanding of how education impacts upon understanding of stoichiometry. These studies have either compared the understanding of a single group of learners before and after instruction (Arasingham et al. 2006; Davidowitz et al. 2010), or compared the understanding of different groups of learners (Cervellati et al. 1982; Kind and Kind 2011). Arasingham et al. (2006) implemented a web-based learning tool with third-level learners and found that their understanding about stoichiometry improved and alternative conceptions decreased between the beginning and end of this instruction. Similar results were obtained by Davidowitz et al. (2010) whose instructional strategy involved the emphasis of submicroscopic diagrams. The understanding of different groups of upper-second-level learners has also been compared (Cervellati et al. 1982). Cervellati et al. (1982) compared the understanding of the mole concept among learners in schools with a traditional rote-memorisation approach and with a student-centred approach in which experimental evidence was used to support and learn about chemical principles. These authors found that a student-centred approach resulted in deeper understanding and fewer alternative conceptions than a traditional didactic approach. Kind and Kind (2011) compared understandings of the mole concept (among other concepts) of PSSTs on a consecutive STE programme according to their subject specialism, i.e. biology, chemistry or physics. They found that the subject specialism of PSSTs had a statistically significant impact on their understanding of, and alternative conceptions about, the mole concept. Chemistry specialists outperformed specialists of physics and biology in their understanding of this concept.25

25 Further details about this study were provided in the PNM Comparative Studies section on pages 42-43.
(d) Equilibrium

Alternative conceptions documented in the area of equilibrium have been categorised into the topic areas of: approach to equilibrium, equilibrium constant, rates and equilibrium, response of equilibria to changes in conditions, and the reversibility of reactions. These areas are defined in Table 2.6.

<table>
<thead>
<tr>
<th>Conceptual Areas</th>
<th>Includes learners’ understanding related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversibility of Reactions</td>
<td>the meaning of dynamic equilibrium and the concentrations of substances that result from this dynamic nature.</td>
</tr>
<tr>
<td>Rates and Equilibria</td>
<td>the meaning of reaction rate, and rates of forward and reverse reactions at equilibrium.</td>
</tr>
<tr>
<td>Approach to Equilibrium</td>
<td>the rates of forward and reverse reactions and the concentrations of products and reactants as a reaction approaches equilibrium.</td>
</tr>
<tr>
<td>Response of Equilibria to Changes in Conditions</td>
<td>changes in concentrations, reaction rates and equilibria in response to varying the temperature, pressure and concentrations of substances of a system in equilibrium.</td>
</tr>
<tr>
<td>Equilibrium Constant</td>
<td>the meanings attributed to the equilibrium constant, its constancy, and the manner in which it varies in response to temperature changes.</td>
</tr>
</tbody>
</table>

**Reversibility of Reactions**

Alternative conceptions in this area are largely related to a view of equilibrium reactions as static rather than dynamic (Gorodestky and Gussenky 1986; Bergquist and Heikkinen 1990; Huddle and Pillay 1996). An example of a conception related to this static view is that equilibrium is reached when the forward reaction has gone to completion and the reactants are completely consumed (Bergquist and Heikkenin 1990; Banerjee 1995; Chiu et al. 2002; Ozmen 2007). Equilibrium may be regarded as meaning that no reaction is occurring in the system (Niaz 2001; Chiu et al. 2002; Bilgin and Geban 2006; Al-Balushi et al. 2012). The conception that the forward reaction goes to completion before the reverse reaction begins has often been reported in the literature (Bergquist and Heikkinen 1990; Huddle and Pillay 1996; Al-Balushi et al. 2012; Kaya 2013). These alternative conceptions are the most commonly reported in the research literature about learners' understanding of equilibrium. This demonstrates the ease with which confusion can arise about the meaning of the dynamic nature of equilibrium and the reversibility of reactions.

At equilibrium, the concentrations of reactants and products remain constant as a result of this reversibility. This concept is easily confused with a number of alternative concepts. Rather than the concentrations of reactants and products remaining constant, some may think that the concentrations are equal (Huddle and Pillay 1996; Stieff and Wilensky 2003; Bilgin and Geban 2006; Pekmez 2010) or that the masses are equal (Atasoy et al. 2009; Pekmez 2010). For those that do develop an idea of the dynamic nature of equilibrium, the
alternative conception that the reaction oscillates between products and reactants can
develop, which leads to a view of the concentrations of products and reactants as varying
over time (Bergquist and Heikkinen 1990; Huddle and Pillay 1996; Bilgin and Geban 2006).

**Rates and Equilibria**

Alternative conceptions about the concept of reaction rate interfere with understanding of
chemical equilibrium. The rate of a reaction may be confused with the extent of the reaction
may be considered by some to increase the yield of the product (Bilgin and Geban 2006;
Cakmakci 2010) or to have no effect on reaction rates (Bilgin and Geban 2006; Cakmakci
2010; Akkus et al. 2011).

The rates of the forward and reverse reactions are equal at equilibrium; however, some may
think that this is not the case (Bilgin and Geban 2006). In the case of a reaction at equilibrium
and that equilibrium being disturbed, due to a change in conditions, alternative conceptions
have been reported about the re-established equilibrium. The rates of the forward and reverse
reactions, and/or the concentrations of reactants or products, for the re-established
equilibrium may be thought of as necessarily being the same as for the initial equilibrium
(Bilgin and Geban 2006; Akkus et al. 2011). The rates of the reactions for the re-established
equilibrium may also be considered to be necessarily lower than the reaction rates for the
initial equilibrium (Bilgin and Geban 2006).

**Approach to Equilibrium**

Alternative conceptions about reactions as they approach equilibrium mostly relate to the
forward and reverse reactions rates. The forward and reverse reaction rates may be
considered to increase with time (Hackling and Garnett 1985; Cakmakci 2010) or to increase
at the same rate as they approach equilibrium (Bilgin and Geban 2006). The forward and
reverse reaction rates may be alternatively-conceived as being equal before a reaction reaches
equilibrium (Al-Balushi et al. 2012). A commonly reported conception is that the forward
reaction rate, rather than the reverse, is the increasing reaction rate on approach to

**Response of Equilibria to Changes in Conditions**

This area has been found to cause difficulty for those learning the topic (Bergquist and
Heikkinen 1990; Bilgin and Geban 2006; Atasoy et al. 2009). The alternative conceptions in
this area will be considered with reference to the condition which has been changed, i.e.
increases in: concentrations, pressure, and temperature. Many of these alternative
conceptions relate to a lack of understanding about the underlying principles of Le Châtelier's Law and a resulting unconditional application of the law. In some cases, alternative conceptions have been uncovered that relate directly to an understanding of Le Châtelier's Law and these will be considered separately.

The addition of a reactant to a reaction system at equilibrium is regarded by some to result in a change to the concentration of every substance in the system except for the reactant itself (Bergquist and Heikkinen 1990). Adding a reactant may also be considered to change the concentration of the added substance only (Bergquist and Heikkinen 1990; Atasoy et al. 2009; Cheung et al. 2009). The changes to rates of reactions that result from the addition of a reactant may also pose learning difficulties. The conception that there is a decrease in the rates of forward and reverse reactions has been reported (Bilgin and Geban 2006). The addition of a substance may also be deemed to have no effect on either the rates of the reaction or the concentrations of the substances in the system (Pekmez 2010). The shift in equilibrium that results from such an addition may also be incorrectly predicted as shifting to the same side as the side to which the substance was added (Bilgin and Geban 2006; Ozmen 2007; Akkus et al. 2011). This latter conception is most likely the result of an incorrect application of Le Châtelier's Law.

Compression, i.e. a decrease in volume and increase in pressure, of gaseous systems at equilibrium leads to an increase in the reaction rate that will result in fewer moles of molecules. Depending on the reaction, this could be either the forward or the reverse reaction rate. However, it has been reported that an absolute rule may be applied to these situations such as: the equilibrium always shifts towards the products (Voska and Heikkinen 2000), both reaction rates decrease with compression (Bilgin and Geban 2006; Akkus et al. 2011), or compression never has an effect on the system (Voska and Heikkinen 2000; Bilgin and Geban 2006; Pekmez 2010). Compression can be achieved while keeping the volume constant by adding an inert gas to the system. However, an inert gas can also be added to the system while keeping the pressure constant, in which case the volume of the system must increase which alters molar concentrations and disturbs the equilibrium. This scenario is often poorly understood and may be alternatively-conceived as having no effect on concentrations or on equilibrium (Atasoy et al. 2009; Akkus et al. 2011).

Alternative conceptions about the effect of a change in temperature on a system in equilibrium are related to misunderstandings, or lack of knowledge, about exothermic and endothermic equilibrium reactions. Again, absolute rules may be applied about the effect of changes in temperature and, as a result, the shift predicted is independent of the type of
reaction taking place (Voska and Heikkinen 2000; Ozmen 2008b). Increasing the temperature of an exothermic reaction may result in predictions that the forward reaction rate will increase more than the reverse reaction rate and, thus, favour product formation (Bilgin and Geban 2006; Akkus et al. 2011). A common conception is that a change in the temperature of systems at equilibrium results in the increase of one reaction rate and a decrease in the other reaction rate (Atasoy et al. 2009; Pekmez 2010; Akkus et al. 2011). Increases in the temperature of exothermic reactions have also been associated with the alternative conception that both reaction rates decrease (Bilgin and Geban 2006; Cakmakci 2010).

Errors in the application of Le Châtelier’s Law may be responsible for many of the alternative conceptions reported about the response of equilibria to changes in temperature. There are additional conceptions that relate specifically to understanding of the purpose of Le Châtelier’s Law. For example, the law may be applied before the reaction reaches equilibrium (Ozmen 2008b). It is also applied at equilibrium when no change in the reaction system's conditions has occurred (Bergquist and Heikkinen 1990).

**EQUILIBRIUM CONSTANT**

The constancy of the equilibrium constant when conditions, other than temperature, are changed is an area in which alternative conceptions have been reported. Changes to concentrations, volumes or the addition of a catalyst (while keeping temperature constant) can be associated with changes to the equilibrium constant (Voska and Heikkinen 2000; Bilgin and Geban 2006; Akkus et al. 2011). Conceptions about the effect of changes in temperature on the equilibrium constant result from misunderstandings about endothermic and exothermic reactions. An increase in temperature may be seen as resulting in an increase in the value of the equilibrium constant, regardless of the type of reaction (Voska and Heikkinen 2000; Ozmen 2008b). A decreasing value of the constant (i.e. favouring the production of reactants) may be associated with an increase in the temperature of endothermic reactions (Ozmen 2007). Increases in the temperature of an exothermic reaction may be identified with increases in the equilibrium constant or increased production of the products of the reaction (Bilgin and Geban 2006; Ozmen 2007).

The meaning of the equilibrium constant also creates confusion when learning about chemical equilibrium. Large values for the equilibrium constant may be regarded as meaning that the reverse reaction rate is higher than the forward reaction rate, when the opposite is the case (Atasoy et al. 2009; Akkus et al. 2011). The role of stoichiometric coefficients in the equilibrium constant may be misunderstood and not included in the expression (Bilgin and Geban 2006; Akkus et al. 2011). The value of the constant may be associated with the
concentrations of only the products. At equilibrium, some expect the value of the constant to have a value of one (Huddle and Pillay 1996). This may be due to the combination of two alternative conceptions previously mentioned: the exclusion of stoichiometric coefficients from the equilibrium constant expression, and the idea that at equilibrium the concentrations of reactants and products are equal (Huddle and Pillay 1996).

**STUDY PARTICIPANTS**

Research into learners’ understanding of chemical equilibrium has taken place mostly with third-level learners (Berquist and Heikkinen 1990, Huddle and Pillay 1996; Voska and Heikkinen 2000; Stieff and Wilensky 2003) followed by upper-second-level learners (Chiu et al. 2002; Bilgin and Geban 2006; Akkus et al. 2011; Al-Baluschi et al. 2012) and PSTs (Banerjee 1995; Bilgin 2006). Unlike the other chemistry areas reviewed thus far, in-service teachers are comparatively well-represented (Cheung et al. 2009; Akaygun and Jones 2013).

**COMPARATIVE STUDIES**

Comparative studies have been carried out on groups of learners’ understanding of chemical equilibrium. Many of these studies have compared learners’ understanding before and after a programme implemented to improve their understanding. These kinds of studies have involved upper-second-level learners (Chiu et al. 2002; Bilgin and Geban 2006; Onder and Geban 2006; Ozmen 2007; Atasoy et al. 2009; Pekmez 2010), PSTs (Bilgin 2006) and pre-service primary science teachers (Kaya 2013). Akaygun and Jones (2013) compared the understanding of groups of learners across different levels of education including third-level and upper-second-level learners. They also included faculty members, in-service chemistry teachers and postgraduate students, which were grouped together as experts. The experts were found to have mental models that incorporated the random motion and orientation of molecules and they represented the features of the system in isolation from the context. The third-level and upper-second-level learners had more context-bound mental models and did not demonstrate the random motion and orientation of molecules. They also included macroscopic elements in their representations, which the expert group did not. Banerjee (1991) compared the understanding of third-level learners and in-service science teachers and found that there was generally a low-level of understanding among both groups. The in-service teachers and third-level learners had many of the same alternative conceptions. Cakmakci (2010) compared the understanding of chemical kinetics and equilibrium of upper-second-level learners and PSTs in their first- and third-years of study. The author found that, while some alternative conceptions were resolved with further study, others persisted or became more prevalent with further study. Examples of alternative conceptions which
were more prevalent among third-year PSSTs than among first-year PSSTs and/or upper-second-level learners include that: the rate of a reaction increases with time, a catalyst increases the yield of a product, and an increase in the temperature of an exothermic reaction system decreases both forward and reverse reaction rates. Cakmakci (2010) notes that: "it is intuitively plausible that they [PSSTs] will pass those alternative conceptions on to their students".

2.4 RESEARCH APPROACHES AND METHODS FOR INVESTIGATING LEARNERS' CONCEPTIONS

(a) Research Approaches

Quantitative, qualitative and mixed methods approaches have been utilised in investigations of learners' alternative conceptions. Quantitative approaches are defined as involving the collection of data about measurable variables so that the resulting numerical data can be analysed using statistical procedures (Creswell 2009, p.4). These approaches may involve the use of a diagnostic instrument which has been developed in another study, adapted from another study, or developed by the authors of the study but without the collection of qualitative data in the process of doing so\(^\text{26}\). Qualitative approaches explore and attempt to understand the meanings that the study's participants attribute to certain phenomena. These approaches are characterised by emerging questions, procedures and themes in which the researcher interprets the data (Creswell 2009, p.4). These approaches usually involve the use of open-ended instruments, semi-structured or structured interviews, or observations of classroom practice or group work. Mixed methods approaches involve the association of both quantitative and qualitative approaches (Creswell 2009, p.4). These approaches may take a number of forms based on: the dominant strand of research, the use of one research approach to inform the other research approach, or the ways in which quantitative and qualitative data are combined (Creswell 2009, p. 206-208).

QUALITATIVE APPROACHES

Qualitative research approaches have used interviews, open-ended questions/questionnaires, or a combination of multiple qualitative research tools. Interview methods may be semi-structured (Paik et al. 2004; Taber 2005; Adbo and Taber 2009; Ozmen 2011b) or clinical interviews (Novick and Nussbaum 1978; Johnson 1998a; Johnson and Papageorgiou 2010; Kirbolut and Beeth 2013) similar to those carried out by Piaget. Semi-structured or clinical

\(^\text{26}\) Studies which did collect qualitative data in the process of developing a quantitative instrument have been categorised as mixed methods studies in this review.
interviews may take the form of an interview-about-events style (Johnson 1998a; Nakleh and Samarakungaven 1999; Krnel et al. 2005; Johnson and Papageorgiou 2010) or a think-aloud protocol (Yarrock 1985; Bergquist and Heikkinen 1990).

Open-ended questions or questionnaires may also be utilised in qualitative approaches (Margel et al. 2001; Ayas et al. 2010; Kern et al. 2010; Nyachawaya et al. 2011). Only studies which do not quantise and subsequently analyse quantised data statistically are considered purely qualitative research approaches27. These questions/questionnaires may be comprised of written explanations (Ayas et al. 2010; Tatar 2011), or a combination of written responses and drawings (Margel et al. 2001; Kern et al. 2010; Nyachawaya et al. 2011). The analysis methods used by these kinds of studies are mainly inductive approaches, such as phenomenographic analysis and grounded theory (Kern et al. 2010; Nyachawaya et al. 2011; Tatar 2011). However, deductive analysis methods may also be used (Ayas et al. 2010).

Studies which use multiple qualitative research tools in their approaches generally include some form of written artefact: usually responses to open-ended questions (De Vos and Verdonk 1987; Chang 1999; Kelly and Jones 2007; Gustafson et al. 2010; Subramaniam and Harrell 2013). In addition to this method, studies may include other data collection tools such as concept maps (Papageorgiou and Sakka 2000), classroom or small group observations (De Vos and Verdonk 1987), interviews (Chang 1999), drawings (Gustafson et al. 2010) or several of these methods (Kelly and Jones 2007; Tytler 2011; Subramaniam and Harrell 2013). However, other combinations of methods may also be used (Becker et al. 2013). Inductive (De Vos and Verdonk 1987; Chang 1999; Subramaniam and Harrell 2013), deductive (Papageorgiou and Sakka 2000; Gustafson et al. 2010) or combinations of both (Tytler 2011; Becker et al. 2013) have been used to analyse the data collected in these studies.

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27 Where statistical analysis has been carried out, this is indicative of a shift to quantitative approaches and, therefore, such approaches have been categorised as mixed methods approaches.
QUANTITATIVE APPROACHES

Purely quantitative approaches in this area use either multiple-choice diagnostic instruments (Birk and Kurtz 1999; Ozmen and Kenan 2007; Othman et al. 2008; Treagust et al. 2011), other achievement tests (such as examinations from the American Chemical Society (ACS) Examinations Institute28 (American Chemical Society 2015)) (Williamson and Jose 2008), or datasets from other studies (Liu and Lesniak 2005). Diagnostic instruments may be used that: have been developed previously in the literature (Banda et al. 2011; Treagust et al. 2011; Aydeniz and Kotowsi 2012), are comprised of items adapted from the literature (Othman et al. 2008; Atasoy et al. 2009; Ozmen 2011a; Stamovlasis et al. 2010), or were developed for the study based on considerations of curricula and documented alternative conceptions (Gabel 1993; Krishnan and Howe 1994; Ozmen and Kenan 2007).

Diagnostic instruments that are the product of previous research have, generally, been already validated using qualitative and quantitative approaches (Birk and Kurtz 1999; Treagust et al. 2011; Aydeniz and Kotowski 2012), although this is not always the case (Banda et al. 2011)29. Authors developing diagnostic instruments may use a process similar to that outlined by Treagust (1988; 1995). Treagust's design involves three phases: 1) defining the content of the instrument, 2) obtaining information about learners’ conceptions, and 3) developing an instrument. Authors may use the existing research literature as the sole source of information on learners' conceptions during the second phase, rather than engaging in a qualitative investigation (Akkus et al. 2003; Othman et al. 2008; Atasoy et al. 2009). Diagnostic items to potentially include in an instrument may also be located within the literature during this phase. This is done based on the rationale that a large body of research into learners' conceptions is in existence, thus, rendering a qualitative investigation unnecessary. Treagust's third stage may be slightly modified, as researchers often adapt diagnostic items identified during the literature review rather than develop new items (Othman et al. 2008). Finally, some instruments are developed based on the content of curricula and a search of the literature (Gabel 1993; Krishnan and Howe 1994; Ozmen and Kenan 2007). These instruments report the development of new diagnostic items rather than the adaptation of previously validated test items. Given that the authors do not validate the resulting instrument through qualitative approaches, the results of these studies may need to be interpreted with caution.

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28 These examinations include both conceptual questions and algorithmic questions.
29 Banda et al. (2011) used the instrument developed by Ozmen and Kenan (2007) which was developed based on curriculum concerns and documented alternative conceptions but was not validated through the use of qualitative approaches with research participants.
MIXED METHODS APPROACHES

Creswell and Plano-Clarke's (2011, pp. 69-104) major mixed methods design options have been used to categorise the mixed methods research studies in the alternative conceptions literature. These research designs are defined based on the level of interaction, priority, timing and mixing of qualitative and quantitative research strands, as shown in Table 2.7.

Where an author explicitly reported on the mixed methods research design, this information was used to categorise the paper into one of the major mixed method designs. However, in most cases the research design is not made explicit; therefore, the reports of data collection, data analysis and results of the study were used to categorise the research according to the decision tree displayed in Figure 2.4. For example, the path of the decision tree, along with the indicators used to answer the questions included in the decision tree, for the study of Abraham et al. (1992) is shown in Figure 2.5. A decision tree was created for each study using the same format (i.e. highlighting the path and identifying the indicators which were used to answer each question on the decision tree).

Table 2.7: Characteristics of main mixed methods designs (Creswell and Plano-Clark 2011, pp. 73-76)

<table>
<thead>
<tr>
<th>Research Design</th>
<th>Level of interaction of strands</th>
<th>Priority given to strands</th>
<th>Timing of strands</th>
<th>Point at which strands are mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convergent</td>
<td>Independent</td>
<td>Equal</td>
<td>Concurrent</td>
<td>Interpretation of results</td>
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<tr>
<td>Parallel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanatory</td>
<td>Interactive</td>
<td>Quantitative over qualitative</td>
<td>Sequential: qualitative first</td>
<td>Data collection</td>
</tr>
<tr>
<td>Sequential</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploratory</td>
<td>Interactive</td>
<td>Qualitative over quantitative</td>
<td>Sequential: qualitative first</td>
<td>Data collection</td>
</tr>
<tr>
<td>Sequential</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embedded</td>
<td>Interactive</td>
<td>Either quantitative or qualitative</td>
<td>Concurrent or sequential</td>
<td>Design level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiphase</td>
<td>Interactive</td>
<td>Equal</td>
<td>Multiple phases (3 or more) of concurrent and/or sequential</td>
<td>Design level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformative</td>
<td>Interactive</td>
<td>Equal, or quantitative or qualitative</td>
<td>Concurrent or sequential</td>
<td>Design level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Figure 2.4: Decision tree used to categorise studies into the major mixed methods research designs

Figure 2.5: The path of the decision tree (highlighted in red) for the study of Abraham et al. (1992). The indicators used to make decisions are provided beside the relevant part of the decision tree.
The **transformative research design** is one in which the design is shaped within a transformative theoretical framework. Such frameworks are those which advance the needs of under-represented or marginalised groups of people: for example, feminist, disability or socioeconomic class theoretical frameworks (Creswell and Plano-Clark 2011, p. 96). All other decisions regarding the mixing, timing and priority of the research strands are made within this transformative framework (Creswell and Plano-Clark 2011, p. 96). Utilising this literature review method, no studies were identified using this research design. However, each of the other five mixed methods research designs was represented.

Creswell and Plano-Clark (2011, p. 77) identify the convergent parallel design as the most common approach used across disciplines. However, this is not the case in the alternative conceptions research. The majority of studies utilise an **embedded research design** (Haidar 1997; Kabapinar et al. 2004; Treagust et al. 2010; Christian and Yezierski 2012). This involves the collection of both quantitative and qualitative data within either a traditional quantitative or qualitative research design (Creswell and Plano-Clark 2011, pp. 90-96). The advantages associated with the embedded design are that it can be used where: the resources necessary for extensive quantitative and qualitative data collection are not available, supplementing the traditional design with an additional type of data can enhance the larger research design, or the data answers different research questions and, therefore, the results can be published separately (Creswell and Plano-Clark 2011, p. 94). Usually, within the alternative conceptions research, a qualitative strand is embedded within a quantitative research approach (Abraham et al. 1992; Kahveci et al. 2004; Akkus et al. 2011; Christian and Yezierski 2012). Studies using this design often have the objective of creating and/or administering alternative conceptions diagnostic instruments (Kahveci 2009; Al-Balushi et al. 2012; Christian and Yezierski 2012). Again, the method used usually follows the procedure outlined by Treagust (1988; 1995). These studies use diagnostic questions from the research literature and adapt them for their study (Kahveci 2009; Al-Balushi et al. 2012; Christian and Yezierski 2012). They may use qualitative methods, such as interviews, to revise and validate the instrument (Al-Balushi et al. 2012; Christian and Yezierski 2012). Studies using this research design may also use open-ended instruments, the data from which are quantised to answer quantitative research questions (Haidar and Abraham 1991; Abraham et al. 1992). This research design has also been used by studies with the primary goal of evaluating the success of a programme of instruction (Chang et al. 2010; Beerenwinkel et al. 2011).

The embedding of quantitative data within a qualitative research design is also common (Lee et al. 1993; Haidar 1997; Tan et al. 2005; Chandrasegaran et al. 2007; Treagust et al. 2010). The development of diagnostic instruments also occurs within this research design. The authors,
again, usually follow the process outlined by Treagust (1988; 1995). The main source of information about learners’ alternative conceptions used in these studies is the research literature (Tan et al. 2005; Treagust et al. 2010). These studies validate their instruments through the use of qualitative methods, which lead to further revision of the instrument. The classification as qualitative embedded research design results from the fact that the authors focus on qualitative results and/or research questions (Tan et al. 2005; Treagust et al. 2010). Chandrasegaran et al. (2007) used the procedure outlined by Treagust (1988; 1995) and used qualitative methods to investigate learners’ conceptions prior to the development of the instrument. Other methods used within this research design to investigate learners’ conceptions are based entirely on qualitative data collection, which is then quantised and subsequently statistically analysed (Haidar 1997; Gomez et al. 2006). These methods include the use of interviews (Gomez et al. 2006) and, in the case of PSSTs, lesson plans and presentations (Haidar 1997).

The other major mixed methods research designs are less common within the alternative conceptions literature than embedded research designs. The **convergent parallel research design** involves the collection of both quantitative and qualitative data during the same phase of research. These data sets are analysed separately and mixed during the interpretation of the results (Creswell and Plano-Clark 2011, p. 77). The advantages of this design are that: it is efficient as both types of data can be collected around the same time, and the data from each type is analysed separately which may be suitable for the work of research teams (Creswell and Plano-Clark 2011, p. 78). This type of research is often used in the evaluation of instructional programmes (Banerjee 1995; Arasasingham et al. 2005; Adadan 2013). It is about equally as popular is the **explanatory sequential research design** (Çalik and Ayas 2005; Boz 2006; Yezierski and Birk 2006). This involves the initial collection of quantitative data, followed up in the next phase of research with the collection of qualitative data that is utilised in such a way as to explain the quantitative findings in greater depth (Creswell and Plano-Clark 2011, pp. 81-82). The advantages of this research design are that: the two-phase structure makes the collection and reporting of data easy to implement for a single researcher, and it is suitable for emergent approaches in which the second phase of data collection is designed based on the findings from the first phase of research (Creswell and Plano-Clark 2011, p. 83). Studies which utilise diagnostic instruments within the explanatory sequential research design use similar strategies to those discussed within the embedded research design.

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30 This study would have been classified as an exploratory research design save for that the authors describe the research design as a case study design, which is a traditional qualitative research design.
designs except that they collect quantitative (or quantised qualitative) data in the first phase of research and use follow-up qualitative methods primarily for the purposes of explaining the quantitative findings (Boz 2006; Yezierski and Birk 2006).

The exploratory research design is also a two-phase design. The qualitative data is initially collected and used to explore a research problem. This is then followed up by a quantitative phase based on the findings of the qualitative results (Creswell and Plano-Clark 2011, p.86). The advantages of this design are that: it is easy to implement and report on for a single researcher, it may be received more favourably by quantitative-biased audiences, and a new instrument may be developed as a potential product of the research (Creswell and Plan-Clark 2011, p. 89). This design is also associated with diagnostic instrument development. Research that follows the procedures outlined by Treagust (1988; 1995), including the initial use of a qualitative investigation of learners’ conceptions, would fall under this category of research design (Agung and Schwartz 2007; Akkus et al. 2011). Creswell and Plano-Clark (2011, p. 86) note that this design is often considered the instrument development design; however, within the alternative conceptions literature, other research approaches are more commonly utilised for the development of diagnostic instruments. This appears to be the result of a significant body of literature in the area which provides a starting point for many researchers.

Finally, the multiphase research design is the least common of the five designs present in the research literature (Barker and Millar 1999; 2000). Studies could only be categorised as this design if they involved three or more stages of concurrent and/or sequential data collection. This was only the case in longitudinal studies and, at that, not all longitudinal studies fitted these criteria (Novak 2005). The multiphase research design is more commonly associated with large funded studies and requires a pool of resources and expertise (usually in the form of a research team) (Creswell and Plano-Clark 2011, pp.101-103). This is the likely reason for few studies adopting such a design in the research literature.

(b) Overview of Data Collection Methods
The data collection methods used in order to determine learners' understanding of concepts involves the use of different types of instruments that may be developed within the research designs previously mentioned. These may be open-ended instruments (Novick and Nussbaum 1981; Haidar and Abraham 1991; Chang 1999; Boz 2006; Nyachwaya et al. 2011), multiple-choice style instruments (Mulford and Robinson 2002; Chandrasegaran et al. 2007; Ozmen and Kenan 2007; Othman et al. 2008; Yezierski and Birk 2012) or instruments which use both open-ended and multiple-choice questions (Lee et al. 1993; Onwu and Randall 2006; Chang et al. 2010).
DEVELOPMENT OF MULTIPLE-CHOICE INSTRUMENTS

Multiple-choice questions may have either a single tier (i.e. the traditional style of multiple-choice question) or two-tiers. In the latter case, the second tier requires learners to select an option which justifies their choice in the first tier. The options in all these multiple-choice questions present a correct response option and three or four distractors which are based on learners' alternative conceptions.

In the development of multiple-choice instruments, researchers have either used the methods set out by Treagust (1988; 1995) (Chandrasegaran et al. 2007; Mulford and Robinson 2002; Tan et al. 2005), as outlined in Section 2.4(a), or their own methods of instrument development (Yezierski and Birk 2006; Ozmen 2011a; Christian and Yezierski 2012). Instruments which are not explicitly developed based on the method outlined by Treagust (1995) use many of the same methods. Content is defined, information is gathered about learners' alternative conceptions through a review of the literature and/or interviews with learners, and, questions are either developed or adapted from the literature, piloted with a sample from the intended learner population and validated by experts (Yezierski and Birk 2006; Ozmen 2011a; Christian and Yezierski 2012).

DEVELOPMENT OF OPEN-ENDED INSTRUMENTS

The process for the development of open-ended instruments is a less rigorous procedure than for multiple-choice instruments. The rigor associated with the use of this research tool arises from the methods of analysis. Questions for these instruments may be taken from pre-existing research literature (Boz 2006; Ayas et al. 2010) or developed for the study. Newly developed questions may result from interviews with learners (Novick and Nussbaum 1981). However, it is more often the case that the method of development of these questions is not specified in the published literature (Pereira et al. 1991; Chang 1999; Papageorgiou and Sakka 2000). These studies may pilot the open-ended instrument with learners and/or have it validated by experts (Pereira et al. 1991; Chang 1999). Studies may also triangulate the data collected using the open-ended instrument with data collected through another method such as a concept map (Papageorgiou and Sakka 2000).

Other researchers have developed instruments composed of both multiple-choice and open-ended questions (Lee et al. 1993; Onwu and Randall 2006; Salta and Tzougriaki 2011) and these instruments utilise a mixture of the methods mentioned above.

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31 The methods of analysis were discussed in the ‘Qualitative Approaches’ within 2.4(a) on pages 62-63.
2.5 **INSTRUCTIONAL AND PEDAGOGICAL APPROACHES**

Many approaches have been adopted in research studies to address the alternative conceptions of learners. It is not possible to review all approaches and, therefore, a selection of approaches was reviewed. Conceptual change texts were selected as an approach to review because usually these studies do not combine these texts with other approaches, thus, making it an interesting example of an approach entirely focused upon addressing alternative conceptions. Context-based approaches, generally, involve multiple approaches and, as such, provide an interesting look at the impact of improving the educational landscape rather than only focusing on addressing alternative conceptions. Cooperative learning is regularly used in conjunction with other approaches. For example, concept cartoons are often used with learners working together in small groups. Therefore, both of these approaches were considered interesting to review. Blended learning was identified as an approach that, although used in other educational research areas, did not appear to have been employed by many studies that investigated its impact on the alternative conceptions of learners.

(a) **Conceptual Change Text**

Conceptual change texts are texts designed in accordance with Conceptual Change Theory. These texts create a cognitive conflict, in which the reader is made aware of the inadequacy of his/her conceptions in explaining certain phenomena. The text also provides scientifically accurate explanations that are intended to be interpreted by the reader as providing a more accurate explanation for the phenomenon in question (Uzuntiriyaki and Geban 2005). Studies utilising this approach are informed by Constructivist Theory and Conceptual Change Theory (Onder and Geban 2006; Çalık et al. 2007; Ozmen 2007; Atasoy et al. 2009; Beerenwinkel et al. 2011). These studies are, generally, carried out over the course of 2-6 weeks with second-level learners using a pre-test/post-test control group comparison research design (Onder and Geban 2006; Ozmen 2007; Atasoy et al. 2009; Beerenwinkel et al. 2011). This research design may be complemented by qualitative methods in order to further probe the conceptual understanding of learners (Çalık et al. 2007; Atasoy et al. 2009).

Ozmen (2007) and Atasoy et al. (2009) noted that upper-second-level learners instructed using conceptual change texts significantly improved their understanding of chemical equilibrium concepts compared with those instructed through conventional texts. Large effect sizes were associated with the mean differences between groups.\(^{32}\) Ozmen (2007) used

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\(^{32}\) Atasoy et al. (2009) obtained a *partial eta square* of 0.59. The effect size associated with the findings of Ozmen (2007) was determined by the current author and a Cohen’s *d* of 0.82 was obtained. Cohen effect sizes are interpreted as: 0.20 is a small effect size, 0.50 is a medium effect size, and 0.80 is a large effect size. Further details on calculation and interpretation of effect sizes may be found in Section 4.3(c).
small group discussion and Atasoy et al. (2009) used concept maps, analogies and predict-observe-explain strategies in addition to conceptual change texts. The instruction used with control groups in both studies did not attempt to address learners’ alternative conceptions.

Other studies (Onder and Geban 2006; Çalik et al. 2007; Beerenwinkel et al. 2011) have also found that upper-second-level and pre-service elementary teachers improved their understanding of equilibrium (Onder and Geban 2006) and PNM concepts (Çalik et al. 2007; Beerenwinkel et al. 2011) after instruction with conceptual change texts (Çalik et al. 2007). They also outperformed those instructed using conventional instruction (Onder and Geban 2006; Beerenwinkel et al. 2011). Beerenwinkel et al. (2011) also found that lower-second-level learners with lower levels of prior knowledge benefited more from these texts than those with higher levels of prior knowledge; this correlation had a moderate association.

(b) Context-Based Approaches

Context-based approaches are those that use science contexts and applications to develop understanding of chemistry (or other science) concepts. These approaches are often characterised by a drip-feed approach in which the learner is introduced to concepts at various levels on a need-to-know basis. The theoretical underpinnings of context-based approaches may broadly be said to be based on some variation of constructivism (e.g. social constructivism, situated learning, etc.) (Gilbert 2006). However, not all context-based approaches are developed with particular educational theories in mind and take a more practical approach e.g. Salters' Science (Bennett and Lubben 2006), Chemistry in Context (Schwartz 2006), and Chemistry in the Community (ChemCom) (developed by the American Chemical Society), while other approaches take in a broader range of theoretical considerations including scientific literacy and theories of motivation, e.g. Chemie im Kontext (Parchmann et al. 2006).

A number of studies have investigated the effect of context-based approaches among upper-second-level learners (Winthur and Volk 1994; Ramsden 1997; Barker and Millar 2000) and third-level learners (Gutwill-wise 2001; Flener-Lovitt 2014). The research design tends to be a post-test control group comparison design (Winthur and Volk 1994; Ramsden 1997; Gutwill-wise 2001; Flener-Lovitt 2014). However, Barker and Millar (1999; 2000) used a

33 Recall that the General Certificate of Secondary Education (GCSEs) in the U.K. has been categorised as within upper-second-level of education in order to map the U.K. syllabus and the existing literature to the Irish context, as mentioned in Section 1.2(b).
longitudinal design in which the chemistry understanding of learners was investigated before the context-based programme and twice more in the 16 months following this.

Barker and Millar (1999; 2000) noted significant differences in upper-second-level learners' responses to a diagnostic instrument with increasing study of a context-based chemistry course. Chi-square tests of independence were carried out on the longitudinal data$^{34}$. These tests indicate that the data does not fit the null hypothesis but do not indicate where the area of significance lies. However, the authors provided data tables which show a trend of increasingly acceptable responses with further study of context-based chemistry. Learners improved the quality of their responses in most of the concepts included in the study (Barker and Millar 1999; 2000). Ramsden (1997), in a study investigating the effect of a context-based approach and a conventional approach, noted no significant differences in upper-second-level learners' understanding of selected chemistry concepts or their alternative conceptions. Winthur and Volk (1994) found that those upper-second-level learners instructed through ChemCom significantly outperformed those instructed through conventional instruction based on scores on an achievement test. However, the effect size associated with this difference indicates a negligible effect$^{35}$. Gutwill-Wise (2001) investigated the understanding of third-level learners at two third-level institutions. In one institution (the smaller of the two institutions: 16 in the experimental group and 30 in the control group), there was no significant difference between those instructed through context-based and conventional approaches in a conceptual post-test. However, a significant difference was obtained for an intermediate in-class examination. The effect size associated with this significance was medium to large$^{36}$. In the other third-level institution (with a larger comparison group: 338 in the experimental group and 255 in the control group), there was no significant difference between the performance of those instructed through the context-based and conventional approaches in the in-class test. However, a significant difference was found between the performance of the experimental and control groups in the conceptual post-test. This had a small-medium effect size$^{37}$.

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$^{34}$ The data provided by the authors does not allow for a discussion of effect sizes or of concepts which significantly improved over the course of the context-based approach.

$^{35}$ The Cohen's $d$ was calculated by the current author as 0.035. Note that this is considered negligible as a Cohen’s $d$ of 0.20 would be considered a small effect size (Cohen 1988).

$^{36}$ Cohen’s $d$ was calculated by the current author at 0.66.

$^{37}$ Cohen’s $d$ was calculated by the current author at 0.33.
The findings of research studies in relation to context-based learning, at minimum, demonstrate that learners develop understanding of chemistry equally as well as those taught through conventional approaches.

(c) Concept Cartoons

Concept cartoons originate from the perceived need to combine Constructivist Theory with classroom practice (Keogh and Naylor 1999). These cartoons are not intended to employ humour or satire. They follow the format of multiple-choice questions, such as those in the alternative conceptions research literature; however, the multiple-choice options are written in dialogue form and incorporate a visual stimulus (Keogh and Naylor 1999). The written dialogue represents a number of alternative conceptions and the scientifically-acceptable explanation. An example of a concept cartoon is given in Figure 2.6. The alternative conceptions incorporated into the concept cartoon are identified from the research literature (Naylor and Keogh 1999; Ekici et al. 2007). The familiar contexts are also selected from areas of difficulty identified in the literature, although they may also be selected based on teachers’ professional experience (Naylor and Keogh 1999).  

![Figure 2.6 An example of a concept cartoon (Keogh and Naylor 1999)](image)

Research into the effect of concept cartoons on learners’ experiences of learning about and understanding of chemistry and science concepts have involved primary-level learners (Stephenson and Warrick 2002; Kabapinar 2005; Dalacosta et al. 2009) and lower-second-

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38 This refers only to concept cartoons as an instructional or pedagogical approach and does not include research studies that utilise concept cartoons as an assessment tool.

39 Only research studies using cartoons that fit these criteria have been reviewed, i.e. cartoons which do not incorporate alternative conceptions and that are used primarily for interest/humour are not reviewed.
level learners (Ekici et al. 2007; Ozmen et al. 2012). Teachers and pre-service primary teachers have participated in studies which investigate their perceptions about and experiences of using concept cartoons with their students (Keogh and Naylor 1999; Balim et al. 2014). Studies have focused on qualitative descriptive data in the evaluation of concept cartoons (Keogh and Naylor 1999; Stephenson and Warwick 2002; Ekici et al. 2007; Balim et al. 2014), have used a pre-test/post-test control group comparison design (Kabapinar 2005; Ozmen et al. 2012; Ultay 2015) or have used a post-test control group comparison design (Dalacosta et al. 2009). Teachers and pre-service primary teachers have positive views of concept cartoons’ ability to motivate and interest their students, and to provide opportunities for learners to think and develop their understanding (Keogh and Naylor 1999; Balim et al. 2014). The use of concept cartoons in their classrooms has also been found to challenge pre-service primary teachers’ naïve views about constructivism (Naylor and Keogh 1999). Qualitative approaches also provide evidence which suggests that this approach is useful for the elicitation and restructuring of learners’ conceptions (Stephen and Warwick 2002; Ekici et al. 2007). There are few studies using quantitative research approaches. However, Dalacosta et al. (2009) and Ozmen et al. (2012), who both used a pre-test/post-test control group comparison design, found that those instructed through the use of concept cartoons performed significantly better on a conceptual instrument than those instructed through conventional approaches. Both studies found a large effect size associated with this difference40. However, Ultay (2015), using the same research design, noted that concept cartoons had no effect on lower-second-level learners’ understanding compared with conventional instruction.

(d) Cooperative Learning

Cooperative learning may be defined as the use of structured tasks that guide a small group of learners toward a common goal or learning outcome (Millis and Cottell Jr. 1997, p.5). There are five important components of this approach: positive interdependence (i.e. the common goal can only be achieved if all group members contribute), face-to-face interaction, individual accountability (i.e. each group member must demonstrate his/her learning), interpersonal skills, and group processing (i.e. group members reflect on the processes that took place within the group) (Johnson et al. 1991). Cooperative learning can take a number of different forms that may be categorised by the level of positive interdependence among group members (Stodolsky 1984). This gives rise to a number of different forms of cooperative learning that can be distinguished from one another. However, these terms

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40 Cohen’s d was calculated at 0.97 by the current author for Ozmen et al. (2012). The correlation coefficient r was calculated at 0.53 by the current author for Dalacosta et al. (2009).
(cooperative learning and collaborative learning, for example) are often used interchangeably in the research literature (Shibley Jr. and Zimmaro 2002). Therefore, this review will encompass all cooperative learning instructional approaches under the term cooperative learning, as is the case within the research literature (Bowen 2000).

Studies investigating the effect of cooperative learning on learners’ experiences and understanding of chemistry conceptions may be informed by constructivism (Hein 2012), research on learning styles (Felder 1996), theories of motivation (Banerjee and Vidyapati 1997), citizenship, equity in science education (Lewis and Lewis 2008) or social interaction (Slocum et al. 2004) or various combinations of these (Towns and Grant 1997; Barbosa et al. 2004; Shacar and Fisher 2004). This approach may also be implemented based on practical concerns (Dougherty et al. 1995) and very often studies do not give an indication of the theories informing the research (Kogut 1997; Shibley Jr. and Zimmaro 2002; Roehrig and Garrow 2007; Cannon et al. 2008) possibly as a result of a focus on practical concerns.

The majority of studies which have implemented and evaluated the effect of cooperative learning on learners' experiences and understanding of chemistry have involved third-level learners (Towns and Grant 1997; Slocum et al. 2004; McGoldrick et al. 2013; Cox 2015). Studies have also been carried out with upper-second-level learners (Shachar and Fisher 2004; Roehrig and Garrow 2007), and pre-service chemistry teachers and PSSTs (Banerjee and Vidyapati 1997; Towns et al. 2000; Barbosa et al. 2004). A post-test control group comparison design may be used, in which learners studying a one-semester third-level chemistry module are compared with previous learners of the module when conventional approaches were used (Banerjee and Vidyapati 1997; Kogut 1997; Shibley Jr. and Zimmaro 2002; Hein 2012). Other research designs include longitudinal (Felder 1996), action research (Towns et al. 2000) and case study (Barbosa et al. 2004) designs.

Studies have investigated the effect of cooperative learning on learners' performance in final examinations on both algorithmic and conceptual questions. Cooperative learning is associated with significantly better performance among learners than conventional instruction approaches at third-level (Ross and Fulton 1994; Kogut 1997; Lewis and Lewis 2008), and upper-second-level (Shachar and Fischer 2004; Roehrig and Garrow 2007). The effect sizes associated with this significance vary from very small to medium\(^4\). This finding is in agreement with the meta-analysis carried out by Bowen (2000), which noted a small-

\(^4\) All effect sizes were calculated by the current author. A Cohen’s \(d\) of 0.30, 0.13, and 0.46 was obtained for Ross and Fulton (1994), Lewis and Lewis (2008), and Roehrig and Garrow (2007), respectively.
medium mean effect size of cooperative learning on learners' performance in chemistry courses. Shachar and Fischer (2004) investigated the effect of cooperative learning approaches on understanding of chemistry concepts differentiated by learners' ability. The authors observed that learners of lower and middle ability experienced far greater improvements in their understanding compared with their peers instructed through conventional methods. A number of studies were also identified reporting that cooperative learning approaches did not have a significant effect on third-level learners’ (Dougherty 1997; Shibley Jr. and Zimmaro 2002) or PSSTs’ (Banerjee and Vidyapati 1997) performance compared with control groups instructed through conventional approaches.

Numerous studies have reported on the effect of cooperative learning on learners' attitudes and perceptions of engagement in learning. Studies which use case study, action research, exploratory, or other research designs, in which comparisons are not made with control groups, all report on the positive impact of this approach on learners' interest, enjoyment, perceived conceptual understanding and engagement (Felder 1996; Wright 1996; Towns and Grant 1997; Cannon et al. 2008). Towns et al. (2000) engaged with third-level learners and pre-service chemistry teachers using a purely descriptive approach and found that learners experienced and valued the sense of community created by a cooperative approach. Studies using a control group comparison design present a contradictory view regarding the effect on learners’ attitudes. Shachar and Fischer (2004) found a significant decrease in perceptions of mastery of content and curiosity between the beginning and end of the implementation of a cooperative learning approach; this effect was not seen among those instructed through a conventional approach. Dougherty et al. (1995) found that those instructed through structured cooperative learning experienced significantly lower perceptions of engagement and interest than those instructed using a conventional approach. Shibley Jr. and Zimmaro (2002) reported that cooperative learning had no effect on perceptions of mastery of content or teaching effectiveness compared with those instructed through a conventional lecture format. Each of these three studies involved large sample sizes. However, Francisco et al. (1998) and Cox (2015) found significantly higher perceptions of engagement and problem-solving ability among those instructed using a cooperative learning approach. Cox (2015) and Francisco et al. (1998) involved large and small sample sizes, respectively.

(e) Blended Learning
Bliuc et al. (2007) describe blended learning as "learning activities that involve a systematic combination of co-present (face-to-face) interactions and technologically-mediated interactions between students, teachers and learning resources". Garrison and Kanuka (2004) state that this combination must represent a thoughtful integration of both types of learning
experiences and that blended learning is a "fundamental reconceptualization and reorganization of the teaching and learning dynamic". According to Garrison and Kanuka (2004), this approach to learning must create a sense of engagement in a community of inquiry. The frameworks used by studies investigating the effects of blended learning on factors related to success in learning may or may not use the specific ideas of the authors mentioned above. These studies often utilise Cognitive Load Theory and some form of constructivism in their theoretical underpinnings (Antonoglu et al. 2011; Dineva and Ducheva 2011). However, often these approaches are implemented as a result of practical rather than theoretical considerations (Ealy 2008; Williams et al. 2008).

Blended learning approaches have been used to change the delivery of third-level chemistry modules to learners (Ealy 2008; Williams et al. 2008; Antonoglu et al. 2011; Dineva and Ducheva 2011). The focus of these studies is on the effect of this approach, during a one-semester module, on learners' experience of and performance in third-level chemistry rather than on improving conceptual understanding and reducing alternative conceptions. Blended learning has been implemented in general, inorganic and organic chemistry modules (Ealy 2008; Williams et al. 2008; Dineva and Ducheva 2011) as well as in more complex chemistry modules (Antonoglu et al. 2011) and more basic modules focusing on experimentation in chemistry (Jagodzinski and Wolski 2011). The design of these studies is usually a post-test control group comparison design in which learners may be compared with previous learners of the module when conventional methods were used (Williams et al. 2008; Antonoglu et al. 2011). Research designs taking a more exploratory approach have also been utilised (Ealy 2008; Dineva and Ducheva 2011). A number of studies investigating the effect of a blended learning approach are limited in terms of generalisability as a result of small sample sizes.

Williams et al. (2008) and Antonoglu et al. (2011) investigated the effect of a blended learning approach on learners' performance in an end-of-module examination. Williams et al. (2008) adapted an inorganic chemistry module for blended learning and compared the performance of two successive cohorts of learners with the performance of a cohort of learners from the previous conventional approach used in the module. The authors found that the average performance was greater among the two blended learning cohorts than among the conventional instruction cohort. The performance of the two successive blended learning cohorts in the module was better than their performance in other chemistry modules that they were studying concurrently. Antonoglu et al. (2011) compared the performance of three successive years of a blended learning approach with a cohort of learners from the previous conventional approach. The authors found that the mean performance of each of the three blended learning cohorts was statistically significantly greater than those instructed through
the conventional approach. However, the generalisability of both of these studies is limited as there is no report made of controlling for other variables and the learners are small groups taken from different cohorts. Jagodinski and Wolski (2011) noted that a blended learning approach to a module focusing on experimentation in chemistry facilitated third-level students and teachers in carrying out more experiments during the face-to-face component, than their peers using paper-based materials to prepare for the face-to-face component.

These and other studies implementing blended learning in chemistry modules have reported learners' positive perception of this method both in terms of their attitudes and experiences of blended learning (Ealy 2008; Williams et al. 2008; Antonoglu et al. 2011; Dineva and Ducheva 2011), and in terms of their attitude to the content of the course (Antonoglu et al. 2011). While attitudes among those learning through a blended approach are generally positive, a few areas of concern for learners were identified. Learners may find the wait-time between asking a question online and receiving a response from the lecturer frustrating (Ealy 2008). Ealy (2008) also noted that learners wished to receive more formative feedback when doing online quizzes. Some of the learners participating in the Williams et al. (2008) study stated that they would like a lecture as part of their module rather than all workshop-based face-to-face meetings. Learners may also access the online materials sporadically, with greater access at the beginning of the module and in preparation for the final examination.

Given the presence of very few studies on blended learning in chemistry, a brief review is given here of the findings of other studies implementing this approach in biology and physics, in relation to learners' performance and understanding of content. Studies have investigated the effect of this approach on learners' performance on achievement tests for biology topics among upper-second-level learners (Yapici and Akbayin 2012a; 2012b; Kazu and Demirkol 2014) and third-level learners (Riffell and Sibley 2005; Pereira et al. 2007; Bergstrom 2011) as well as a small number of studies carried out with primary-level learners (Jussila and Virtanen 2014) and pre-service biology teachers (Yaman and Graf 2010). The research is more limited within the discipline of physics and, using this literature review method, studies were identified involving lower-second-level (Psycharis et al. 2013) and upper-second-level learners (Chandra and Watters 2012). Examining the studies that used a pre-test/post-test control group research design (Riffell and Sibley 2005; Pereira et al. 2007; Chandra and Watters 2012; Yapici and Akbayin 2012; Kazu and Demirkol 2014) reveals that in all cases the performance of those instructed through a blended learning approach was significantly higher than those instructed through conventional approaches. The effect sizes associated with these statistically significant differences range from a medium effect size...
(Kazu and Demirkol 2011)\textsuperscript{42} to a large effect size (Pereira \textit{et al} 2007; Chandra and Watters 2012; Yapici and Akbayin 2012)\textsuperscript{43}. Bergtrom (2011) utilised a post-test control group comparison design in which the control group was taken from a different cohort of students. Bergtrom found that there was no significant difference between the performances in the final examination of those instructed through conventional or blended learning approaches.

The findings of studies investigating the effect of blended learning approaches on performance and experiences of education are interesting. However, it is important to be cognisant of the fact that these studies were more focused on performance in achievement tests rather than on tests which were designed to test conceptual understanding. However, this appears to be an area in which further research could prove valuable.

\textbf{2.6 RELEVANT STUDIES IN THE IRISH CONTEXT}

An aspect of the doctoral study of Maria Sheehan (2010) investigated the alternative conceptions of lower-second-level and upper-second-level learners in Ireland. The author found that the majority of learners had alternative conceptions about many chemistry concepts. The gender, mathematics experience, and cognitive level\textsuperscript{44} of learners had a statistically significant effect on the prevalence of alternative conceptions. Higher cognitive levels and higher-level experience of mathematics were correlated with fewer alternative conceptions among both lower- and upper-second-level learners. At lower-second-level, female learners had statistically significantly fewer alternative conceptions than their male peers. This trend was reversed at upper-second-level. The author implemented a multi-faceted instructional programme (which combined constructivist teaching approaches, visualisation and modelling, and cognitive acceleration through science education) with upper-second-level learners over a twelve-week period using a quasi-experimental design with non-equivalent control group. The experimental group outperformed the control group in their responses to a diagnostic instrument in almost all of the tested concepts.

The doctoral work of Anne O'Dwyer (2012), involved the development of an instructional programme for the teaching and learning of organic chemistry for upper-second-level chemistry learners in Ireland. Instruction was informed by considerations of context-based chemistry, guided-inquiry learning, a spiral curriculum approach, and the direct targeting of alternative conceptions, among other considerations. The potential effect on attitudes and

\textsuperscript{42} Cohen’s $d$ was calculated by the current author at 0.58 for Kazu and Demirkol (2014).

\textsuperscript{43} Cohen’s $d$ was calculated by the current author for Pereira \textit{et al}. (2007) and Yapici and Akbayin (2012) and values of 0.89 and 1.50 were obtained, respectively. Chandra and Watters (2012) report a partial eta squared value of 0.55.

\textsuperscript{44} According to Piaget’s Theory of Cognitive Development discussed in Section 2.2(b).
understanding of organic chemistry concepts was determined by comparison with a control group. While no effect on learners’ overall achievement in a diagnostic instrument was observed, there was evidence of a differential effect for male and female participants, and for those studying chemistry at higher- and ordinary- levels

The instructional programme significantly benefited female but not male learners and those studying chemistry at the higher-level but not those studying at ordinary-level.

2.7 IMPLICATIONS OF THE LITERATURE REVIEW
A review of the research literature has identified that alternative conceptions have been documented among PSSTs and other learners in both fundamental and more complex conceptual areas of chemistry. The body of this research focuses on second-level and third-level learners. Many research approaches and data collection methods are associated with investigations of learners’ alternative conceptions. A number of instructional and pedagogical approaches have been implemented to address learners’ alternative conceptions and to improve their experience of the study of chemistry. These approaches are primarily informed by constructivism. Varying levels of success are associated with these approaches. Blended learning is an under-represented pedagogical approach in this area of research. Studies utilising blended learning investigate the effect of the approach on learners’ achievement and do not focus on the potential impact on learners’ conceptions.

The potential effect of SMK on teaching and learning has been highlighted by a number of studies. PSSTs have been shown to have alternative conceptions that are similar to other groups of learners and it has been postulated that this may impact on the understanding that their future students will develop. The impact of consecutive and concurrent models of STE on PSSTs’ conceptual understanding presents a gap in the research literature. Furthermore, few studies have investigated the change in PSSTs’ conceptual understanding over the course of concurrent STE programmes. SMK is an important cornerstone of professional knowledge for teaching although, like the other cornerstones, it is not sufficient in itself to create high quality teaching and learning. However, poor SMK has been shown in the literature to have a negative effect on teaching and learning.

45 Recall from Section 1.2(b) that chemistry may be studied at two different levels in preparation for examinations in Ireland; in the Republic of Ireland, these are known as higher-level and ordinary-level.
Chapter 3  Foundations of the Study

Constructivism, in its many forms, underpins a majority of the research about alternative conceptions. The first phase of the current research study follows suit with this tradition. It combines constructivism with postpositivism, leading to distinct quantitative and qualitative strands of research. The original intention was that this combination would provide the foundation for the entire research study. However, after my experiences with PSSTs in Phase 1, I began to reflect upon the philosophical positioning of the study. This led to a critique of the philosophical positioning of Phase 1, and to the search for a more suitable philosophical grounding. The phenomenological works of Edith Stein form the philosophical basis of Phase 2 of the research study: specifically, her works *On the Problem of Empathy* (Stein 1989) and *Philosophy of Psychology and the Humanities* (Stein 2000).

This chapter will first present an overview of postpositivism and constructivism. The philosophical backgrounds of a few key thinkers, who are disputed as potential founders, in constructivism will be highlighted, before a critique of the philosophies is provided. Stein’s philosophy will then be introduced. Given that Stein is not well-known, her life and works will be given an in-depth treatment. The work of Leslie Baxter (2011) on Relational Dialectics Theory (RDT) was considered suitable for use with Stein’s philosophy of empathy and community. Baxter’s work, founded upon that of cultural theorist Mikhail Bakhtin, will be presented, and the complementarity between RDT and Stein’s philosophy will be discussed. This chapter culminates in a presentation of the design of the research study, and the blended learning programme called SuBATOMIC. There is a strong tradition within philosophy, beginning with Augustine, of using the first person in philosophical writings (Curren 2003, p. 51). Therefore, this chapter will break in parts from the format of preceding and subsequent chapters by employing this style of writing in discussion of philosophy.

3.1 POSTPOSITIVISM AND CONSTRUCTIVISM

(a) Postpositivism

Positivism maintains that the only true knowledge that can be obtained is based on sensual experiences (or outer perception) and the scientific method (Levin and Clowes 1991; Phillips and Burbules 2000, p. 15). This is *the* pathway to knowledge. The only knowledge is that which can be verified in this way and such knowledge is the only form of truth. Positivism suggests that subjective views are meaningless and that objective views are the foundation of knowledge (Racher and Robinson 2002). Postpositivism is a philosophical position arising out of the criticisms of positivism (Bentley and Garrison 1991; Philips and Burbules 2000, p. 4). Like its predecessor, postpositivism places a focus on causal relationships, engages in
reductionism (by focusing on certain variables only), and seeks to predict behaviour based on causal explanations (Allison and Pomeroy 2000; Creswell and Plano-Clark 2011, p. 40). However, unlike its predecessor, it maintains that the arising knowledge can only be imperfectly obtained and that subjective and objective views are not mutually exclusive (Bentley and Garrison 1991; Racher and Robinson 2002). It recognises that my human experience is imbued with value and that my experience is dependent on my conceptual structures (Bentley and Garrison 1991). As such, there is no such thing as objective experience as I can never experience the world without reliance upon my conceptual structures (Bentley and Garrison 1991).

(b) Constructivism

Main Tenets of Constructivism

Constructivism has been considered a theory of learning, a theory of teaching, a theory of education, a theory of cognition and a worldview (Matthews 2002). Constructivism informed Phase 1 of this study as a theory of learning, cognition and teaching as well as a worldview. This section focuses on constructivism as a worldview and seeks to outline the philosophies which have formed the basis of the constructivist worldview.

A common theme in all writing on constructivism is that it comes in many forms that differ from each other to varying degrees (Bodner et al. 2001; Matthews 2002; Null 2004). Bailey et al. (2010, p. 7) state that the common ground to be found in all forms of constructivism is that knowledge is constructed or made by the learner and not discovered. Other authors claim that more commonalities may be found than this. For example, Fox (2001) identifies six claims which are common to all forms of constructivism:

1. learning is an active process,
2. knowledge is actively constructed rather than innate or absorbed,
3. knowledge is made not discovered,
4. a) all knowledge is personal OR b) all knowledge is socially constructed,
5. learning is a process of making sense of the world, and
6. learning requires meaningful and challenging problems for learners to solve.

Note that many authors do not maintain this dichotomy and recommend that both personal construction and social construction should be seen as complementary (Duit and Treagust 1998).
Given the many types of constructivism, Phillips (1995) attempts to broadly categorise these types and he identifies three axes on which they may be placed. The first of these axes Phillips labels as *individual psychology versus public discipline*. The former is concerned with how I, as a learner, construct or make my own knowledge and the latter is concerned with how societies construct bodies of public knowledge (e.g. the body of scientific knowledge). The second axis that Phillips identifies is, what he terms, *humans the creators versus nature the instructor*. At one extreme, *humans the creators*, learners create all of their own knowledge and at the other extreme, *nature the instructor*, knowledge is imposed from the outside. Those thinkers which are located at the *nature the instructor* extreme of the axis are not technically constructivists. The final axis which he identifies is *individual cognition versus socio-political processes*. This axis focuses on individual psychological constructivism. Piaget is typically considered the founder of the *individual cognition* end of the axis (Kruckeberg 2006) while Vygotsky is often associated with the *socio-political processes* end of the axis\(^{47}\) (Phillips 1995). Piaget did acknowledge that social factors played a role in learning, although he did not investigate these factors to any great extent (Tudge and Winterhoff 1993). Vygotsky also acknowledged the importance of individual cognition in his writings, although he emphasised the role played by social factors. Therefore, neither Piaget nor Vygotsky are truly at the extreme ends of the axis.

Among the forms of individual psychological constructivism that could be mentioned are radical constructivism (Von Glasersfeld 1989), Piagetian constructivism (Adey and Shayer 1994), and Vygotskian constructivism (Liu and Matthews 2005). There are many other forms and Matthews (2000) has identified eighteen different variations. However, Duit and Treagust (1998) recommend that researchers “should not focus on the differences but present an inclusive view of learning and conceptualise the different positions as complementary features that allow researchers to address the complex process of learning”. I took such an approach in this study by taking into account the aspects of constructivism common to all variants and, in particular, the work of Piaget and Vygotsky. Fox’s (2001) clarification of the common elements of constructivism is useful in proceeding in the manner recommended by Duit and Treagust. However, in order to add further clarification to what constitutes constructivism as a worldview, I will discuss the philosophies of three significant constructivist figures\(^{48}\): John Dewey, Jean Piaget and Lev Vygotsky.

\(^{47}\) The main principles associated with each of these constructivists have been presented in Section 2.2(b).

\(^{48}\) Many constructivists cite different founders of their particular movement. Thomas Kuhn is also considered to be a central figure in the Constructivist Movement (Matthews 2002). However, it is beyond the scope of this study to review all areas of constructivism. Only the constructivists which directly influenced the research study are discussed here.
Philosophical Background to Dewey

Dewey was influenced, in part, by the thought of Rousseau expressed in *Emile*\(^9\) (Curren 2003, p. 96; Bailey et al. 2010, p. 92). Both saw learning as intrinsic to the very nature of human beings and that it should be allowed to follow its natural course as much as possible (Curren 2003, p. 96). Dewey was also very influenced by the work of William James, whose ideas form the basis of much of Dewey’s theory of learning (Bailey et al. 2010, p. 102). Learning is seen by James and Dewey as a product of the evolutionary origins of man. The ability to learn is an adaptive feature of human beings that was, and is, essential to our survival in the world (Kruckeberg 2006; Bailey et al. 2010, p. 237). Therefore, Dewey was a naturalist and was of the opinion that natural laws, rather than any transcendental principles, govern the entire universe including the nature of human beings (Bailey et al. 2010, p. 103). Dewey was also an empiricist in that he viewed the scientific method as the method of human inquiry in all areas of life, experience and the universe (Kruckeberg 2006). This view follows on from his naturalist position (i.e. natural laws govern all things in the universe and, therefore, the methods used in the natural sciences are the best suited to discover these natural laws). Dewey, in addition to being a naturalist, was a pragmatist (Curren 2003, p. 104). The pragmatist position is that questions of truth and the true nature of knowledge should not be asked and are not worth asking (Rorty 1982). Pragmatists do not suggest alternative theories about the true nature of knowledge and have no relativistic or subjectivist accounts of knowledge; they are simply of the opinion that such questions should no longer be asked (Rorty 1982). Throughout its history, philosophy has investigated the problem of how human beings come to know the world around them. The essential difficulty with this investigation is that: if there is an objectively real world around us, how can we know the accuracy of our mental representations of the world, given that the world is constituted for us based on our senses and experiences? Dewey, according to his pragmatist view, does not see this problem as worth investigating because it can never be verified (Russell 1993; Curren 2003, p. 104). For Dewey, the problem is better framed as: why are some ideas more useful than others in allowing human beings to carry out their activities in the world (Curren 2003, p. 104)? Therefore, the question is not ‘what is true?’ but ‘what is useful?’ Ideas then are socially constructed tools which allow human beings to predict, model and interpret experience (Curren 2003, p. 105).

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\(^9\) In *Emile*, Rousseau writes about a young boy being taught by his tutor. The tutor takes the boy out into the world to experience things for himself according to his natural tendencies. He learns all things only when something in his natural environment or experience leads to a natural interest to learn more. For example, he learns to read only when he has a need of the skill of reading (Bailey et al. 2010, p. 11).
The result of Dewey’s naturalism and pragmatism was a philosophy of education and a theory of learning that placed the learner at the centre of the experience (due to his naturalist philosophy) and that placed value on ideas based on their usefulness (due to his pragmatist philosophy). From his naturalist position, the learner should be actively engaged, both intellectually and physically, with problems and materials of relevance to everyday life and that are, preferably, practical (Curren 2003, p. 237). As such, Dewey was highly critical of the prevailing educational practices of the time which were passive. Dewey referred to these practices, along with all the classic epistemologies, as the ‘spectator theory of learning’, which he likened to a spectator at a sporting event (Curren 2003, p. 237; Krukeberg 2006): the learner was a spectator passively watching the game and never influencing it. According to Dewey, the learner was a player in the game who actively interacted with and directly affected the game. Therefore, he was a strong advocate of discovery methods and activity-based methods of learning (Curren 2003, p. 238). In Dewey’s educational setting, the teacher was a facilitator who did not impose any knowledge upon learners but allowed learners to construct their own meaning based on appropriate experiences. Lee Shulman was inspired by this vision of the teacher in his appeal for the professionalisation of teaching; in order to be effective facilitators, teachers would need to understand subject matter in a different way from non-teachers and would need to understand greater issues, such as the psychology of the learner (Shulman 1986; Curren 2003, p. 238). Dewey also recognised the pivotal importance of social factors and believed that the learner could not be separated from the community in which he/she lived and learned (Bailey et al. 2010, p. 61). Through interactions with others, we come to view the world in a particular way. It is also in these interactions that our ideas are challenged and transformed. An integral aspect of learning is to encourage the development of the disposition to learn from the criticisms and experiences of the community and to actively contribute to the community (Kruckeberg 2006; Bailey et al. 2010, pp. 61-62). In Dewey’s work, the foundations of the Constructivist Movement may be observed. He took both individual cognition and social factors into account and he emphasised the basic tenet of constructivism: that learners must actively construct their own knowledge and that knowledge cannot be imposed from outside the learner.

**Philosophical Background to Piaget**

Piaget’s work on the stages of cognitive development and the cognitive processes (such as assimilation, equilibration, etc.) involved in learning was, in a manner similar to Dewey’s, developed based on biological processes. The process of evolution was applied by Piaget to the nature of human cognition (Fosnot and Perry 1996). Piaget viewed learning and intellectual development as a process of adaptation made necessary for survival during the
process of evolution (O'Loughlin 1992). Piaget took a middle ground between the two prevailing theories of evolution at the time: Darwin’s and Lamarck’s (Fosnot and Perry 1996). Darwin’s theory relies upon chance genetic mutations; those mutations which allowed the species to better survive in its environment would be carried on as they would allow for better survival and competition within the environment (Perrier 2009, p. 151). Lamarck’s theory relied upon the species altering its behaviour according to its particular environment. The repetition of these behaviours then led to genetic, structural modifications (Perrier 2009, p. 60). For example, the giraffe developed a long neck due to its need to stretch to the higher branches of trees. The middle ground identified by Piaget was one in which adopted behaviours caused imbalances in the genome which in turn resulted in a number of mutations, the most suitable of which survived (Fosnot and Perry 1996). These imbalances result in a number of possibilities and order is then placed upon the system in the process of equilibration. Piaget proposed that the mechanism by which cognition developed and changed was the same as the mechanism involved in evolution: equilibration. When cognitive structures are disturbed (by means of disequilibration), new possibilities arise that are possible new actions or explanations. The possibilities are explored and organised and reflection brings about a structural change (i.e. adaptation or accommodation) (O'Loughlin 1992; Fosnot and Perry 1996). The evolutionary basis of his theory of cognition does place importance on the effect of the environment; therefore, social and cultural factors do play a pivotal role in Piaget’s theory. However, he does not explore the relationship between individual cognition and environment to the same depth as he explores individual cognition. Piaget’s naturalist position was also linked to an empiricist philosophy. Staver (1986) notes that, for Piaget, “science represented an activity for resolving philosophical problems”. Finally, Piaget’s fundamental views on objectivity or the truth of knowledge are in part inspired by Kant50 (Staver 1986) but he maintained a Hegelian51-inspired dialectical view of objectivity (Tudge and Winterhoff 1993). According to Piaget, the ‘real’ world is not an external, objectively-real world and it is not, at the other extreme, given to human beings in the form of innate ideas (i.e. objectivity does not arise through introspective evidence). Rather, objectivity and truth are between these two extremes and are acquired by in the active construction of mental schema (O'Loughlin 1992; Tudge and Winterhoff 1993).

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50 For example, the notion of mental schema arises from Kant (Staver 1986).

51 This bears little relation to the dialectics of RDT. Hegel suggested that when presented with two opposing forces/ideas/etc. the truth lies in the synthesis of these opposing ideas – just as Piaget synthesised the Darwinian and the Lamarckian theories of evolution. As we will later see in Section 3.7, RDT presents an entirely different view on the role of dialectical tensions.
PHILOSOPHICAL BACKGROUND TO VYGOTSKY

Vygotsky took on the work of investigating the relationship between individual and society partly in response to the lack of investigation of this relationship in the work of Piaget (Fosnot and Perry 1996). He also acknowledges the importance of biological processes and evolutionary theory in the development of understanding (Russell 1993). Tudge and Winterhoff (1993) note that the intellectual roots of Vygotsky and Piaget are intertwined. For example, both held a dialectical view of objectivity as they were both inspired by Hegel (Duncan 1995). However, Vygotsky is primarily influenced by the philosophy of Marxism52 (Davydov and Kerr 1995; Liu and Matthews 2005). Marxism posits that all forms of knowledge are social and economic constructs53 (Bailey et al. 2010, p. 24). Vygotsky greatly admired Marx and notes in his *The Socialist Alteration of Man* that changes to the consciousness and behaviour of man is an inevitable consequence of changes to the social relationships between people: “if the relationships between people undergo a change, then along with them the ideas, standards of behaviour, requirements and tastes are also bound to change” (Vygotsky 1994, p. 181). This highlights the importance placed by Vygotsky on the relationship between the learner and society. For Vygotsky, any function in my development as a learner appears first in the social context of which I am a part, and then in my individual psychological context (Duncan 1995). Therefore, any investigation of learning should have as its basic unit of analysis the learner engaged in social activity (Tudge and Winterhoff 1993; Bodrova 1997). In contrast to Piaget’s view that development necessarily precedes learning, Vygotsky was of the opinion that learning *is* development (Tudge and Winterhoff 1993). That is not to suggest that he dismisses Piaget’s view, as he recognises that elementary mental functions are the result of biological processes. However, higher mental functions are always the result of social factors (Tudge and Winterhoff 1993). Furthermore, Vygotsky sees the relationship between person and environment as dynamic with each one shaping the other and, as such, does not truly give full primacy to either individual or social factors in the learning process (Bodrova 1997).

Russell (1993) notes a number of parallels between Dewey and Vygotsky. Both were inspired by, and also moved on from, Hegel. Dewey and Vygotsky also deny the existence of absolutes and both build their educational theories on evolutionary theories (Russell 1993). As we have

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52 Note that the Marxism which Vygotsky was influenced by was before the time of Stalin and should not be considered to be the same as Stalin’s Marxism. In fact under Stalin’s regime it was forbidden to publish Vygotsky’s work (Davydov and Kerr 1995).

53 This is a crude summation of Marxism and is not intended to reflect the full thought of Karl Marx. However, this basic premise is enough to further discussion about the work of Vygotsky.
seen in the previous section, all of this can also be attributed to Piaget. Furthermore, both Dewey and Vygotsky refuse to take a metaphysical approach to objectivity (i.e. refuse to engage in questions regarding the accuracy with which the mind mentally represents the world) (Russell 1993). However, while Dewey placed the emphasis on the value of knowledge in its utility to navigate human experience, Vygotsky places the emphasis on the value of knowledge in its utility for participation in society (Glassman 2001). Despite the fact that each of the three constructivists discussed in this section are often presented as positing fundamentally different theories of learning\(^54\), the philosophies and the worldviews of each share many similarities.

(c) Rationale for Selection of Postpositivism and Constructivism
Constructivism is the most commonly applied philosophical and theoretical basis of alternative conceptions research\(^55\). This may be the case as the development of alternative conceptions among learners seems to confirm that learners do construct their own knowledge and meaning. However, I felt that constructivism alone could not inform the research project as it does not address (or, at least, does not present a coherent view of) the objectivity of knowledge. Dewey did not address the issue as it was not a valid question, given that it was not verifiable. Vygotsky’s Marxism posits that all knowledge is merely a social construct, thereby also lacking any statement of objectivity. Piaget asserted a Hegelian dialectical position on objectivity, i.e. that in the case of two extreme positions objectivity may be found somewhere in the synthesis of these positions or in the middle ground\(^56\). Given the lack of clarity on the issue within the Constructivist Movement, postpositivism was also selected to inform the research study. Postpositivism presents a view of the world as an objective reality and, therefore, suggests that there is objective knowledge. It also acknowledges that this objective world can only be imperfectly known by human beings. These two philosophies may be taken as contradictory if one takes into account the statements of Von Glasersfeld and others which indicate that all knowledge is constructed in the mind and that the concept of truth should be replaced with the concept of viability (Von Glasersfeld 1989). However, many constructivists deny that this is the case (or deny that it has to be the case for one to be a constructivist) and maintain that there is objective knowledge, which is subjectively represented in the mind of the learner (Bodner et al. 2001; 

\(^{54}\) Although there are differences, and Vygotsky engages in a critique of Piaget’s theories and his thoughts on socialisation, he commends his work in other places (Tudge and Winterhoff 1993).

\(^{55}\) Constructivism was repeatedly highlighted as a philosophy underpinning much of the research on instructional pedagogical approaches in Section 2.5.

\(^{56}\) His opinion that the true process of evolution must be a synthesis of the ideas of Darwin and Lamarck is one example of this dialectical position at work.
Liu and Matthews 2005; Hyslop-Margison and Strobel 2007). The confusion within the Constructivist Movement over this issue means that no truly definitive account of constructivism can be provided. Therefore, I considered postpositivism and constructivism as complementary; postpositivism allows for the existence of objective reality while constructivism focuses on the representations of knowledge in the mind of the learner.

3.2 CRITIQUE OF CONSTRUCTIVISM
This section could also have been entitled 'Rationale for Change of Philosophical Direction'. The criticisms of the philosophical underpinnings of Phase 1 paved the way for a different approach to Phase 2. This section is not intended to be a comprehensive critique but merely a presentation of some concerning elements of constructivism. The section outlines the concerns which led to a search for another approach, and reflects the organic development of the researcher and study towards a more holistic view of learning for Phase 2.

As other authors have noted, the constructivist literature is quite confusing to navigate (Suchting 1992; Matthews 1998). Some constructivists trace their origins back to Piaget, Dewey, Vygotsky, or Kuhn (to name a few possible founders) (Tudge and Winterhoff 1993; Matthews 2002; Kruckeberg 2006). The fact that there does not appear to be a clearly delineated philosophical thought on constructivism is a concern. While it is possible to adhere to a single form of constructivism, there is dispute even about the philosophical thought underlying these individual forms. For example, critics of Von Glasersfeld’s radical constructivism highlight the philosophy’s relativistic account of knowledge and truth (Suchting 1992; Phillips 1995; Matthews 2002). An example of some of Von Glasersfeld’s own words leading to such criticisms is that:

For constructivists, therefore, the word knowledge refers to a commodity that is radically different from the objective representation of an observer-independent world which the mainstream of the Western philosophical tradition has been looking for. Instead, knowledge refers to conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable.

(Von Glasersfeld 1989).

However, many constructivists following his form of constructivism deny that this is the case (Quale 2007). It would be impossible to critique every form of constructivism within the confines of this thesis so this section will confine itself to a few criticisms and their relevance for the constructivists previously discussed. This critique is limited to three areas: treatment of objectivity, possible presence of scientism, and nature of starting assumptions.

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(a) Treatment of Objectivity
Dewey, Piaget and Vygotsky address the issue of objective knowledge in varying ways, though they arrive at similar results. Constructivism has been criticised in the research literature for its relativistic view of knowledge (Phillips 1995; Matthews 2002). Relativism espouses the view that we each construct our own knowledge and that each person’s subjective knowledge is equally as valid. The place of objectivity is not well clarified in the work of Dewey and Vygotsky. Dewey rejects the dualism of mind-world and the question of how a person comes to know the world (Russell 1993). In his view, this question is flawed because there is no way, other than through the sense organs, for a person to experience the world. Therefore, it is not an answerable, verifiable question (Curren 2003, p. 104). By stating that this was not a question worth answering, Dewey did not end the discussion (as evidenced by the continued publications on constructivism’s treatment of objectivity) but perhaps left the question unanswered. Vygotsky’s worldview is informed by Marxism (Davydov and Kerr 1995). Marxism is a relativistic philosophy which views all knowledge as socially constructed. The prevailing knowledge of any period is that which furthers the views of those with power for whom the current system is of the most benefit (Bailey et al. 2010, p. 24). The presence of a relativistic philosophy within constructivism is very much disputed (Phillips 1995; Liu and Matthews 2005; Quale 2007). I cannot take up a definite position without recourse to a more in-depth study of the original works of these constructivists which is beyond the scope of this thesis. However, at minimum one might say that there is a lack of clarity on the issue.

The doubt as to constructivism’s potentially relativistic position is of serious concern for education and, in particular, science education; if all knowledge is equally as valid, then that means that the body of scientific knowledge is no more valid than naïve views of the world. This is obviously untenable and is the reason for the concept of viability and usefulness in constructivist literature; knowledge that works well in helping us to navigate our experiences is more valuable than knowledge that is less useful. This allows a value to be placed on the body of scientific knowledge that is over and above naïve views, as scientific knowledge works better in navigating our experiences of the world. All scientific knowledge is not in fact true as, for example, Newtonian physics is incomplete and not true in certain contexts, while Einseinian physics is true (or truer than Newtonian physics). However, we continue to use and teach Newtonian physics because it is useful for predicting the behaviour of physical bodies on the everyday scale of experience. The concept then of viability does seem to fit well with science. However, what then is the purpose of science? Humanity has, in some areas, learned enough ‘useful’ information to allow for the navigation of experiences in the world. Yet scientists (in every scientific discipline) continue to investigate the world.
This suggests that the purpose of science is not utility (or not solely utility) but is the natural human curiosity which drives us to continually seek out the objective knowledge of the universe. The philosopher Alberto Cordero characterised science as “the pursuit of truthful understanding, honestly, openly and forcefully conducted” (Matthews 2009, p. 17). Therefore, the concept of truth and objectivity is not one to be cast lightly aside in either the realm of science or science education. It is preferable for any educational philosophy to have a clear position on the role of objectivity and how it relates to what we learn.

(b) Scientism

Scientism is an ideology which maintains that the scientific method of the natural sciences is the means for answering all questions relating to the seeing and understanding of life and the world, including all that is natural57, humanistic, philosophical, spiritual, psychological, mystical and artistic (Hyslop-Margison and Naseem 2007, p 10-11). The origins of scientism in the field of education arise from the work of British philosopher Herbert Spencer who was interested in how science could improve education (Hyslop-Margison and Naseem 2007, p. 16). Egan (2002, pp. 47-68) notes that Spencer is the unacknowledged and forgotten founder of modern educational principles. Spencer presented a number of educational ideas as scientific principles based on the biological principles of evolution58 (both Lamarckian and Darwinian) as determining the development of human cognition, biological organisms, the universe, human culture, and societies. In doing so, he presented all his ideas as scientific principles. According to Egan (2002), Spencer’s educational principles were used by Dewey and Piaget in the development of their philosophies and theories of education and learning59. They did not credit him due to the growing unpopularity of his application of evolutionary ideas to human societies60. However, their educational thought is in line with Spencer’s ideas. Dewey does appear to give primacy to the scientific method in all areas of human life and knowledge as the method of human enquiry (Kruckeberg 2006). Piaget also suggested that the scientific method could answer philosophical questions (Staver 1986). Spencer’s hidden presence in the philosophies of Dewey and Piaget may be indicative of an underlying influence of the ideology of scientism.

57 This is the proper place of science. Scientism is not a reflection of the validity of science proper.
58 His understanding of evolution was considered eccentric by the end of 19th cent. (Egan 2002, p. 34).
59 For example, Piaget draws an analogy between the evolution of cognition and the evolution of human culture – another idea originating as a scientific principle from Spencer (Sawicki 2001, p. 271).
60 Spencer applied his evolutionary concepts to class structures, concluding that those in lower classes of society were there due to their inferior intelligence, etc. On the basis of this evolutionary application, he stated that nothing should interfere with the class system. His application of evolutionary principles to human culture lead him to identify some cultures as primitive and of low intelligence. This provided a pseudo-scientific justification for the institution of slavery (Egan 2002, pp. 23-28).
(c) Starting Assumptions

The final point to make regarding Dewey and Piaget is the difficulty associated with their starting assumptions. Dewey’s naturalism (and also Piaget’s\(^{61}\)) rests on the assumption that human beings are governed solely by natural laws and that, therefore, the human being is capable of nothing which transcends these natural laws. As such there is nothing metaphysical about human beings or nature in general. However, he does not first investigate this possibility. Such an investigation cannot be carried out according to Dewey, given that the scientific method cannot be applied. In this way, an assumption is made about the nature of human beings and it is from this assumption that his views on objectivity and truth arise: that although there may be objectivity, what human beings develop is knowledge that is useful and this usefulness is the measure of its value. Furthermore, the assumption that there is nothing metaphysical about human beings is itself, arguably, based upon an ability to engage in metaphysical thinking which is in contradiction to naturalism.

Given these concerns, the intended philosophical and theoretical underpinnings were abandoned for Phase 2 in favour of a philosophy that was more clearly delineated and that began its development with the investigation of the phenomenon of the human person in their nature, rather than from starting assumptions about that nature. This path leads to an understanding of learning which takes into account subjectivity, intersubjectivity and objectivity and is found in the Phenomenological Movement and the works of Edith Stein.

3.3 OVERVIEW OF STEIN’S LIFE AND PHENOMOLOGY

The phenomenological works of Edith Stein form the philosophical foundation of Phase 2 of this research study. Phenomenology arose at the end of the 19th century with the work of Franz Brentano and was developed by Edmund Husserl. Edmund Husserl, Stein’s doctoral supervisor, is commonly considered to be the father of phenomenology (Moran 2002, p. 1). Phenomenology may be described as “the unprejudiced, descriptive study of whatever appears to consciousness, precisely in the manner in which it so appears” (Moran 2002, p.1). In this section, the backdrop to Stein’s works will be presented; her work as a teacher, her position as a central figure in the Phenomenological Movement, and her own phenomenological practice will be outlined. This section is the first of four addressing Stein’s work. Each section builds upon the preceding one. My ultimate goal is to demonstrate the place of objectivity in Stein’s work and the value of empathy and community as they relate to understanding. An advance organiser of these four sections is provided in Figure 3.1.

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61 Piaget, although inspired by Kant and Hegel, makes assumptions consistent with a naturalist view: e.g. the assumption that only evolutionary processes govern the human mind.
Edith Stein is not a well-known phenomenologist. She tends to appear in works regarding the Phenomenological Movement as a brief entry or, often, she is not included at all (Baseheart 2010, p. ix). It has been speculated that this may be the result of her conversion to Catholicism and her later decision to enter into a Carmelite Convent (Calcagno 2007, p. 18). This resulted in the introduction of theology into her written works produced in the latter part of her life. The purpose of this section is to place each of Stein's main works in relation to the rest of her life. Stein engaged in some form of teaching throughout all of her adult life and her works form a theory of understanding based on her philosophical approach to the human person. This section will also highlight Stein's role as a teacher, which demonstrates her lifelong commitment to understanding the human person and how he/she encounters the world and learns from it.

Figure 3.2 depicts the main portions of Stein’s adult life. Her academic career ended in 1933 as a result of the decree of the National Socialist (Nazi) Party stating that non-Aryans could not work in any profession (Baseheart 2010, p. 15). It is at this point that Stein entered into the Carmelite community as a nun and that her work increasingly blended her philosophical
and psychological training with theology. Figure 3.3 shows some important points in Stein’s career and highlights the points at which her works *On the Problem of Empathy* and *Philosophy of Psychology and the Humanities* were developed within the broader context of her life. These two works have been highlighted as they form the philosophical underpinnings of the current research study. Both of the works were completed between 1916 and 1920.

| **University of Breslau 1911-1913** | • Stein is a student studying psychology, literature and philosophy. |
| **University of Göttingen 1913-1916** | • Stein completes her previous studies and her doctorate. |
| **University of Freiburg-im-Breisgau 1916-1918** | • Stein works as Husserl's assistant. |
| **Second-Level School Teacher in Speyer 1922-1931** | • Stein is a teacher of German language and literature. |
| **Gives Popular Public Lectures 1927-1933** | • Stein lectures on the topics of woman and education. |
| **German Institute for Educational Theory in Münster 1932-1933** | • Stein begins to work with educational authorities to reform teaching but is banned from work before this could come to fruition. |
| **Carmelite Convent in Cologne 1933-1938** | • Stein begins her life as a Catholic nun and continues to write within the disciplines of philosophy and theology. |
| **Carmelite Convent in Echt, Holland 1938-1942** | • Stein has sought refuge from the Nazi regime. |

Figure 3.2 Stein’s career (dates and information from Baseheart (2010) and Sawicki (2001)).

According to Baseheart (2010, pp. 3-20), Stein studied philosophy and psychology at the University of Breslau. While studying at the university, she read Husserl’s *Logical Investigations* and became interested in phenomenology. Therefore, she moved to the University of Göttingen to learn from him in 1913 and completed her doctoral dissertation by 1916. During her time at the University of Breslau, Stein was an active member of several pedagogical societies that were concerned with the issues of education, the University’s failure to educate and prepare pre-service teachers, and the education of women in a male-dominated educational system. Stein also engaged in the voluntary teaching of adults in German and arithmetic. Within the University of Göttingen, Stein became a vocational counsellor for women students - a role that was established by the Society of Women’s

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62 It can be argued that she had begun to blend these two areas prior to this: beginning with her comparison of the philosophies of Husserl and Thomas Aquinas. However, Sawicki (2001, p. 150) points out that this work should be considered a purely philosophical one.
Education. Stein also took up a role as a substitute teacher in her former second-level school during World War I. It is around this time that Stein wrote *On the Problem of Empathy* (her doctoral dissertation) which forms the basis for her theory of understanding (Sawicki 2001).

Prior to Stein's completion and defence of her doctoral dissertation in 1916, she went to the University in Freiburg with Husserl. There she successfully defended her thesis and obtained the highest grade *summa cum laude* and was offered a position as Husserl's assistant. In this role, Stein also engaged with teaching in the form of introductory phenomenology courses at the university. After Stein resigned from her role as Husserl's assistant, she attempted to obtain a lecturing post at the University of Göttingen. She would have been one of the first women to take up such a role in Germany. However, her attempts were unsuccessful. This is most often attributed to her gender leading to a disadvantage in an entirely male-dominated system (Sawicki 2001, p. 149), although it has been suggested that the ideas put forth in her doctoral dissertation may have been contrary to the university's position63. Stein took up a teaching position as a German language and literature teacher in a school in Speyer for eight years before she eventually resigned the post to focus on lecturing at the German Institute for Educational Theory in Münster in 1932. She had begun discussions with the education board in Berlin to reform education at the higher grades. However, this work never came to fruition as she could not continue to work there as a non-Aryan after 1933. The barriers placed before Stein may have contributed to the long-term tendency to overlook her work as her difficulties in progressing in her career meant that her work was not spread as widely and she did not publish as much as her male peers (Baseheart 2010, pp. 16-17).

It was at this time that Edith Stein made the decision to enter the Carmelite Convent in Cologne. She continued her academic work during this period and produced one of her most important works *Finite and Eternal Being* which is a philosophical and theological investigation of the nature of the human person (which was published posthumously). In 1938, when it became obvious that Stein's presence was dangerous both for herself and the other Sisters at the convent, she fled to the Carmelite Convent in Echt, Holland. Here she stayed for almost four years. Stein again took up her role as teacher and taught the younger Sisters at the convent. On 27th July 1942, it was declared that all Jewish-Christians were to be deported. On August 2nd 1942, Edith Stein was deported and died seven days later in Auschwitz (Baseheart 2010, pp.17-20).

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63 Baseheart (2010, p. 12) bases this on a letter between Stein and Fritz Kaufmann in which Stein says that a Professor of Philosophy and Psychology at Göttingen told her that the ideas put forth in *Philosophy of Psychology and the Humanities* were in contradiction to psychology as it was taught at the University.
Figure 3.3 Important dates in the life and works of Edith Stein (dates and information obtained from Baseheart (2010) and Sawicki (2001)).
Anonym: the hidden role of Edith Stein in the Phenomenological Movement

Stein was a central, though unacknowledged, figure in the Phenomenological Movement. She wrote anonymously at some point for several important figures in the Phenomenological Movement. It has been reported that Stein viewed this with some amusement early in her career. Given her body of anonymous work, she became known by the nickname 'Anonym' within her close circle of friends (Sawicki 2001, p. 152). The main source of the detail in this section is from Marianne Sawicki’s (2001) investigation in which she examined the original manuscripts of Husserl with which Stein had worked.

Stein took a role as Husserl's assistant during 1916-1918. Husserl was mid-career and had published his *Logical Investigations* and *Ideen I* in which he had outlined the Phenomenological Method (Sawicki 2001, p. 149). Stein was hired to convert Husserl's notes (written in shorthand) into long form for a number of works, including *Ideen II*. However, this job involved more than a simple transcription and included such tasks as: the selection and organisation of manuscripts, the writing of introductory and linking passages, the removal of portions of the work that interrupted the flow of writing, separating the work into paragraphs, the titling of all sections, and the drafting of an overall plan for working towards a publishable document (Ingarden 1962; Sawicki 2001, p. 149). Husserl was supposed to correct and review the work but Stein had great difficulty compelling him to do so (Ingarden 1962). In their work on *Ideen II*, Husserl was having difficulty in defining the constitution of the human person. Husserl and Stein were not in agreement on this issue (Sawicki 2001, pp. 158-159). However in *Ideen II*, Stein's views are those which were published (Sawicki 2001, pp. 159-162). Stein's work on *Ideen II* doubled its size. She had arranged the manuscript into three sections and inserted a section entitled *On the constitution of soul-reality in empathy*. Her work on the document presented the constitution of the human person as founded upon body and empathy - a notion previously expressed in her doctoral dissertation. This was accomplished by inserting the section just mentioned, along with the addition of other sections and rearranging or removing Husserl's passages that led to contradiction with this (Sawicki 2001, pp. 159-162). Husserl never reviewed the work while Stein was his assistant (contrary to what had been the previously held belief of commentators). However, in the mid 1920's he did review the manuscript but elected not to alter the views (Sawicki 2001, p. 160). Commentators have previously suggested that Edith Stein did not go beyond the work of her teacher, Husserl, by making direct references to Husserl's ideas on empathy in *Ideen II*

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64 The detail of these ideas is less important for the moment. The purpose of this section is merely to highlight Stein’s role in the Phenomenological Movement.
(Leask 2002). However, Sawicki’s investigation demonstrates that this portion of Ideen II is based on Stein’s views and not on Husserl’s. This was not Stein’s only contribution to Husserl’s work (Sawicki 2001, pp. 162-164) though it is arguably the most important. Sawicki points out that more of Stein’s anonymous collaborations with Husserl will no doubt come to light as his work continues to be edited and published and as the process of Husserlian text-production is clarified.

During her time as Husserl’s assistant she also uncovered a bundle of old manuscripts on the topic of time-consciousness which eventually came to be published as On the Phenomenology of the Consciousness of Internal Time (Sawicki 2001, pp. 164-165). The manuscripts were unfinished and disorganised but Stein took it upon herself to bring them to a publishable state. Some years later, Heidegger (who went on to become one of the most well-known phenomenologists, rivalling even Husserl) asked to see the manuscripts and published Stein’s edition of them but inserted his own name as the editor (Sawicki 2001, pp. 164-165). Heidegger claimed this was not the case and that he had received the manuscripts two years before they were published. However, the above account was confirmed by another phenomenologist, Roman Ingarden, who had been asked by Husserl to look at the manuscript shortly prior to their eventual publication (Ingarden 1962). Ingarden declined but informed Heidegger of their existence. As Sawicki points out, he could not have been working on them for two years if he had only discovered their existence shortly before their publication. Stein again took up her role as Anonym for Heidegger, though unintentionally.

Stein also took up an anonymous role for Reinach, another significant figure in the Phenomenological Movement, after his death during World War I. In his honour, she worked from his lecture notes and an unfinished manuscript to compose his essay Concerning the Essence of Movement (Sawicki 2001, p. 165). Stein also wrote anonymously for the phenomenologist Hans Lipps (Sawicki 2001, pp. 166-168). Stein was blocked from progressing in her career and Husserl was of no assistance to her as he did not want her to become a member of faculty. In his letter of recommendation, he spoke favourably of her but reinforced the university’s position of not permitting women to enter into faculty roles (Sawicki 2001, p. 167). Around the same time, Lipps had been disgraced as he was being sued for paternity by a student. Edith hatched a plan that could help them both. He would be sponsored to a faculty position by her cousin who was a mathematician. She would then
help him to write his habilitationsschrift. When he got his job he would teach advanced courses on phenomenology and would work with her as she privately taught introductory phenomenology courses. In this way, they could both progress their careers. Stein and Lipps laboured on his habilitationsschrift together entitled Investigations into the Philosophy of Mathematics (Sawicki 2001, pp. 166-168). After he successfully got a position on the faculty, the planned collaboration never happened.

Considering the volume of work to which Stein contributed but for which she was not acknowledged, it is not surprising that she garnered the nickname Anonym. The purpose of reporting on this area of her life is to demonstrate her central contribution to the Phenomenological Movement. Her most significant anonymous contribution must be said to be to Ideen II in which she was more collaborator than mere assistant, even to the extent that the central issue of constitution addressed in Ideen II was written by Stein. No doubt Husserl may have changed his opinion to one in agreement with Stein's given that he did review the manuscript before publication and opted not to remove Stein's views (Sawicki 2001, pp. 159-160). Stein remains written into the background of phenomenology where her thoughts and words helped to shape this aspect of the movement.

(c) Stein’s Phenomenology

Stein was attracted to phenomenology, as presented in Husserl’s Logical Investigations, as it turned away from the idealism that dominated philosophy at the time and turned towards realism (Baseheart 2010, p. 21). Stein appreciated phenomenology as it examined all presuppositions, investigated without prejudice, and was open to all phenomena (Baseheart 2010, p. 22). Stein used the eidetic reduction of phenomenology, which involves the descriptive analysis of the essence of the thing itself as it appears to consciousness. Husserl later moved towards idealism and his resulting transcendental reduction suspended all judgement about the possibility of an objective reality (Sawicki 2001, pp. 20-22). However, Stein does not use the transcendental reduction. Both Stein and Husserl treat the individual ego as the zero point of orientation (Calcagno 2007, p. 28). Stein’s approach blends parts of Husserl’s phenomenology (such as the eidetic reduction) with the realist personalism of one

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65 This is a high quality postdoctoral thesis which was required to be written as part of the job application process.
66 Husserl gradually moved towards transcendental idealism which many of his students considered fundamentally flawed (Baseheart 2010, p. 22).
67 Idealism posits that reality is mentally constructed and that it is impossible to gain knowledge about anything which is independent of the mind (Curren 2003, p. 177).
68 Realism posits that things have an objective reality that is independent of conceptual schema (Curren 2003, p. 177).
of Husserl’s contemporaries Max Scheler. An aspect of Scheler’s work which Stein blended with Husserl’s phenomenology was his recognition of the difference between subjective contents and subjective acts in which these contents are grasped (Sawicki 2001, p. 33). For example, this is the distinction between knowledge and knowing.

Stein’s philosophy begins first and foremost with empathy. She investigates the nature of empathy in her first work On the Problem of Empathy. She then treats empathy as fundamental for developing an understanding of the human person, i.e. empathy is fundamental for our recognition of ourselves as human persons. In the Philosophy of Psychology and the Humanities, Stein investigates the relationship between individual and community. A discussion of Stein’s work will be presented according to her own presentation as just described. Once her work has been presented, the particular relevance of her work to a science education context will be discussed. Stein’s theory of empathy is a theory of understanding and, as such, it is relevant for all forms of learning. Community is also a central aspect of her work. Learning in educational settings takes place among a group of people who may be said, at least in part, to form a community.

3.4 THE MEANING OF EMPATHY

Empathy, as described by Stein, is the perceiving of foreign subjects (for example, other people) and their experience (including their acts of thought) and her first task is to describe the nature of this phenomenon (Stein 1989, pp. 1-6). This section will first describe Stein’s empathy and how it is experienced by the individual. In order to do this, it will be compared to the act of outer perception and acts of consciousness which are somewhat analogous. These acts are memory, expectation and fantasy. In doing this, the experience of empathy will be explained as it relates to these other acts. The depths to which empathy is experienced (i.e. the modes of empathetic experience) will then be described. Many examples used involve emotion. However, anything which has an objective meaning or sense is available through acts of empathy. A clear understanding of the meaning of empathy is needed to fully appreciate: 1) how my own individuality is constituted for me in relief against the individuality of other people – of which I become aware in empathy, and 2) how empathy, and the intersubjective experience provided through it, allows for us to come to know the objectively real world. These two points will be addressed in the two sections following this. This allowance for objectivity through intersubjectivity is central to the selection of Stein’s work as the foundation for Phase 2 of this study.
(a) Empathy in Comparison to Outer Perception

Outer perception is the perception of the world (the perception of physical bodies e.g. a book). Stein notes that I cannot see all sides of a book at once. I can obtain only one orientation of the book, which is dependent on where I am standing. However, I can move my body to change this orientation and, therefore, see other aspects of the book. Stein describes the side turned to oneself as there in an originary way, in comparison with the portions of the book, which I cannot see from my current position which are there only in a non-originary way (Stein 1989, p. 6). A comparison is drawn between outer perception and acts of empathy. Taking the case of someone who is sad over the loss of a loved one; I see the sad face (like I see the sides of the book that are within my field of vision) but the pain and grief that he/she is experiencing are also given to me (just as I have an awareness of the averted sides of the book). It is important to note that Stein only sees this analogy as a very loose parallel and this will not be the basis of her understanding of empathy. She points out that in the case of the book; I can walk around to the other side of it and confirm my non-originary experience as an originary experience. However, I can never gain such an orientation (to use the spatial analogy) on the pain and grief of a friend. Therefore, empathy is fundamentally different from outer perception. However, in both cases the object (the book and the person in grief) is present before me. Outer perception is an originary experience. However, acts of consciousness can also be given to us as originary experience. Intuitive insight (or ideation) is also given to us in this way (e.g. the instant and intuitive understanding that the mathematical expression ‘2 + 2 = 4’ is true). Valuing is also an originary experience, as are our own experiences given to us upon reflection (Stein 1989, p. 7). All our present experiences are originary experiences. However, there is a distinction between the manner in which the experience is given and the content of the experience (Stein 1989, p. 8). This will be further clarified in the next section.

(b) Empathy in Comparison to Memory, Expectation and Fantasy

In investigating the nature of acts of empathy, Stein compares it with other acts of consciousness: memory, fantasy and expectation (Stein 1989, pp. 8-11). In all these acts of consciousness, there is an originary I that has an originary experience and a non-originary

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69 Stein uses the word ‘primordial’ and ‘primordiality’, however, Marianne Sawicki (2001) substitutes the word ‘primordial’ for ‘originary’ and ‘primordiality’ for ‘originarily’ which will be used throughout this thesis. The term refers to my actual experience or experience that is present for me in the here and now.

70 In other words, I do not have direct perception of the averted sides of the book. I do not have direct sensory access to those sides of the book.

71 In Stein’s initial discussion of empathy, I denotes the pure I such as the I in I think, I feel, etc. This pure I is the individual ego and is her application of eidetic reduction. Later she will investigate what constitutes the human person in all its aspects and a discussion of this will take place in Section 3.5(a).
The experience of the non-originary I forms the contents of the acts of memory, expectation and fantasy. However, in empathy, the contents of the act issue from an originary I that is not my own, i.e. from another person. This is outlined in Table 3.1 at the end of this section.

In any act of remembering, there is a present I (who is carrying out the act of remembering) and a past I (for whom the remembered event actually took place). The memory of the joy (the act carried out by the present I) is an originary experience; it is a present act in the here and now. However, the actual joy (that is, the content of the act) is a non-originary experience for the present I. At the time the joy was actually felt, that is for the past I, it was an originary experience but in the act of remembering the joy is non-originary. Stein describes it as a joy which was once bodily present but is no longer bodily present - it is as if "having once been alive" (Stein 1989, p. 8). In the case of an expectation, the act of expecting is carried out by the present I and is an originary experience (i.e. it is present in the here and now). The present I, in the act of expecting, looks forward to a future I which is the non-originary subject. Take the case of expecting to receive a good grade in an examination. The present, expecting I is originary and the content of the expectation (the reception of a good grade) is non-originary; it is not bodily present in the here and now. Expectation, therefore, is a parallel to memory.

Free fantasy differs from both memory and expectation. In memory, it is obvious that the present I and the past I are connected in a continuous stream of experiences. In remembering the past I, it is possible for me to then recall each event that occurred between the past and present I's, thus bringing the past I right up to the present time through this continuous stream. While possibly less obvious, the same is true for expectation. The future I can be returned to the present I by returning through each expected event between the time I sit my examination and the present time. However, in fantasy there is no continuous stream of temporal experiences and this is the fundamental difference between fantasy and either memory or expectation. The fantasising I is the present I and the act of fantasising is originary. The fantasised I also lives in a fantasised present time (for example, perhaps someone has been unjust towards me in the workplace and I fantasise about the things I should say to them). In this way the originary fantasising I is engaging in a non-originary representation of imagined present experiences, i.e. the content of the fantasy (the things I wish to say to my colleague, for example) (Stein 1989, p. 9).

Empathy is somewhat similar to fantasy in that the two subjects are not connected by a continuous stream of temporal experiences. Taking the example of empathising with a person in grief over the loss of a loved one, the empathised grief is originary and is experienced by my I. However, the content of the act is non-originary, as the grief that my I
experiences does not belong to me but to a foreign I (though the grief is originary for them) (Stein 1989, p. 10). The distinction between empathy and memory, expectation or fantasy is in relation to the subject of the experience. In the other acts of consciousness, the subject to whom the act is directed (the remembered I, expected I, or fantasised I) is the same as the subject engaged in the act (the remembering I, expectant I, or fantasising I). The two are recognisable as the same (though separated by spatial and/or temporal distance). However, in empathy, the subject to whom the act is directed is another person, a foreign I, that is distinguishable from my I. Thus, the experience does not have the same character as a remembered experience (the character of having 'once been alive') and is more 'alive' than a fantasised content as, in empathy, the foreign I is originary (as opposed to the non-originary fantasised I that is the subject of fantasy). In empathy, the empathising I is led by an empathised I for whom the content is originary (Stein 1989, p. 11). Stein concludes then, that empathy is "a kind of act of perceiving sui generis". In other words, empathy is a unique form of perception with its own set of characteristics that cannot be reduced to a wider category of inner or outer perception or acts of consciousness. It is through empathy that human beings come to know the inner psychic/mental life of each other (Stein 1989, p. 11).

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<td>Act of Consciousness</td>
<td>Originary Subject</td>
<td>Originary Experience</td>
<td>Non-originary Subject</td>
</tr>
<tr>
<td>Memory</td>
<td>Present I</td>
<td>Act of remembering</td>
<td>Past I</td>
<td>Past I’s experience (e.g. joy)</td>
</tr>
<tr>
<td>Expectation</td>
<td>Present I</td>
<td>Act of expecting</td>
<td>Future I</td>
<td>Future I’s experience (e.g. joy over passing exam)</td>
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<tr>
<td>Fantasy</td>
<td>‘Real’ I</td>
<td>Act of fantasising</td>
<td>Fantasised I</td>
<td>Fantasised I’s experience (e.g. speaking one’s mind to the boss)</td>
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<td>Empathy</td>
<td>• My I</td>
<td>Act of empathising</td>
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<td>Foreign I’s experience (e.g. someone else’s grief)</td>
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<td>• Foreign I (i.e. the other person)</td>
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(c) Modes of Empathy and Other Acts of Consciousness
Stein discusses three modes in which acts of empathy (and also memory, expectation and fantasy) can be experienced (Stein 1989, pp. 10-11).

1. Emergence of Experience
This mode of experience is one in which the experience comes into view. It is the non-originary parallel to perception. Stein describes it as arising before me all at once. In empathy, it is the initial givenness 72 of sad countenance and sadness, for example. In this mode, the empathised experience is an object facing me.

2. Fulfilling Explication
This mode of experience could be rendered as ‘Unfolding of Full Potential of Experience’ 73. It is the non-originary parallel to the having of the experience. In this mode, the content (the sadness, for example) has "pulled me into it" and as such I am no longer truly turned to it as an object but am 'at' the foreign I's place (though I am in no way one with him 74) and am facing the subject of the content (the event causing the sadness in the foreign I).

3. Comprehensive Objectification
This mode of experience could also be entitled as ‘Extensive Mental Grasp of Experience as Object’. It is, similar to Emergence of Experience, the non-originary parallel to perception. This mode of experience follows on from the previous mode. Only after the successful unfolding of the nature of the foreign experience do I again face it as an object and, as a result of this unfolding, view it with a thorough grasp of the foreign experience.

The same modes of experience are true also of memory, expectation and fantasy. The experience (the memory, for example) arises and at first it is an object. However, once I allow the memory to 'take' me, I am now 'at' the past I's place. Once the experience has unfolded, I can now view the memory again as an object but with a comprehensive understanding of it. Stein points out that it is not necessary to engage in all three modes and that often people do not engage in all three modes, rather being satisfied with one of the first two modes.

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72 The term ‘givenness’ refers to the immediate intuition of something. It is not an interpretation of something or a projection of myself into another’s circumstances. It is an immediate grasping of the experience of another person.
73 This is not intended to be translation of Stein’s German. It is simply a title which is suggested as a way to give clarity to a modern reader about the meaning of the particular mode.
74 This was an aspect of the theory of empathy of Theodor Lipps of which Stein was highly critical (Stein 1989, p. 12-14).
3.5 EMPATHY, INTERSUBJECTIVITY AND OBJECTIVITY
Stein’s method leads her to a view of the human person that is holistic: one that encompasses all aspects of individuality and which is founded upon the physical living body. In her analysis, she finds that empathy is essential for the constitution of our individuality as unique psycho-physical persons. This comes to be constituted for us when we see ourselves in relief, through acts of empathy, against other unique psycho-physical individuals. Our ability to empathise with others, gives us access to their perspectives (both physical and mental) and the number of perspectives we have access to is limited only by the number of available people, with which to empathise. These perspectives gained through empathy are not confined to my own sensory experience and cognitive structures; they are independent of my perception. As a result, the objectively-real world becomes available to me through acts of empathy with other individuals. This section will give an overview of how Stein constituted the human person, the necessity of empathy constituting our own individuality, and demonstrate how empathy is the mechanism by which we have access to objectivity. It will culminate in a discussion of Stein’s empathy as a theory of understanding.

(a) Understanding Ourselves as Psycho-Physical Individuals
Stein constitutes the individuality of the psycho-physical person based on four related concepts: the pure I, the stream of consciousness of the pure I, the soul, and the living body. Each of these concepts will be briefly discussed here with a view to demonstrating that Stein’s philosophy presents a holistic view of the human person.

THE PURE I
The pure I, or individual ego, is an I that is individual and has a sense of uniqueness. The awareness of this individuality becomes apparent when seen in relief against others (given in empathy); there is a recognition that I is separate and different from you. There is also the realisation that this you experiences itself as I experience myself and that the you is another I. The recognition of this difference is one element of individuality (Stein 1989, p. 38).

STREAM OF CONSCIOUSNESS
Each I is affiliated with a stream of experiences. I is the subject of an experience in each instant. The I that is the subject of an experience in this instant, flows over into an experience in the next instant. Therefore, the I is associated with a stream of experiences or a stream of consciousness75, which forms an inviolable unity. The I of another person is qualitatively

75 This could be thought of as something like the narrative writing style called stream of consciousness in which the author seeks to demonstrate the flow of the character’s thought processes.
different from my I, as it is part of an inviolable unity formed of a different stream of consciousness. This qualitative difference forms another element of individuality (Stein 1989, p. 38-39).

**Soul or Individuality of Psyche**

The concept of soul refers to the individuality of the psyche. It is constituted from the content of the stream of consciousness and has certain attributes (such as the ability to categorise). The soul is recognisable as my soul when I can recognise my I within my experiences. There is a reciprocal dependence in that the character of the individuality of the psyche depends on the content of the stream of consciousness, and the content of the stream of consciousness depends on the character of the individuality of the psyche. Soul then, also, contributes to the individuality of the psycho-physical individual (Stein 1989, pp. 39-40).

**Living Body**

The previous concepts related to the psyche, however, in order to get to the psycho-physical individual the body must be introduced. Stein’s analysis (Stein 1989, pp. 40-48) of the body reveals the concept of a living body, which is unique in comparison to some other physical body (e.g. a chair). For example, my living body always surrounds my zero point of orientation. This zero-point of orientation has no distance from my I but has a distance from my body; it makes good sense to say, I move my hand closer to me or further away from me. It is also impossible to see with outer perception all outer aspects of our own bodies, though it is possible for me to see all outer aspects of a physical object if I move the zero point of orientation of my body (i.e. I can walk around the chair). The body forms part of the constitution of the psycho-physical person in that it demonstrates psycho-physical causality as, for example, I might have a general feeling of sluggishness and this is noticed in my limbs and colours my thoughts. The psycho-physical person also experiences the phenomenon of expression such as blushing from shame. In this case, the reddening of the cheeks is not a mere accompaniment but rather as I live the feeling, I feel it release some expression. Feelings are loaded with an ‘energy’ that must be released or unloaded in some expression, which can take a number of forms including: physical expression, action, fantasy, or reflection.

(b) Foreign Individuals as Psycho-Physical Individuals

The foreign I is constituted for me as another zero point of orientation. The living body is not separated from the outer spatial world and as such, in outer perception, I perceive the foreign living body as at a certain distance from me and other physical bodies. However, in an act of empathy with this living body, a new image of the spatial world is obtained from a different orientation arising from another I. This foreign world image is not a fantasised
world. It is non-originary for me (though originary for the foreign I) and it does not take the place of my originary world image. Rather I have both at the same time. In this way (i.e. by means of the co-givenness of living body with outer perception, and by means of empathetic representation with another I), the sensing subject is given to me as at one with the acts that he/she carries out (Stein 1989, pp. 61-62). The foreign world image obtained by empathy is not only affected by the spatial orientation of the foreign I but also by the character of the foreign living body. For example, the world image of a blind person is different from the world image of a person with all senses even if they take up the same spatial orientation (Stein 1989, pp. 62-63).

(c) Empathy as Necessary for the Constitution of Our Own Individual
Through acts of empathy I come to understand my zero point of orientation as one point among many. I also understand my body is a physical body like that of others, although it is only in originary experience that I understand my body as a living body. Furthermore, in empathy with others that perceive me, I interpret my body as a living body and obtain a full view of myself as a psycho-physical individual. Empathy is also the necessary condition for obtaining a reflection of myself in acts of memory (my past I), expectation (my future I) and fantasy (my fantasised I) (Stein 1989, p. 63).

(d) Objectivity as Developed through Intersubjectivity
A fantasy world is not a real world. However, the world image obtained empathetically is an existing world and is like the world I originary perceive. The empathetic world and the originary world are the same but differently perceived (based on the other’s zero point of orientation and the nature of the other). Both worlds are perceived at the same time. The world exists independently of consciousness, however, the world as I perceive it is dependent on consciousness. Within the boundaries of my individuality, I am confined to the ‘world as I perceive it’ or, at minimum, the existence of an objectively existing world is indemonstrable. However, in empathy such a demonstration is possible as I can obtain as many images of the world as there are subjects. These world images are independent of my perception. Empathy as the basis for intersubjective experience76 is, therefore, necessary for obtaining any knowledge about the world (Stein 1989, pp. 63-64).

(e) Empathy as a Theory of Understanding
Empathy as foundational for intersubjectivity is essential for developing an understanding of the world and of other people. Through intersubjective experience one comes to understand

76 That is, experiences that are comprehensible to and available to a plurality of subjects.
objective reality. This aspect of Stein’s work is essential for placing the natural sciences in their right place and acknowledges this body of knowledge as one which seeks out and is capable of seeking out objective reality. In this sense, Stein’s theory of understanding can attribute to the body of scientific knowledge what constructivism or postpositivism\(^7\) cannot attribute to it.

Education is a communicative practice that takes place in a setting in which each communicative human person stands in relation to others (i.e. an intersubjective setting). Science education seeks to cultivate an understanding of: the scientific endeavours and practices of the whole human community, and the place of humanity in the world as a whole and as individuals. Empathy is the vehicle by which such communicative practices occur. In any classroom practice, communication takes place. In order for communication to be at its most effective, teacher and students must engage in empathy. A student who is listening to the teacher discussing the meaning of the concepts of ‘molecule’ or ‘atom’ will not develop an understanding of these concepts if they cannot empathise with the teacher and stand ‘at’ his/her place, in order to better grasp his/her meaning. Similarly, the teacher cannot hope to gain clarity on the understanding that the student has developed, without engaging in acts of empathy. Statements, without empathy, cannot substitute for empathy. Stein points out that “statements can fill the breach and supplement where empathy fails. Possibly they may even serve as points of departure for further empathy. But in principle they cannot substitute for empathy” (Stein 1989, p. 65).

Stein’s constitution of the human person as psycho-physical individual has greater significance than its role in empathy. Seeing the human person as a unity that includes a stream of consciousness allows for recognition of prior experiences, including previous empathetic experiences and learning. Finally, her discussion of the individuality of the human person recognises that even though, in principle, two people could have the same stream of consciousness (i.e. have the exact same experiences in life), individuality would always remain, due to the individuality of the psyche or soul. As such, every experience is saturated with this individuality. Such a view of the human person permits recognition and valuing of learners as individuals who each have unique experiences and can contribute in unique and meaningful ways to the learning environment.

\(^7\) As previously discussed in Section 3.1(b), some forms of constructivism posit that nothing outside of the mind can ever be known. Postpositivism and other forms of constructivism suggest that the world can only be known imperfectly as we are confined by our own conceptual schemas.
3.6 INDIVIDUAL AND COMMUNITY

In Philosophy of Psychology and the Humanities, Stein (2000) investigates the manner in which the psyche of an individual becomes part of the mental world of a community. The meaning of community will first be clarified along with the meaning of the other most relevant social grouping: association. The characteristics of communal experiences that distinguish them from personal experiences will then be discussed. Finally, the acts which contribute to communal experience will be described, with a focus on those that are of particular relevance for science education.

(a) Types of Social Groups

Community is a natural and organic grouping of individuals. It is characterised by one individual facing another as a subject and in doing so 'lives with him' and is affected by those things which affect the other person (by means of empathy). The contrast to this is when one person confronts another person as an object and in doing so seeks only to manipulate certain reactions from him/her based on some knowledge he/she may have. In this case, the term association is used (Stein 2000, p. 130). Within an association, each person is completely alone, whereas the community is characterised by solidarity. Stein points out that in reality our personal connections and relationships with each other are mixtures of these ideal types (Stein 2000, p. 131). The association is cold observation but based on an understanding gleaned from having lived, at some point, in community with those one wishes to control. This is necessary in order to be able to know how to coerce the desired reactions (Stein 2000, p. 131). Conversely, if one is a true servant of the community and becomes the head of the community, it is necessary at times to enter into association with the community in order to study the members and, thus, guide them appropriately. This is the case even though, at all times, it is the will and wishes of the community that the community person wishes to carry out (Stein 2000, p. 132). It is not entirely necessary to enter into full association with the community in order to carry out this task but it is absolutely necessary that the association person have lived in community with those he/she seeks to control (Stein 2000, p. 132). Stein seeks to understand the nature of community life.

A class group in school may then be defined as an association which lives alongside the character of community. It is an association as it is set up with particular goals in mind and it is not an organic grouping of individuals. In a community, members are not replaceable. Although new members may enter into community or members may leave the community, one is not replaceable by the other. The association does not develop its goals based on the personal distinctiveness of its members, as is the case with a community (Stein 2000, p. 255). In an association members are replaceable as the focus is on their functional role as it
contributes the goal(s) of the association (Stein 2000, p. 256). In some cases members of a class group may be replaced as it is their functional role which is of the most significance. Notably the role of teacher can be replaced by anyone else who can fulfil this duty. Furthermore, an association may be dissolved at any time before its goal(s) has been achieved (Stein 2000, p. 255). A class grouping also behaves in this way. For example, the school may close down or may decide to dissolve one class group and spread its members among different groups. In either case, the class group has been arbitrarily dissolved. However, the class also displays the characteristics of a community. In a community, members live with one another. The community constantly grows and changes due to its organic nature and, therefore, it displays its own unique character (Stein 2000, p. 256). Learners in a class group live with one another as they progress through their education together. The class displays its own unique character as evidenced by the fact that different class groups in the same school may have different characters. For example, one class group may be referred to as boisterous and another as motivated and so on. The same points apply to any voluntary educational grouping created as part of a research study. The educational grouping is in some aspects an association and in other aspects a community.

(b) Experience of the Community

There are a number of distinctions between personal experience and the experience of the community. The subject of a personal experience is the individual ego. In a communal experience, the subject is a plurality of individual egos. In any communal experience, such as the death of a community leader, there is a personal experience of grief; there is my grief. However, within the communal experience it can be seen that the experience is also our grief. I grieve as a member of my community and my community grieves with me. The subject of the communal experience cannot be thought of as a pure ego but the community can be said to have a collective personality. (For example, the community that is the German people are often characterised as efficient.) However, ultimately it is the individual egos which are the source of the community (Stein 2000, pp. 134-135).

The composition of a personal experience and a communal experience is also different. The content of the personal experience is an individual content and is saturated by my individual life. In a communal experience, the content is the same for each member. As Stein puts it:

The grief [for example] is quite a private content that I feel, but it is not only that. It has a sense, and by virtue of that sense it claims to count for something lying beyond the private experiencing, something subsisting objectively.

(Stein 2000, p. 135).
My experiencing of this content takes on an individual flavour but the content of the experience exists outside of me. This objective content is, in our example, the loss of a community leader and the content is the same for each member of the community. Therefore, the experience is the same for each member of the community but private experience also contributes to my experience of it. As such the core sense (the experience of the loss of a leader which is the same for everyone) and the flavour it takes on (in the contributions of my private experience) are to be distinguished. Stein points out that it is possible to identify the grief that belongs to the I and the grief that belongs to the we. It is important to note that the experience of this content is not an empathised experience. The experience is an originary one and not the non-originary experience of another’s mind (Stein 2000, pp. 135-139).

The stream of consciousness is also different when comparing a private and a communal experience. In a personal experience, the stream of consciousness is constituted from all the experiences of my I\(^78\). In reflection, I can become conscious of my experiencing and my stream of consciousness. However, the community only becomes conscious of itself in its members. As such when I reflect on my experience, the community does not become conscious of its experience but rather I become conscious of what the community experiences within me. As such there is no stream of consciousness of the community comparable to that of the individual ego. However, the experiences of the community do form a unity such that the community may be said to have an experiential current (Stein 2000, pp. 139-141).

(c) Experiences that Constitute the Communal Experiential Current
Experiences that have only an individual sense cannot contribute to the communal experiential current as they are confined to the individual. Experiences that contribute to the communal experiential current include those based on observation and acts of thought (as well as affective acts, such as attitudes and values, and acts arising from sensory experiences) (Stein 2000, pp. 145-167).

Stein highlights the necessity of empathy in any discussion of observation. In order for any communal understanding to develop, individuals must be open for each other in empathy (Stein 2000, p. 148). "With all our empirical knowing, we sink our roots not only into what we've perceived with our own senses, but what we've heard from all sides and taken over through tradition" (Stein 2000, p. 148). For a communal observation to occur, it is more than just a collection of disparate individual observations, rather one pervasive sense must be

\(^{78}\) This was previously discussed in Section 3.5(a).
common to the personal observations. Thus, the knowledge of any scientific field that is
developed over time is an "experiential complex that runs through the experiential current
of the community" (Stein 2000, pp. 148-149).

Stein also discusses acts of fantasy as they contribute to communal experience. Can fantasy
form part of a communal experience in the same way as empirical observation can? Stein
reaches the conclusion that this is not the case. I can present my fantasy to another and vice
versa but our fantasy worlds remain separate and another cannot live in my fantasy world
nor I in theirs. Yet suppose we fantasise about a world with a common property? Stein, being
German herself, provides examples from German fairy tales such as Sleeping Beauty.
Sleeping Beauty has defined traits and fates that cannot be tampered with, in the same way
that one could not tamper with the personality of an historical figure. Therefore, such a
fantasy world can become part of a communal experience. Stein notes this conflict in relation
to fantasy and in order to clarify it she separates out the experience into fantasy-intention
and fantasy-intuition. Fantasy-intention is what we mean to fantasise about. For example,
when we speak of Sleeping Beauty we all mean the same thing. However, the manner in
which we present Sleeping Beauty to ourselves (that is, the fantasy-intuition) can be different.
For example, one person could present Sleeping Beauty to him/herself in a particular dress;
the forest and castle in which Sleeping Beauty lives may also be presented differently. Thus,
we may have the same fantasy-intention but we each have different fantasy-intuitions of the
same thing (Stein 2000, pp. 149-151).

All acts of thought are essentially communal experiences or have the potential to become
communal experiences (Stein 2000, p. 152). All acts of thought are founded acts. What Stein
means by this is that are founded upon the ‘stuff’ of experiences: acts of thought are founded
on experiential substrate (Stein 2000, p. 152). Objects (as in objectively real things) arise out
of the experiential substrate provided by our senses: we receive visual data such as a flickering
of light, for example, and out of this data the object of a fire arises for us. In the same way
acts of thought (mental acts) arise out of experiential substrate in the same manner. However,
all acts of thought do not need to be founded directly on sensory experience. In an entirely
theoretical context, acts of thought can be founded upon other objectivities that have arisen
from other acts of thought. However, all acts of thought ultimately point back to sensory
experiences (Stein 2000, p. 153).
(d) Relevance of Community for Alternative Conceptions and Science Education

Insofar as a group of learners can be characterised as a community of learners (which surely differs from group to group), the notion of the experience of the I as being separate and yet also belonging to the we of the community is one with relevance for the problem of alternative conceptions. In order for there to be a communal understanding of any scientific concept, one pervasive meaning must be common. In order for such a meaning to be accomplished, communication becomes essential. This communication also ultimately points back to all members of the group being open for each other through acts of empathy. Therefore, trust, respect and communication become essential characteristics to be fostered among and between any group of learners.

Finally, a point must be made about Stein’s discussion on fantasy in relation to science education. If we consider teaching and learning about the atom, we must note that evidence for the existence of atoms actually exists and is in no way like a fantasy. However, for the learner of chemistry and science, the science behind such observations is very complex, often even in its simplified form. Atomic mass spectroscopy, for example, is generally not presented to learners because even when simplified it is quite complex. Therefore, when the atom (or the formation of ions, chemical bonding, etc.) is presented to learners, we expect them to take it as an objectively real thing, evidence of which has been found by others but with little explanation or discussion of this evidence. Certainly, Rutherford’s foil experiment is presented but the experiments precipitating this are not discussed. Prior to the foil experiment is the assumption that atoms exist. Thus, learning about many abstract chemistry concepts is merely a step away from fantasy from the perspective of the learner. The learners and teacher all mean the same thing when they speak of an atom, yet the intuition of the atom is different. Each intuits the look and feel of an atom is different ways, in ways which make sense to them. The task of the teacher is to ensure that each intuition holds certain characteristics of the atom in common.

Some alternative conceptions may arise as communal understandings due to the models used in science education. It is a feature of the Bohr model of the atom that electrons move in circular two-dimensional pathways and this, therefore, arises as a communal understanding of the intended meaning of the atom. This model has commonalities with the solar system model and the Rutherford model - all early presentations of the atom that reinforce this communal understanding. It becomes difficult then to displace this communal understanding with more advanced models of the atom in which electrons do not move in such patterns. The task then is not simply to teach a new model but to displace the features of the old model and also teach the features of the new model. More time may be needed to allow a
new intended meaning of ‘atom’ to arise among a group of learners. Such an approach is necessarily time consuming and may not be realistic for science classes that must work in accordance with prescribed curricula and within a limited timeframe. Therefore, opportunities may need to be created that can allow learners to develop communal understanding outside of the classroom with adequate input and supervision from teachers. Blended learning provides one such opportunity.

Stein’s philosophy, then, provides a solid foundation in epistemology, ontology and the connection between the two; the objectively-real world exists, and individuals can come to know this world through empathy – which frees us from solipsism, i.e. the theory that only the self can be proven to exist, and the confines of our own perception. Stein’s philosophy arises, not from starting assumptions about of the nature of human beings, but from a phenomenological investigation of the nature of the human being and the role of empathy. However, the philosophy, by itself, is too broad to be directly used in the analysis and interpretation of qualitative data, thus necessitating a theoretical lens which can inform such an analysis. This theoretical lens comes in the form of Baxter’s (2011) Relational Dialectics Theory (RDT), which is founded upon the work of the Russian cultural theorist, Mikhail Bakhtin, on dialogism (Baxter 2004). RDT became of interest during the analysis of qualitative data from Phase 2 of this study, as a number of the characteristics or behaviours of the community-oriented groups appeared to be defined in contradiction to each other and were mutually negating. For example, some groups appeared to struggle with the contradiction between expressing their conceptual ideas and a reluctance to express their conceptual ideas. The observation of these dialectical tensions in the data led to a review of the area of social dialectics and, ultimately, to RDT. Stein’s philosophy and Baxter’s RDT together can provide an effective tool to lend a new perspective to the problem of alternative conceptions in chemistry.

79 As opposed to the work of Marx on the dialectics of materialism.
3.7 RELATIONAL DIALECTICS THEORY

Dialectical theory broadly refers to the study of the interplay of opposing or contradictory forces, i.e. “the interplay of unified opposites” (Baxter and Braithwaite 2006). The particular way in which these dialectical tensions are studied and understood depends upon the particular branch of dialectical theory to which the researcher subscribes. All branches of social dialectics have a few assumptions in common (Baxter and Braithwaite 2006):

- relating to one another is a process of contradiction,
- contradiction is essential to bringing about relational change, and,
- communication is an intrinsic part of the process of contradiction.

The various branches of social dialectics vary in terms of the social unit in which dialectical tensions are studied. They may be examined within the individual (Dindia 1998), within a relationship (VanLear 1998), and within society at large (Brown et al. 1998). The strands of research also diverge depending on whether the researchers seek to identify a number of idiosyncratic presentations of dialectical tensions depending on context, social unit, and so on (Baxter 2004). RDT is a branch of dialectics first conceived of by Baxter and Montgomery (1996) and later refined by Baxter (2011). It is informed by Mikhail Bakhtin’s work on dialogism (Baxter 2004). The interplay of dialectical tensions referred to in RDT and Bakhtin’s dialogism bears little resemblance to Hegelian dialectics, in which the synthesis of opposing forces is generally considered to be of central importance80 (Hegel 2010, p. 81).

RDT is considered a sensitising theory rather than a hypothetico-deductive theory. Such a theory represents a collection of concepts for the purpose of sensitising and appropriately orienting researchers to important characteristics and processes of the problem at hand (Turner 1986, p. 11). In this case, RDT orients us to the interplay of dialectical tensions in people’s relating to each other. RDT focuses upon these tensions within relationships and seeks to uncover the idiosyncratic presentation of these tensions in different contexts, relationships, etc. (Baxter 2004). RDT considers individuality, thoughts, ideas, utterances, and relationships to be constituted in the act of relating to one another (Baxter 2004). As a result, RDT is in many ways a good fit for the philosophy of Edith Stein. It complements Stein’s work in several ways, though it differs in its conception of empathy. The overlap of this theory with Stein’s philosophy will be presented, before discussing how RDT has been used in the research literature.

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80 I am being very simplistic here but this is sufficient for understanding how Hegelian dialectics is different from the dialogism of Bakhtin, which will be addressed later in this section.
(a) Complementarity between Relational Dialectics Theory and Stein’s Philosophy

Baxter’s RDT and the underlying theories of Bakhtin’s dialogism generally complement Stein’s philosophy of empathy and community. Bakhtin’s and Baxter’s views on how our language-use, relationships, dialectical tensions, and sense of self, are constituted through communication with others, rest well alongside Stein’s views on the constitution of our individuality in acts of empathy with others. This constitutive approach is the foundation of both Stein’s philosophy and Baxter’s theory. RDT focuses upon the dialectical tensions constituted in communication, and upon the interplay of these tensions. No such analysis exists in Stein’s philosophy. However, the philosophy is itself founded upon a number of dialectical tensions and the interplay between them.

CONSTITUTION OF SELF AND COMMUNICATION IN THE PROCESS OF RELATING

Bakhtin’s dialogism presents dialogue as a constitutive process. In his worldview, communication cannot be considered as a separate entity from either self, relationships, or society. The self is constituted through dialogue, as are any relations (Bakhtin 2011, pp. 11-12). This constitutive approach is very similar to Edith Stein’s and that of the wider phenomenological movement. As discussed previously, Stein viewed our own individuality, as constituted through empathy with others: in empathy, I come to understand the individuality of my own I, stream of consciousness, and soul, as seen in relief against another foreign I. Even my own living body is first constituted for me though empathy with others. Bakhtin’s own words might best elaborate on the similarity between his worldview and Stein’s in this regard.

“I achieve self-consciousness, I become myself only by revealing myself to another, through another and with another’s help”

(Bakhtin, cited in Baxter 2011, p. 100).

For both Stein and Bakhtin, communication (or in Stein’s case empathy) does not represent a revelation of the pre-formed self but rather the constituting or authoring of the self (Bakhtin 2011, p.5). ‘Openness’ has long been a central concept in social dialectics. However, many theories take a non-constitutive approach in which openness is the disclosure of a pre-formed self (Baxter 2004). Bakhtin’s work in relation to constitution-through-communication results in a conception of ‘openness’ in Baxter’s RDT that is one of “openness-to.” Here openness is conceived of as a state: the state of being willing to listen to another and being open to changing attitudes, beliefs, opinions, etc. (Baxter 2004).

In Bakhtin’s dialogism, there is a focus upon language use or the utterance. His conception of an utterance is one which is inherently social, wherein the utterance is the product of both
the one speaking and the other to whom the utterance is directed (Bakhtin 2011, p. 68). The utterance is not the outcome of an autonomous individual’s thought process driven by his/her goals, etc. It is shaped by all the involved parties and by that which came before it, and which will come after it. In this way, he conceived of an utterance as a link in a chain; it is inherently influenced by the preceding utterances (which in turn were influenced by that before it, and so on) and is, therefore, partly the property of the person whom made that utterance, and it is also influenced by the anticipated response, thereby, also making it the property of the individual(s) to whom it is directed (Bakhtin 2011, p.68). Baxter (2004) also makes room for the influence of community in RDT. She not only emphasises the influence of past and anticipated utterances of the other party upon any single utterance, but she also recognises that the cultural or societal discourse influences any utterance. Just as past and anticipated utterances of the other communication party shape the current utterance, so too does the cultural discourse and the anticipated response from others within the culture (Baxter 2004). As a result of Bakhtin’s influence, RDT emphasises the shared ownership of statements between those persons engaged in the communication process. Dialectical tensions are considered to be constituted and shaped through communication between people and, as such, dialectical tensions are situated within relationships, rather than isolated in the mind of an individual. In the language of Stein, the utterance could be said to belong to the community and is a communal experience, or to belong to parties engaged in empathy. 

Bakhtin’s view of the utterance as a link in a chain, and of dialectical tensions and relationships as constituted within this chain, complements Stein’s philosophy of empathy and how she constitutes the human person. For Stein, the pure ego (the I) has an associated stream of experiences, wherein one experience flows into the next and so on. Each experience influences the next experience in the stream and all experiences thereafter. This is the case given that my individuality is constituted within this stream of experience, and this individuality in turn saturates all my originary experiences; thus, each experience influences any later experiences81. For Stein, not only utterances influence any experience but also all manner of experience given in empathy. Any experience, including a communicative one, is influenced by that which went before it. This may be other utterances or impressions, feelings, moods, ideas, and so on, that are given in empathy. For example, take a person expressing a conception of a chemical bond. In one case, the person expresses the conception of a chemical bond and a sense of defensiveness is co-given with the utterance

81 These ideas were presented in Section 3.5.
in an act of empathy. The speaker crosses his/her arms in the phenomenon of expression. In the other case, the speaker expresses his/her conception of a chemical bond but what is co-given in empathy is uncertainty and doubt. Perhaps he/she shrugs her shoulders while speaking to also convey this doubt. In either case, my response to this experience is likely to be different, whether in the use of language, tone, attitude, accompanying gestures, etc. In this way, the previous experience influences the next experience in the chain. Similarly, the reaction I anticipate to my utterance is likely to be different in each situation, and this anticipated reaction also influences my utterance. As a result, my utterance is the product of both my thoughts, goals, feelings, etc. as well as those of the person with whom I am engaged.

Bakhtin’s consideration of an utterance as belonging to both the speaker and the person to whom the utterance is directed can also be considered to be a more honed or narrower case of a communal experience in Stein’s work. In a community, the subject of the experience is the plurality of egos, as opposed to an individual experience in a personal experience, and the community has an experiential current rather than stream of consciousness. A community is built upon its members being open for one another in empathy, yet it is also more than that. In order for an experience to form part of the experiential current of the community, it must have a common pervasive sense for the group members. Stein notes all acts of thought have the potential to be communal experiences, as all acts of thought are founded acts, i.e. based on the ‘stuff’ of experience. However, acts of thought need not be founded upon sensory experience, but can be based on theoretical objectivities and other acts of thought. In the context of this study then, the idea that a chemical bond is formed between a hydrogen and an oxygen atom is founded upon the objectivity that atoms exists and that they have certain characteristics and properties. It is also founded upon the acts of thought regarding the rationale for bonding. Where these acts of thought have a common pervasive sense for the community, they are communal experiences which belong to the entire community rather than to any particular individual. The manner in which I present these ideas to myself is saturated with an individual flavour (i.e. my experiencing of them may differ from that of another); however, the contents of the experience (i.e. the bonding of the atoms, characteristics of the atom, and so on) are the same, or have the potential to be the same, for the entire community. Therefore, the notion of utterances belonging to a number

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82 These concepts and others in this paragraph were discussed in Section 3.6.
83 Recall that Stein incorporated Scheler’s distinction between subjective acts and subjective contents, e.g. the distinction between knowing and knowledge. This is Scheler’s distinction at work.
of people, and to the community at large, rather than simply the person currently using language is not only consistent with Stein’s philosophy but is a natural consequence of it.

Bakhtin also considered utterances to be a continuum from single-voicedness to multi-voicedness (Baxter 2004). That is, a continuum with the recognition of only a single voice at one end and the recognition of more than one voice at the other end. These ‘voices’ need not refer to the contributions of various individuals but to the contribution of various perspectives, values, etc. In language-use, multi-voicedness is often marked by connecting phrases such as ‘but’ or ‘however’ but may also be more hidden (Baxter 2004). In Stein’s work, for example, she expresses her own view of empathy, along with the views of Lipps, Scheler, and other significant perspectives: though she is a single ‘voice’, her work also presents the perspectives of other philosophers and theorists, giving it a multi-vocal quality.

**Presence of Dialectical Tensions**

Another area of complementarity, albeit less explicit, is in the presence of dialectical tensions. For Bakhtin, dialogue is the simultaneous integration and separation of one perspective from another. Those in the process of relating to each other, both integrate their perspectives and maintain their own individual and unique perspectives (Baxter 2011, p. 122). He referred to the presence of unifying forces, which he called centripetal forces, and divergent forces, which he called centrifugal forces, and described all areas of life as the result of experiencing the tension-filled unity arising from the simultaneous presence of these forces (Baxter 2011, p. 42). In relational dialectics, these opposing forces are central to all relationships which form a knot of many interrelated dichotomies or multichotomies (Baxter 2004). Although Stein does not give explicit focus to dialectical tensions per se, her work is based upon a number of tension-filled unities. The most obvious is the tension of individual-community.

Stein’s work in understanding the nature of community is situated upon this dialectical tension. The subject of any personal experience is the individual ego, while the subject of the communal experience is the plurality of egos\(^84\). The community does not have a pure ego and the source of the community is always the plurality of individual egos. In this way, the individual is essential for the community to exist and yet to experience the community is to enter further into its collective personality. This presents a mutually negating unity. We come to know ourselves through empathy and community with others. One cannot exist without the other, and yet one is a differentiating force, individual, and the other is a unifying force.

\(^{84}\) Recalling the earlier example from Section 3.6(b), there is *my* grief and there is *our* grief.
Stein wrote about the various types of social groupings, two of which I have previously discussed: association and community\(^85\). Stein explicitly states that all of our personal connections and relationships and actually some mixture of these ideal types (Stein 2000, p.131). However, these two ideal types are contradictory and mutually negating. A community is an organic grouping of individuals who face each other as subjects. These individuals enter into the experiences of one another and *live with one another*. The community is characterised by solidarity. On the other hand, an association is a grouping of people created for a specific purpose or goal. The individuals making up the association face each other as objects, as each person’s place within the association is based upon what he/she has to contribute (knowledge, skills, intellect, etc.) towards achieving the association’s purpose. Individuals relate to one another for the purpose of eliciting a desired reaction. The association is characterised by isolation – each person is alone. This forms a dialectical tension which, according to Stein, is present in all of our relationships with each other. This suggests a non-binary tension, or a multichotomy, in which both individual and association are negating forces against community (and vice versa).

Her work on empathy is founded upon another dialectical tension: *my* individuality – *other* individuality. In any experience, *I* am the experiencer. *I* empathise, *I* remember, etc. However, the contents of the experience may or may not be saturated with my individuality or the individuality of another. If I experience grief and the grief is *mine* (i.e. *my* mother died), then the contents of the experience are saturated by my individuality, in addition to my being the person experiencing it. However, in empathy, it is the individuality of another which saturates the contents of the experience. If I empathise with my friend who is in grief over his mother having died, then the empathetic grief is saturated with his individuality and not my own. This is primarily the case with the ‘fulfilling explication’ mode of empathy\(^86\) (i.e. wherein I am standing ‘at’ his/her place and facing the subject of the content *with* him). This presents a tension, because it is only through acts of empathy that I develop an awareness of my own individuality. It is own within acts of empathy that my nature as a psycho-physical human person is constituted for me. Thus, we see once again that this tension is in fact a unity, despite the fact that the experience of *my* individuality negates my experience of another’s individuality, and vice versa. Yet both are needed in other to understand the other. We can see how this dialectical tension could impact upon the individual-community tension and

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85 These ideas were previously presented in Section 3.6(a).
86 These ideas were discussed in Section 3.4.
association-community tension. Therefore, the subject of relational dialectics, i.e. the knot of many interrelated dichotomies and/or multichotomies, can be observed within Stein’s work.

Research studies based on RDT often refer to three supra-dialectics which are central to all interpersonal relationships: integration-separation, stability-change, and expression-non-expression (Baxter and Erbert 1999; O’Boyle 2014). However, these supra-dialectics present in ways idiosyncratic to the type of relationship, the context, and so on. Taking the dialectic of integration-separation, this refers to the tension between social solidarity and social division (Baxter and Erbert 1999). In Stein’s work, this dialectic presents itself in a multichromatic, rather than binary, manner with the tensions between community and both individual and association. It also presents at multiple levels as it presents within empathy between two people as a *my* individuality – *other* individuality dialectic, which in turn influences the higher multichromatic dialectic tension previously mentioned. In romantic couples, the integration-separation dialectic often presents as an autonomy-connection dialectic in which those involved experience a tension between desiring independence and interdependence (Baxter and Erbert 1999). Another sub-dialectic of integration-separation which has been identified among romantic dyads, friendships, and stepchild-stepparent relationships is a rights-obligations dialectic, in which a partner/friend/stepchild experiences a tension between his/her own right to have his/her needs met, and his/her obligation to fulfil the needs of the other party (Baxter et al. 1997). The supra-dialectic of stability-change also has many idiosyncratic presentations. This dialectic is typically described as a predictability-novelty dialectic in which there is a tension experienced between the need for spontaneity/uncertainty and for certainty/predictability in the relationship (Baxter 2004). The expression-non-expression supra-dialectic often arises in dyadic relationships in the form of an openness-closedness dialectical tension (Baxter 1990). This refers to the need for open and honest expression with the other half of the dyad as an opposing force to the need to maintain privacy, as absolute honesty can lead to hurt feelings, disappointment, etc. In RDT, these alterations to language to better describe the idiosyncratic presentation of dialectical tensions are encouraged (Baxter 2004; Halliwell 2015).

**INTERPLAY OF DIALECTICAL TENSIONS**

As previously mentioned, Bakhtin’s influence on RDT resulted in the emphasis on the constitutive nature of communication with both relationships and dialectical tensions themselves being constituted by communication experiences (Baxter 2004). Baxter has identified two forms of communicative interplay in which contradictions are constituted: synchronic and diachronic (Baxter 2011, pp.130-138). Those communicative activities categorised as synchronic are characterised by the co-occurrence of oppositional forces or
opposing voices at a given point in time. Diachronic communicative activities are characterised by the domination of a single-voice at a particular time or space. Competing voices are isolated from one another in an attempt to evade the inherent contradiction. These types of communicative activities are more common than synchronic activities (Baxter 2004). Two types of diachronic communication appear to be very common: spiralling inversion, and segmentation (Baxter 2004). In the former case, one contradiction or another always dominates, but these alter over time. In the latter case, one contradiction dominates over the other depending on the topic of communication.

Synchronic communicative activities have been conceptualised as potentially occurring across four dimensions: antagonistic – non-antagonistic struggle, direct – indirect struggle, serious – playful struggle, and polemical – transformative struggle (Baxter 2011, p. 131). The antagonistic – non-antagonistic struggle refers to the extent to which a discourse or system of meaning is at stake, with the stakes being higher closer to the antagonistic end of the dimension. This occurs when one (or more) discourse directly challenges the legitimacy of another discourse. The direct – indirect dimension refers to the extent to which speech is open or hidden (Baxter 2011, p. 134). Indirectness in the interplay between discourses allows for ambiguity of meaning, while directness does not. This indirectness can allow parties to avoid the direct interplay between the opposing discourses in an interplay known as disqualification (Baxter 2011, p. 134). Indirectness can also function to allow certain discourses to be marginalised by never directly responding to them – responding directly would legitimate the discourse (Baxter 2011, p. 135). The serious – playful dimension relates to the extent to which communicating parties engage in playfulness in their utterances. Playfulness can allow discourses to be challenged, by parodying them, for example (Baxter, 2011, p. 136). The final dimension, polemical – transformative struggle, refers to the potential for discourses to remain entirely negating of one another or for there to be a profound recalibration, or reframing, of the discourses such that they become complementary. The latter is often referred to as an interplay of recalibration. Discourses may also continue to be negating but find balance in a sort of discursive compromise where neither discourse is fully embraced (Baxter 2011, p. 138). Such an interplay is referred to as balance or moderation.

Stein does not consider communications with such a micro-focus. However, a number of these ways of communicating are present in her work. She addresses the dialectical tensions of individual-community, association-community, and my individuality-other individuality in a synchronic manner. Both poles of the individual-community and my individuality-other individuality tensions are wholly present at any one time and, though they are mutually negating, are often reframed as complementary: I must experience other individuality in
empathetic experience in order for my individuality to be constituted for me, and the community arises from the plurality of individual egos. She addresses the association-community dialectic through moderation, wherein all personal relationships are mixtures of these two ideal types. There is no perfect association type as in order to coax the desired reactions from members of the association, the association-person must have, at least at some point, lived in community with the members. Similarly, the community-leader must, at times, face the group members as objects to be observed in order to better lead them.

(b) Stein’s Empathy in Comparison to the ‘Aesthetic Moment’
The primary distinction between RDT and Bakhtin’s underlying theory, and that of Stein’s philosophy relates to one of her most central concepts: empathy. Bakhtin’s conception of empathy followed that of Theodor Lipps – who was arguably the most prevalent thinker on empathy at that time (Bakhtin 2011, p.64). This conception of empathy is one of ‘oneness’, wherein there is no distinction between my I and the foreign I during an act of empathy. This stands in opposition to Stein’s empathy, wherein my I is only ‘at’ the place of the foreign I, facing the object with him: there is still a distinction between my I and the foreign I. Lipps demonstrated this ‘oneness’ with an example of a spectator watching an acrobat on a tightrope (Sawicki 2001). When empathising with the acrobat, according to Lipps, I am pulled into his/her experience of walking the tightrope, such that my experience as a spectator is displaced with that of the acrobat. It is only upon the cessation of empathy that I become aware that I am distinct from the acrobat. For example, perhaps I drop my program and am recalled back to an awareness of my experience as a spectator rather than my experience on the tightrope.

Bakhtin’s agreement with Lipps’ empathy is of most significance for his views on the ‘aesthetic moment.’ This moment is one in which relating parties can create a temporary, momentary instance of wholeness, in which the many opposing forces that form social life are unified (Baxter 2004). This aesthetic moment requires: 1) empathy (Lipps’ conception of it) between parties, 2) a “return into myself” which allows me to more meaningfully understanding the other party’s experience, and 3) ‘aesthetic love’ wherein relating persons view each other as whole persons. Bakhtin’s own words emphasise the extent of his agreement with Lipps’ empathy in his consideration of the aesthetic moment.

“The first step in aesthetic activity is my projecting myself into him and experiencing his life from within him.”

(Bakhtin 2011, p. 25)
“My projection of myself into him must be followed by a return into myself, a return to my own place outside the suffering person, for only from this place can the material derived from my projecting myself into the other be rendered meaningful ethically, cognitively, or aesthetically. If this return into myself did not actually take place, the pathological phenomenon of experiencing another’s suffering as one’s own would result—an infection with another’s suffering, and nothing more.”

(Bakhtin 1990, p. 26)

Lipps’ conception of empathy is very evident in these excerpts, to the extent that Bakhtin notes that if empathy did not end, we would be infected by the foreign experience. In response to Lipps’ conception of empathy, Stein makes the following salient point:

“Were this description correct, the distinction between the foreign and our own ‘I,’ would actually be suspended… What my body is doing to my body and what the foreign body is doing to the foreign body would then remain completely obscure, since I am living ‘in’ the one [body] in the same way as the other, experience the movements of the one [body] in the same way as those of the other. This assertion is not only refuted by its consequences, but is also an evidently false description.”

(Stein 1989, p.16)

Stein goes on to emphasise the distinction between the having of the experience and the contents of the experience. Although the contents of the empathetic experience are the same for both my I and the foreign I, i.e. the experience of walking a tightrope, this experience is non-originary for me but is originary for the acrobat: though the content of the experience is the same, the sense of that experience as my experience is only present for the acrobat. Therefore, it is not possible for there to be a full experience of oneness as I am not one with the acrobat, I am only ‘at’ his place (Stein 1989, p. 16-17).

Bakhtin’s aesthetic moment, when examined against Stein’s philosophy of empathy, is the same as the experiencing of the three modes of empathy: 1) emergence of experience, wherein the foreign experience comes into view; 2) fulfilling explication, wherein the full experience unfolds and I am ‘at’ the place of the foreign I; 3) comprehensive objectification, wherein I again face the foreign experience as an object, having gained a thorough grasp of the experience. Empathy can potentially occur in any moment of relating as long as parties are open to each other. Baxter recognises the wider applicability of the ‘aesthetic moment,’ i.e. empathy, and notes its existence in friendships, familial relationships, etc. She recognises it as the basis for many types of communication, such as ‘conversational flow’ in which communication between relating parties occurs with ease (Baxter 2004).

87 Bakhtin’s three steps of the aesthetic moment were presented on the previous page.
(c) Use of Relational Dialectics Theory in the Literature

Research which has taken a relational dialectical perspective has primarily focused on various types of dyadic relationships, be they romantic (Baxter 1990; Sahlstein 2006), platonic (Brooks 2007; O’Boyle 2014), blended (i.e. a mixture of types such as work-based and platonic) (Bridge and Baxter 1992), familial (Braithwaite and Baxter 2006; Wozniak et al. 2014), etc. However, some studies have examined the dialectical tensions that exist within various types of groups including: community theatre groups (Kramer 2004), groups of in-laws (Prentice 2009), groups involved in whole-class discussion (Prentice and Kramer 2006), and small task-oriented groups (Galanes 2009). RDT is one of the most prominent theories in communications research (Halliwell 2015). Despite its popularity in this area, its use within educational research is extremely limited. Within educational research, such studies have typically focused upon various types of students’ (e.g. mature students, African-American students, first-generation students) experience of attending third-level educational institutions (Lowery-Hart et al. 2011; Simmons et al. 2013; O’Boyle 2014). Where applied within an educational context, it has also been used to examine cultural differences between lecturers and third-level students (Natalle 2012) and to investigate a superiority-equality dialectic between lecturers and students (Campbell 2008). I could identify no research within the alternative conceptions literature, or within the body of science education literature, which has adopted this theoretical lens to examine students’ experiences while engaged in learning. The adoption of this lens can shed new light on the experience of alternative conceptions, the barriers to addressing alternative conceptions, and how alternative conceptions come to be held by a plurality of individuals rather than presenting idiosyncratically for every individual.

3.8 DESIGN OF RESEARCH STUDY

(a) Purpose Statement

The intention of this two-phase mixed methods study is to: 1) describe PSSTs’ experiences of learning in a community-oriented, blended learning environment with particular attention to experiences surrounding alternative conceptions, and 2) investigate the effect of concurrent and consecutive STE models on PSSTs’ understanding of fundamental chemistry conceptions. In the first phase of this study, the relationship between the model of STE and

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88 It is common within argumentation research literature for dialectics to be discussed. However, this refers to Aristotelian ideas and revolves around the idea of resolving differences of opinion through critical testing (Van Eemeren et al. 2008), rather than referring to the interplay of tension-filled unities in our interactions with others.

89 As evidenced by the fact that learners have many of the same alternative conceptions.
PSSTs’ alternative conceptions throughout a number of third-level institutions in Ireland was investigated using a quantitative instrument. Qualitative data, in the form of interviews, were also collected in order to validate the quantitative instrument and further probe PSSTs’ understanding. PSSTs’ experiences of learning in a blended learning environment were explored in the second phase of research using a number of qualitative data types including reflective journals, social media comments, and audio-visual data of PSSTs in the learning environment. The analysis of this data maintains a focus on community and on the dialectical tensions observed within the data. A quantitative instrument was used to collect data about the effect of the blended learning programme (if any) on PSSTs’ alternative conceptions. This second phase of research took place with a group of PSSTs in one third-level institution in Ireland. The resulting findings are interpreted in light of Baxter’s RDT. Quantitative and qualitative methods have been combined in this study for two main reasons: 1) triangulation of data within each phase of research for the purpose of confirming/refuting the findings, and 2) the greater suitability of one method over the other in addressing different aspects of the research topic.

(b) Research Questions

QUESTIONS ADDRESSED BY PHASE 1

Central Question

C1. Does the model of STE (concurrent or consecutive) on which PSSTs are enrolled have an effect on the prevalence of alternative conceptions about fundamental chemistry concepts, taking into account other variables such as subject specialism, year of study (for those on the concurrent model), degree classification (for those on the consecutive model), and previous second-level school experiences?

Minor Question

M1. How do PSSTs approach conceptual questions in a quantitative alternative conceptions diagnostic instrument?

QUESTIONS ADDRESSED BY PHASE 2

Central Question

C2. How do PSSTs experience the issue of alternative conceptions in chemistry in a community-oriented, blended learning environment?

Minor Question

M2. Does a blended learning programme improve PSSTs’ understanding of fundamental chemistry concepts?
(c) Research Approach

Mixed Methods Research

Creswell and Plano Clark (2011, p. 5) identify a number of key components of mixed methods research. Mixed methods research involves the:

- rigorous collection and analysis of quantitative and qualitative data,
- mixing of both types of data in one or more of the following levels: design, data collection, data analysis, and/or interpretation (Creswell and Plano Clark 2011, pp. 66-68),
- prioritising one (or both) of these forms of data based on the research questions,
- carrying out these procedures in a single study of one or more phases,
- framing these procedures within a philosophical and theoretical lens (or lenses), and,
- combination of these procedures within a clearly defined research design that directs the research process.

A mixed methods strategy was utilised in this study. Such a strategy was deemed appropriate for this research study as the topic cannot be addressed by the sole use of either quantitative or qualitative methods. The methods are used to answer different research questions: quantitative methods are most suitable to address Research Questions C1 and M2, while qualitative methods are most suitable to address Research Questions C2 and M1.

Mixed Methods Strategy

The strategy used in this study was that of a two-phase convergent design. According to Creswell and Plano-Clark (2011, p. 70) this strategy typically involves:

- using concurrent timing in the collection of qualitative and quantitative data,
- placing equal priority on the quantitative and qualitative strands of research,
- keeping the two strands independent during data analysis, and
- the mixing of the strands in the overall interpretation of the findings.

This mixed methods strategy can be used for a number of purposes including the synthesis of complementary qualitative and quantitative results to present a more holistic understanding of the phenomenon (Creswell and Plano-Clark 2011, p. 77); this is the reason for its selection in this research study. The strategy used in this study differs in some ways from that of a traditional mixed methods convergent strategy. The main difference is that it incorporates two phases rather than the typical single phase. Each phase uses a self-contained convergent design in which there are two strands of research answering one particular set of research questions. Therefore, this could be called a two-phase convergent design. There are
a number of other differences between the traditional convergent design (as outlined by Creswell and Plano-Clark (2011, pp. 77-81)) and the two-phase convergent design used in this study as outlined in Table 3.2. The two-phase convergent design used in this study, along with the data collection methods used in each strand of research, is depicted in Figure 3.4.

| Table 3.2 Differences between the traditional convergent and two-phase convergent designs |
|---------------------------------------------|---------------------------------------------|
| Priority of Strands                        | Priority given to quantitative in Phase 1 and qualitative in Phase 2 |
| Traditional Convergent                     | Two-phase Convergent                        |
| Equal priority                             | Postpositivism and constructivism in Phase 1, and Stein’s philosophy of empathy and community in Phase 2 |
| Philosophical Foundation                   | Pragmatism                                  |

The rationale for giving unequal priority to the research strands is due to the suitability of each strand in addressing the research questions associated with the phase of research. Therefore, the research topic and questions informed this variation on the traditional design. The decision to provide an explicit philosophical foundation rather than carrying out the study under the umbrella of the pragmatist philosophy (as Creswell and Plano-Clark suggest) is based on the following rationale:

1) the objections noted earlier in this chapter regarding pragmatism (discussed in the context of critiquing the philosophical foundation of constructivism\(^{90}\)), and,

2) it was previously stated by Creswell and Plano-Clark (2011, p. 45) that “multiple paradigms may be used in mixed methods research; researchers must simply be explicit in their use”. It is the opinion of the current author that explicitly stating the philosophical position allows for better framing of the research design, data analysis methods, interpretation of findings, etc.

The major quantitative strand of Phase 1 and minor quantitative strand of Phase 2 utilised surveys and an alternative conceptions diagnostic instrument. The purpose of these research tools was to collect data that could address Research Questions C1 and M2. These research questions involve the investigation of the relationship between a number of variables and, therefore, quantitative instruments are the most appropriate tool. Quantitative instruments have previously been used in the research literature to investigate learners’ alternative conceptions\(^{91}\). Therefore, a quantitative alternative conceptions diagnostic instrument can be used for this purpose. This instrument was developed during the research study.

\(^{90}\) Referring to ‘Philosophical Background to Dewey’ in Section 3.1(b) and to Section 3.2(a), in particular. The main criticism is that it suggests that questions regarding whether, or how well, a person’s mental representations can reflect reality are of no value. It therefore places little value on objectivity.

\(^{91}\) This was previously discussed in Section 2.4(a).
Research Questions M1 and C2 seek to explore PSSTs’ attitudes, thought processes, and lived experiences of learning and recognising alternative conceptions. Therefore, qualitative research tools were the most appropriate to address these questions. Semi-structured interviews were used in Phase 1 to investigate PSSTs’ approaches when responding to a quantitative instrument. The interviews also provided a way to validate the quantitative alternative conceptions diagnostic instrument used in the research study. Research Question C2 is far more exploratory than M1; therefore, open research tools were used such as audio-visual recordings of PSSTs learning in the blended learning environment, reflective journals about their experiences of learning, and comments made through social media. Audio-visual data is recognised as an under-utilised investigative tool in qualitative studies that has significant potential in this research area (Heath et al. 2010).

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92 The diagram follows the convention, described in Creswell and Plano-Clark (2011), of representing a major qualitative or quantitative strand of research as ‘QUAL’ or ‘QUAN’, respectively, and representing the minor strands as ‘qual’ or ‘quan’.
As Heath et al. note:

“If the key principle of qualitative research is taking the participant’s perspective seriously… then a technology that enables the repeated, fine-grained scrutiny of moments of social life and sociability would seem to provide, at worst, a complement to the more conventional techniques for gathering ‘scientific’ information, at best, a profound realignment in the ways in which we analyse human activity.”

(Heath et al. 2010, p. 2)

This potential for “a profound realignment” in how we view human activities and interactions makes this form of data very complementary with an underlying philosophy which focuses intensely upon these activities and interactions. Furthermore, given the body of literature already available regarding the problem of alternative conceptions in chemistry, and science in general, perhaps such a realignment can provide a fresh perspective that has not been previously considered. Therefore, the audio-visual data is the central component of the major qualitative strand of this research study, with social-media and reflective journal data used to add further insight.

3.9 DATA COLLECTION

(a) Population and Sample Groups

The population under investigation in this study are PSSTs enrolled in consecutive or concurrent models of STE in Ireland. All PSSTs were included in the population (rather than just those specialising in chemistry) as, in Ireland, teachers from any science background are qualified to teach lower-second-level science (which includes concepts in the disciplines of biology, chemistry and physics). PSSTs following the concurrent STE model in Ireland undertake courses in general chemistry regardless of their subject specialisation for this reason. These general chemistry courses revise the content of the upper-second-level chemistry syllabus in order to give PSSTs a good grounding in chemistry. PSSTs following the consecutive model of STE have undertaken a degree in some science discipline. These degree programmes usually include general chemistry (and other chemistry modules) in their first year. As a result, PSSTs have studied chemistry at third-level education and all will be qualified to teach lower-second-level chemistry. Therefore, Irish PSSTs that were to receive a qualification to teach lower-second-level science on completion of their STE programme were the target population for the study.

93 A selection of such courses includes those in Dublin City University and in the National University of Ireland, Cork, e.g. the Bachelors of Science in: Biotechnology (Dublin City University 2016b), Genetics and Cell Biology (Dublin City University 2016a), Nutritional Sciences (University College Cork 2016a), Genetics (University College Cork 2016b), and Physiology (University College Cork 2016c).
Four sample groups were involved in this study, three in Phase 1 and one in Phase 2;

1) In developing the diagnostic instrument, a sample of PSSTs was required that would agree to pilot the instrument. These will be referred to as the Pilot Sample,

2) A group of PSSTs were also needed that would agree to be interviewed about their approach to answering a diagnostic instrument (Research Question M1) and also to validate the instrument. This group shall be referred to as the M1 Sample;

3) Addressing Research Question C1 involved administering the research tool to PSSTs across concurrent and consecutive STE models and many STE courses. This research sample shall be referred to as the C1 Sample;

4) In investigating the experience of PSSTs in a blended learning environment and the impact of blended learning on PSSTs’ alternative conceptions, i.e. addressing Research Questions C2 and M2, a sample of PSSTs were needed. This sample group will be referred to as the C2-M2 Sample. This sample was split into a Blended Learning Group, that joined the blended learning programme as an addition to their STE programme, and a Conventional Group, that experienced only the STE programme.

(b) Sampling Method and Data Collection

Two non-probability sampling methods were used in this study: convenience sampling and volunteer sampling. Convenience sampling was used to form the Pilot and C1 Samples. The Pilot Sample agreed to pilot the initial $\alpha$-version of the alternative conceptions diagnostic instrument. The C1 Sample agreed to the assessment of their alternative conceptions using the final $\beta$-version of this instrument. The Pilot Sample comprised 212 PSSTs undertaking concurrent STE programmes in a single STE institution. The total number of PSSTs in this institution was 274. These programmes are of four years’ duration and PSSTs were to be from each year of study. The C1 Sample was to be derived from the 916$^{94}$ PSSTs enrolled in any STE institution in Ireland at the time of the study; there were seven consecutive and six concurrent STE programmes. PSSTs were recruited for the Pilot and C1 Samples during scheduled lecture or laboratory times with the permission of the relevant lecturers. Both samples were comprised of PSSTs that were: 1) in attendance at these lectures or laboratories, and 2) gave their informed consent to take part in the study. The strength of such a data collection process is the consistency in which the instrument is administered; the instructions, procedure and setting were similar for each group of PSSTs. This consistency

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$^{94}$ This figure is based on each lecturer’s report on the number of PSSTs enrolled in the relevant teacher education programme in that year.
was considered important as one of the purposes of the instrument was to allow for comparison between consecutive and concurrent models of STE.

The convenience sampling method was used for the Pilot and C1 Samples as it would not have been possible to identify all the individuals in the population prior to sampling; there is no available list of members of the population from which to carry out a probability sampling method. In order to carry out a probability sampling method, such a list would first need to be compiled. This would have been: time consuming, and unethical to create without each member’s consent. The advantage of convenience sampling is that it is an inexpensive and time-saving technique. The disadvantage associated with convenience sampling is that bias can be introduced (Cohen et al. 2007, pp. 113-114); PSSTs in attendance at lectures and laboratories may be more highly motivated than those not in attendance. Therefore, the findings may be reflective of a more motivated group of PSSTs than if a probability sampling technique had been used.

Volunteer sampling was the method used to form the M1 Sample and the C2-M2 Sample. In creating the M1 Sample, PSSTs from the Pilot Sample were contacted by email and asked if they would take part in a one-to-one interview about the diagnostic instrument. The M1 Sample was comprised of PSSTs that responded to this email, and gave their informed consent to participate in this aspect of the study. From the possible 212 PSSTs that composed the Pilot Sample, seven met these criteria and volunteered to form the M1 Sample. PSSTs for the C2-M2 Sample (comprising the Conventional and Blended Learning Groups) were recruited from PSSTs in a single STE institution during a scheduled lecture. PSSTs were informed about the relevant aspect of the study (the blended learning programme) and asked if they would like to experience the blended learning programme and, if not, whether they would agree to form the Conventional group. 45 PSSTs volunteered to participate in the blended learning programme and seven agreed to participate in the Conventional group only. In order to obtain approximately equal numbers in each group, 30 PSSTs were randomly selected from the 45 PSSTs that volunteered to participate in the blended learning programme. This provided a total of 52 PSSTs in the total C2-M2 Sample: 30 in the Blended Learning Group and 22 in the Conventional Group.

Volunteer sampling was selected for the M1 Sample and, in particular, for the C2-M2 Sample as a deeper involvement in the study was required. The M1 Sample were to take part in a semi-structured interview of between 30 and 60 minutes’ duration to validate the diagnostic instrument and to discuss their thoughts and strategies in answering the items on the instrument. This required a willingness to admit errors, difficulty in understanding the items,
and/or difficulty in understanding the content of the instrument. It was considered that such a willingness was best supported by their desire and commitment to take part in the research. The C2-M2 Sample consisted of a Blended Learning Group and a Conventional Group. Commitment was required on the part of the Blended Learning Group to attend face-to-face sessions that were not part of their STE programme and would not count for any credit on these programmes, as well as a willingness to try out new ideas and maintain online contact with other PSSTs and the researcher over a period of seven months. Those forming the Conventional Group also needed to provide a commitment to further data collection seven months after the initial data collection. Such high levels of commitment could only be supplied by volunteers. However, the disadvantage of this form of sampling is that the group may not be representative of the PSST population. Motivation may be very different between those taking part in the study and the general population for the following reasons:

1) those in attendance at the recruitment lecture may be more motivated than those not in attendance, and,

2) those volunteering to take part in the Blended Learning Group may be more motivated than those volunteering to form only the Conventional Group.

(c) Details of the Sample Groups

**PILOT SAMPLE**

This sample comprised 212 PSSTs on concurrent STE programmes in one institution. PSSTs in their first (68 PSSTs), second (61 PSSTs), third (32 PSSTs) and fourth (51 PSSTs) years of study were included. The sample consisted of 35% (74 PSSTs) male and 65% (138 PSSTs) female PSSTs; 48 of the PSSTs (23%) had not studied upper-second-level chemistry, 4 (2%) had studied ordinary level chemistry and 122 (58%) had studied higher-level chemistry.

**C1 SAMPLE**

The age and gender profile of the C1 Sample is outlined in Table 3. The majority of participants were female and under 25 years of age. The concurrent group displays a lower age profile than the consecutive group. They were studying for their undergraduate degrees and most entered directly from upper-second-level education. The majority of those on consecutive courses were also under 25 years, as many of these PSSTs came straight from a three- or four-year science degree. The gender balance is similar for the two models of STE with females accounting for about 70% of all PSSTs. Approximately half of all PSSTs (52%)

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95 The remaining 38 PSSTs did not provide this information.
had studied upper-second-level chemistry, while 45% had not studied chemistry at upper-second-level. Within the concurrent model 35% (112) of PSSTs were specialising in teaching chemistry and 22% (31) of PSSTs in the consecutive model were specialising in chemistry.

<table>
<thead>
<tr>
<th>Table 3.3 Age and gender profiles for participants on consecutive or concurrent programmes96</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Cohort</strong> (n = 467)</td>
</tr>
<tr>
<td><strong>Consecutive Model</strong></td>
</tr>
<tr>
<td>31% (144)</td>
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<tr>
<td></td>
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<tr>
<td><strong>Concurrent Model</strong></td>
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<tr>
<td>69% (323)</td>
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<td></td>
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</tbody>
</table>

M1 SAMPLE

The M1 Sample included seven PSSTs. All were specialising in chemistry and either physics or biology. Table 3.4 shows the profile of these PSSTs. The names used are pseudonyms.

<table>
<thead>
<tr>
<th>Table 3.4 Profile of the M1 Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pseudonym</strong></td>
</tr>
<tr>
<td>Brendan</td>
</tr>
<tr>
<td>Eamon</td>
</tr>
<tr>
<td>Eileen</td>
</tr>
<tr>
<td>Patricia</td>
</tr>
<tr>
<td>Nora</td>
</tr>
<tr>
<td>Deirdre</td>
</tr>
<tr>
<td>Anne</td>
</tr>
</tbody>
</table>

C2-M2 SAMPLE

The profile of the PSSTs in the C2-M2 sample with respect to age, gender, and specialism in teaching chemistry is provided in Table 3.5. The proportion of PSSTs specialising in teaching chemistry in their STE programme is approximately equal for the Conventional and Blended Learning Groups. All PSSTs were in the autumn semester of their second year of study on an STE programme in one institution. They were due to undertake their first Teaching Practice in the spring semester of the same academic year. The gender profile of the groups differs, with the Conventional Group comprised almost equally of both male and female PSSTs, while the Blended Learning Group was dominated by female PSSTs.

96 Where percentages do not account for the total cohort (i.e. do not add up to 100%), this is due to the fact that all participants did not respond to all questions.
Table 3.5 Profile of the C2-M2 Sample

<table>
<thead>
<tr>
<th>Role in Study</th>
<th>Mean Age (SD)</th>
<th>Gender (% within role)</th>
<th>Specialism (% within role)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Group (n = 22)</td>
<td>20.47 (2.20)</td>
<td>Male (45.45%)</td>
<td>Chemistry Specialism (72.73%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female (54.55%)</td>
<td>No Chemistry Specialism (27.27%)</td>
</tr>
<tr>
<td>Blended Learning Group (n = 30)</td>
<td>20.49 (5.68)</td>
<td>Male (20.00%)</td>
<td>Chemistry Specialism (76.67%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female (80.00%)</td>
<td>No Chemistry Specialism (23.33%)</td>
</tr>
</tbody>
</table>

(d) Ethical Considerations

Ethical issues surround a balance between a desire to rigorously pursue the answers to research questions and respecting the rights and values of participants involved in the research (Cohen et al. 2007, p. 51). In the first phase of this research study, many PSSTs from institutions across Ireland were involved. Therefore, there were two types of participants: individual PSSTs, as well as the institutions which they attended. Research Question C1 involved an investigation of the potential impact of the model of STE on PSSTs’ alternative conceptions, while taking other variables into account. Early in the research study, I had considered taking the educational system into account (i.e. whether participants were in the Republic of Ireland or Northern Ireland educational systems). Given that only a single consecutive STE institution is situated in Northern Ireland, to do so would have identified the results of the alternative conceptions diagnostic instrument for PSSTs attending that institution. This would have been unethical and would have resulted in the findings of this study being used for the purpose of comparison between specific institutions, which was never my intention. Therefore, ethical considerations shaped the nature of this research study from its inception.

A number of steps were taken in order to protect the PSST participants in this study, including: following the University of Limerick regulatory ethics framework, obtaining ethical approval from the University of Limerick Research Ethics Committee (ULREC)\(^97\), obtaining informed consent from all individuals in each sample, maintaining the confidentiality of data collected from all of the study participants, and maintaining the anonymity of all quantitative data collected in the Pilot, C1, and C2-M2 Samples\(^98\). Anonymity was provided for through the use of a ‘Gate Keeper.’ Each consent form was numbered, along with the quantitative instrument that was attached to it. The Gate Keeper collected the consent forms, in which the participant was identified, while I collected the quantitative instrument, in which there was no indication of the participant’s identity. The

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\(^97\) The ULREC identification codes for ethical approval are: S&E11/66 and S&E12/23

\(^98\) Given that face-to-face interviews were carried out with the M1 Sample as they examined their responses to the alternative conceptions diagnostic instrument, anonymity could not be provided in this case. However, this data was only de-anonymised after they had given their consent.
Gate Keeper never had access to the data, and I never had access to the consent forms. This ensured that neither of us could link an identity to a quantitative instrument. This approach was used for all quantitative data in the study. The confidentiality of all data, both quantitative and qualitative, was also maintained. As such, names provided in this thesis are pseudonyms. Data was stored on a password-protected computer and backed-up to an encrypted hard-drive. A sample of the style of information sheets and consent forms used in this study are provided in Appendix A.

3.10 **SUBATOMIC BLENDED LEARNING PROGRAMME**

The SuBATOMIC (Supporting Better Activities To Overcome Misconceptions In Chemistry) blended learning programme was carried out in Phase 2 of this research study. A blended learning programme was selected for two main reasons:

1) the findings of the literature review, presented in the previous chapter, suggested that the potential for blended learning as a strategy to improve conceptual understanding and reduce the prevalence of alternative conceptions has not been investigated, and,

2) Stein’s philosophy highlights the need for time to be dedicated to developing understanding among groups of learners. As it may not be possible to allow for such time in a face-to-face setting, the combination of face-to-face and online communication is a plausible way to allow for more time in communication.

The programme was influenced by the qualitative findings of Phase 1 of the study and by the associated search for an alternative philosophical foundation. As such, the desire to create a community-oriented group of learners was central to the development of SuBATOMIC. The programme was participated in by the Blended Learning Group from the C2-M2 Sample and it was carried out concurrently with their STE programme.

(a) **Outline of the Programme**

The Blended Learning Group from the C2-M2 Sample took part in the SuBATOMIC learning programme from the beginning of October in 2013 until the end of April in 2014. All components of the study did not take place for the entire seven months and an outline of the timing of the programme, in relation to their STE programme and Teaching Practice (TP), is shown in Figure 3.5. The face-to-face component took place over seven weeks at the beginning of the programme. The online component began simultaneously but continued on until the end of April – after they had completed their TP. During the PSSTs’ winter break from their STE programme, the SuBATOMIC programme also went on hiatus.
The two components of the SuBATOMIC programme were a face-to-face and an online component. The online component comprised the materials on the SuBATOMIC website and communication on Facebook. The face-to-face component consisted of six sessions which took place over seven weeks. The Blended Learning Group was divided into two groups and the same session was run twice: once for each group. This decision was made in order to provide sufficient facilitator interaction to each small-group of three-to-four PSSTs. Each of the six sessions was of 50 minutes’ duration. The same session was run on a Monday afternoon at 2-3pm and a Wednesday evening from 5-6pm. Each session was composed of an opening exposition of approximately 10 minutes’ duration, 30–35 minutes of small-group work and a 5 minute closure. Therefore, PSSTs experienced a total of 3–3.5 hours of discussion in small groups.

(b) SuBATOMIC Face-to-Face Sessions
There were six face-to-face sessions in the learning programme. Small-group learning was the primary teaching and learning approach used in these sessions, and the same group composition was used in each session 99. The development of social presence is a central aspect of creating a community of learners, and one element of this is the development of cohesion between group members (Garrison and Vaughan 2008). The small-group approach was considered to be appropriate for the face-to-face sessions given that it has been shown

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99 With the exception of one session – this is clarified on Table 3.6.
to encourage cohesiveness (Slavin 1996; Johnson and Johnson 1999; Shachar and Sharan 1994). In these sessions, I, and the tasks which I developed, approached the participants in their roles as PSSTs. The conversation typically took the perspective that the PSSTs were preparing for their TP and, as part of this, that they would need to address the alternative conceptions of their future students. As a result, the tasks carried out by the small-groups involved creating resources that they, or their peers in the wider-SuBATOMIC group, could use on TP to address their students’ misunderstandings. Alternatively, they were asked to create explanatory materials for the SuBATOMIC website which could help their peers to revise their understanding prior to teaching a topic on TP. Any appropriate resources which were created by the groups were adapted in terms of content and appearance and added to the website. This approach created an underlying goal for the SuBATOMIC group of advancing the collective knowledge, which is essential for the creation of a learning community (Bielaczyc and Collins 1999). The decision to approach the participants in their role as PSSTs served two purposes: 1) it allowed for the creation of authentic tasks for the small groups, and 2) it ensured common learning goals for the wider group. These were considered important to achieve given that part of what lends to the development of community is a common learning goal and shared values (Rovai 2002).

As a result of these design decisions, each face-to-face session typically involved a brief exposition about a teaching and learning approach in the alternative conceptions research literature that has been used to address, or uncover, the alternative conceptions of learners, e.g. concept cartoons. The advantages and disadvantages of the particular approach were discussed before the groups were given instruction on their task for the session, which usually involved creating a teaching resource, based on the approach that had been discussed, in an area of the Junior Certificate chemistry syllabus. For example, one task was to create a concept cartoon in the area of ‘Water and Solutions.’ Examples of resources from, or based on the research literature, were always provided. Often, I provided examples of resources which I had created and showed these at each stage of the progression of the resource in order to further clarify the task. Depending on the complexity of the task, varying amounts of scaffolding were provided. Basic instructions for creating the resource were always included on PowerPoint™ and displayed for the duration of small-group work. However, in some cases the task was more open-ended and a ‘Task Sheet’ was provided which included suggested online learning resources, a suggested series of task steps in the form of ‘Guiding

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100 The graphic design software Adobe Illustrator™ was used for this purpose, such that the materials which they created would have a professional appearance.

101 That is, the chemistry section of the science syllabus for lower-second-level students in the ROI.
Questions,’ and other useful ideas such as search terms to aid them in locating relevant information on the web. In every session, the small-groups produced a written artefact which they provided to me to adapt for the SuBATOMIC website.

An outline of the face-to-face sessions and the types of small-group tasks involved in each session is provided in Table 3.6.

<table>
<thead>
<tr>
<th>Session No.</th>
<th>Session Title</th>
<th>Detail of small-group task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Setting the Context</td>
<td>This session was introductory. It contained a number of ice breakers, negotiation on the rights and responsibilities of the facilitator and participants, and discussion of expectations of group work.</td>
</tr>
<tr>
<td>2</td>
<td>Concept Cartoons</td>
<td>Groups created a concept cartoon, in the area of either ‘Water and Solutions’ or ‘Materials’.</td>
</tr>
<tr>
<td>3</td>
<td>Diagnostic Questions</td>
<td>Groups created two diagnostic questions, in the chemistry area which they did not work in during the previous session. They then developed a teaching idea to address any alternative conception used in their diagnostic questions.</td>
</tr>
<tr>
<td>4</td>
<td>Cooperative Learning Part 1</td>
<td>The group modelled cooperative learning. A different group composition was used in this session as ‘Expert groups’ were created. These ‘Expert groups’ wrote a revision sheet for their peers to use prior to a teaching a lesson in the area of covalent, ionic, or intermolecular bonding.</td>
</tr>
<tr>
<td>5</td>
<td>Cooperative Learning Part 2</td>
<td>Groups returned to their original compositions and wrote down the bonding rationale for differences in the behaviour of chemical substances. Questions were provided to them which would require input from the various ‘experts’ e.g. why does ethanol have a higher boiling point than n-pentane? Why does graphite conduct electricity but diamond does not? etc.</td>
</tr>
<tr>
<td>6</td>
<td>Concept Mapping</td>
<td>Groups modelled the use of concept maps by creating a concept map based on the question: ‘what types of chemical bonds are there and how do they form?’</td>
</tr>
</tbody>
</table>

Embarrassment and shame on the part of PSSTs was considered to be a potential barrier to open communication and the development of community in this study. This arose as a result of the qualitative semi-structured interviews, which took place in Phase 1. During these interviews, embarrassment, and other negative self-perceptions, were found to be an issue for PSSTs while they discussed their understanding. In other research areas, issues associated with embarrassment, shame or stigma have been shown to be normalised or destigmatised through the open sharing of personal stories or experiences (Kilinc and Campbell 2009; Millen and Walker 2014). Seeing others also engaging in the stigmatised behaviour, or others leading by example, can also be a factor in breaking down barriers (Leahy-Warren et al. 2016), as can placing emphasis on the prevalence of the embarrassing/shame-inducing

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102 This will be discussed in Chapter 8.
issue (Smith 2002; Waller et al. 2007). In facilitating the SuBATOMIC learning programme, I presented the issue of alternative conceptions as one that is prevalent and normal. I emphasised the absence of the need for any blame or shame, particularly at the outset of every face-to-face session. I also shared stories with the participants of the study about my own experiences of uncovering my alternative conceptions. I tried to keep these stories as recent as possible in my own education. For example, a story I shared with them was one in which I had created an alternative conceptions diagnostic question about a topic, but I had an alternative conception about that very topic – which was discovered by a peer in a very embarrassing experience! These stories could also build a trusting environment; I made myself as vulnerable as I was asking them to become and presented opportunities for empathy and understanding. Participants often responded to these stories with empathetic responses or admitted that they had the same alternative conception that I once had. These approaches were used in both the online and face-to-face components of the study.

(c) Online SuBATOMIC Component

The online learning component of SuBATOMIC involved the use of a website designed for this study (www.subatomic.ie) and a Facebook™ group for online discussions. There were a number of other configurations that could have been used for online learning, such as a Course Management System (CMS) like Moodle™. One of the factors that is essential for sustaining community in online environment is regular interaction (Garrison and Vaughan 2008). Participation in online discussion environments is impacted upon by the usability, i.e. the ease of use, of the technology being used (Sánchez and Hueros 2010). PSSTs, and third-level students in general, have been found to show a preference for Facebook for educational discussion and peer support (particularly during TP) compared with alternative CMSs (English and Duncan-Howell 2008; Schroeder and Greenbowe 2009; Deng and Tavares 2013). The main advantage of traditional CMSs is the ability to upload materials for discussion. However, Facebook also offers the ability to do this and links can also be provided to other online materials when posts are created (Facebook 2016). Furthermore, learners perceive traditional CMSs to be quite formal and, therefore, spend more time crafting formal responses. However, their perception of Facebook lends to more frequent, less formal interactions (Deng and Tavares 2013). Therefore, Facebook was the communication technology of choice for the programme. A ‘secret’ Facebook group was created and used for this purpose.

---

103 This feature ensures that only members of the group can access or view posts within the secret group. Furthermore, the posts are not included in search engines, ensuring total privacy.
A website was also designed and developed for this study. As was the case with the face-to-face sessions, and the communications on Facebook, the website was focused upon the participants in their role as PSSTs. A sitemap of the top three levels of the website is shown in Figure 3.6. The website section ‘Topics’ also had a fourth level, i.e. each topic, such as ‘Materials,’ had sub-pages. The titles of the fourth-level webpages for one of these topics is shown in Figure 3.7. The titles of fourth-level webpages were the same for most topics.

Figure 3.6 Sitemap showing first-, second-, and third-level webpages for the SuBATOMIC website

An outline of the main sections of the website is provided in Table 3.7. The content of the website was updated and expanded over the duration of the study. The content was based on my own and the participants’ thoughts about their needs. For example, the majority of the ‘Teaching Tips’ section arose from the needs expressed by the group, and many of the resources added to each topic area were based on the small-group work task products from 104. A username and password to access the website are provided in Appendix B. The website continues to be available only to users given that research literature is directly available on the website. This was considered unproblematic in the context of the study given that all papers were available to the study participants in the university’s library already but it makes it unsuitable for public access.
the face-to-face sessions and participants’ ideas on their TP. As new sections, resources, ideas, etc. were added to the website, links were added on the Facebook group to inform participants and start discussions.

![Diagram of SuBATOMIC website](image)

**Figure 3.7** Fourth-level webpages for the 'Topics' section of the SuBATOMIC website

**Table 3.7** Outline of each main section of the SuBATOMIC website

<table>
<thead>
<tr>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topics</strong></td>
<td>This section was designed to be the go-to area for PSSTs prior to teaching a chemistry topic on the Junior Certificate science syllabus. Topics contained common alternative conceptions, a section for PSSTs to revise their own understanding, diagnostic questions to allow them to revise their understanding, suggested teaching activities, teaching and learning resources, and an outline of the relevant portions of the syllabus.</td>
</tr>
<tr>
<td><strong>Research</strong></td>
<td>This section was designed to be an area that informed PSSTs of research in science education more generally. Research was presented with a focus on practical outcomes of the research and contained my own images and teaching suggestions. This section also often provided instructions for creating resources based on the research under discussion.</td>
</tr>
<tr>
<td><strong>Teaching Tips</strong></td>
<td>This section was more focused on teaching in general. Tips were sought from experienced teachers. General practicalities that were issues for the PSSTs were also added to this section, i.e. embedding YouTube videos and planning lessons. This section also provided science education research studies that contained practical teaching advice (in any area of science) for download. Comments were added to direct the PSSTs to the relevant portion of the study in an effort to reduce the barriers to using research.</td>
</tr>
<tr>
<td><strong>About Us</strong></td>
<td>This was a very short section containing basic information about the researchers involved in the study.</td>
</tr>
</tbody>
</table>
Discussions on Facebook could be in relation to any aspect of teaching and learning. PSSTs were never constrained in their choice of discussion topic, which ranged from pedagogical discussions of website materials, to their experiences in lectures, or to discipline and teaching advice while on TP. I participated in the Facebook group frequently and took the same approach to communication as I took in face-to-face sessions, e.g. sharing personal stories of my own teaching and learning experiences.

**CONCLUSION**

This chapter and that preceding it, provide the background and foundations to this research study. As the study progressed, the research questions and direction of the study changed along with my own perspective as a researcher. This led to a change in philosophical underpinning, a change from a major quantitative research strand in Phase 1 to a major qualitative strand in Phase 2, and a change from the original orientation of ‘fixing’ alternative conceptions to one of investigating the experiences of PSSTs as they become aware of their misunderstandings. The extent to which philosophy was considered and used to direct the research questions and design is one of the strengths of this study. The re-discovery of the philosophy of Edith Stein and the application of Relational Dialectics Theory to provide insight into PSSTs’ experiences is one of the unique contributions of this research. This thesis is, generally, presented according to this shifting perspective with all quantitative methods, results, and discussion being presented together, before introducing the qualitative findings.
Part II
Quantitative Strands
Chapter 4  Methodology
The major strand of research in Phase 1 of this study, and the minor strand of research of Phase 2, use quantitative research tools and quantitative data analysis methods in an attempt to address Research Questions C1 and M2. Given the reliance on only quantitative research methods to answer these research questions, a comprehensive account of these methods is provided in this chapter. This account includes an outline of all quantitative research tools used in this study and how they were combined when administered. Particular attention will be paid to the development of the primary quantitative research tool – an alternative conceptions diagnostic instrument – which was used in both phases of the study. The next chapters, Chapters 5 and 6, present the quantitative results of Phases 1 and 2 of the study. These chapters, particularly Chapter 5, rely upon descriptive and inferential statistics, many of which require assumption-testing in order to ensure that any results obtained are valid. Therefore, the analytical methods used in the quantitative research strands will be outlined in detail in this chapter, along with the assumptions of each statistical test. Sections within this chapter will be referenced in the chapters that follow to ensure the clarity of the various procedures, while avoiding repetition.

4.1 QUANTITATIVE RESEARCH TOOLS
A number of research tools were used over the course of this study and combined according to the purpose of the quantitative data collection. Some of these research tools were surveys: Demographic Survey, SuBATOMIC Website Survey, Science Education Research Survey and Motivated Strategies for Learning Questionnaire. In the case of the Demographic Survey, the purpose was to collect background information about those participating in the research study. The Motivated Strategies for Learning Questionnaire (MSLQ) was used to assess the comparability of the Conventional Group and Blended Learning Group in the C2-M2 Sample. The purpose of the other two surveys was more informal – to collect information that would inform the development of the online website component of the SuBATOMIC programme. The main data collection research tool is an alternative conceptions diagnostic instrument. This research tool was designed to contribute to addressing the research questions and, as such, a more rigorous development procedure was required. Each of these research tools will be discussed, as well as the manner in which they were combined at different stages of quantitative data collection.

105 This sample group was previously described, along with the other sample groups, in Section 3.9(c).
(a) Overview of Research Tools

The Demographic Survey collected information about PSSTs’ STE model, previous upper-second-level school experience, gender, subject specialism, year of study (for those studying on concurrent programmes) and degree classification (for those studying on consecutive programmes). Depending on the research purpose, the specific information collected varied; for example, PSSTs’ STE model was included in the survey for Phase 1, as PSSTs involved were studying on either consecutive or concurrent models of STE, but was not included in Phase 2, as all PSSTs involved were studying on concurrent STE programmes. The SuBATOMIC Website Survey was a basic survey designed to obtain PSSTs’ views on the type of information that they would consider useful to include on the SuBATOMIC website. This was administered during Phase 2 of the research study. Its purpose was to determine PSSTs’ interest in using the website and to inform the development of the website. The Science Education Research (SER) Survey was used to determine what value PSSTs in the C2-M2 Sample placed on SER and how often they engaged with SER. The main purpose was to assess the comparability of the Blended Learning and Conventional Groups in the C2-M2 Sample in terms of their exposure to SER. It also served to inform the researcher about how to introduce PSSTs to SER as part of the blended learning programme. This survey was again administered at the conclusion of the study as an interesting exploratory aspect in order to investigate whether PSSTs’ perceived value and exposure to SER had changed over the course of the research.

The MSLQ was used to determine whether there were any significant differences in terms of the motivation and learning strategies used by those PSSTs that formed the Conventional and Blended Learning Groups of the C2-M2 Sample. This questionnaire utilises seven-point Likert rating scales and has been found to be valid and reliable (Pintrich et al. 1991). The alternative conceptions diagnostic instrument was developed as part of this research study. The purpose of the instrument was to determine PSSTs’ conceptual understanding of fundamental chemistry concepts. It included four conceptual areas: particulate nature of matter (PNM), chemical bonding, stoichiometry, and equilibrium. The details of the development and analysis of each item of the instrument will be presented in Section 4.2.
(b) Stages of Research Tool Use
In order to answer Research Question C1, a pencil-and-paper instrument was created\textsuperscript{106}. This was administered during Phase 1 of the research. The sections of the instrument were as follows:

- Section A: Demographic Survey, and
- Section B: alternative conceptions diagnostic instrument.

At the beginning of Phase 2 of the research, a pencil-and-paper research tool was used to:
determine whether PSSTs in the Conventional and Blended Learning groups were comparable, and inform the development of the blended learning website. The research tool consisted of the following sections:

- Section A: Demographic Survey,
- Section B: SuBATOMIC Website Survey,
- Section C: Science Education Research Survey, and
- Section D: Motivated Strategies for Learning Questionnaire.

At the end of Phase 2 of the study, a pencil-and-paper research tool was required that could address Research Question M2. The sections of the instrument were as follows:

- Section A: Demographic Survey,
- Section B: Science Education Research Survey, and
- Section C: alternative conceptions diagnostic instrument.

The independent and dependent variables associated with each of the quantitative research questions (C1 and M2) are shown in Table 4.1. Where relevant, the abbreviations of variable names used to present data in Chapters 5 and 6 have also been provided.

(c) Adaptation of the Motivated Strategies for Learning Questionnaire
A questionnaire was required which could determine whether there were any significant differences in terms of the motivation and learning strategies used by those PSSTs that formed either the Conventional or Blended Learning Groups of the C2-M2 Sample. The MSLQ was adapted for this purpose. The MSLQ is an 81-item instrument comprising six subscales on motivation and nine subscales on learning strategies. Of these scales, four motivation subscales and seven learning strategy subscales were included in the instrument.

\textsuperscript{106} This instrument and all others described here are available in Appendix C.
<table>
<thead>
<tr>
<th>Research Question</th>
<th>Independent Variables</th>
<th>Abbreviated Independent Variable Names</th>
<th>Dependent variables</th>
<th>Abbreviated Dependent Variable Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Model of STE</td>
<td>STEModel</td>
<td>Score in PNM section of alternative conceptions diagnostic instrument</td>
<td>PNM</td>
</tr>
<tr>
<td></td>
<td>Concurrent year of study</td>
<td>ConeYear</td>
<td>Score in chemical bonding section of alternative conceptions diagnostic instrument</td>
<td>ChemBond</td>
</tr>
<tr>
<td></td>
<td>Degree classification of previous science degree for consecutive PSSTs</td>
<td>ConsecDegree</td>
<td>Score in stoichiometry section of alternative conceptions diagnostic instrument</td>
<td>Stoichio</td>
</tr>
<tr>
<td></td>
<td>Subject specialism in chemistry</td>
<td>ChemSpec</td>
<td>Score in equilibrium section of alternative conceptions diagnostic instrument</td>
<td>Equilib</td>
</tr>
<tr>
<td></td>
<td>Study of upper-second-level chemistry</td>
<td>USLChem</td>
<td>Total score in alternative conceptions diagnostic instrument</td>
<td>TotScore</td>
</tr>
<tr>
<td></td>
<td>Level of study of upper-second-level mathematics</td>
<td>USLMath</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Study of upper-second-level physics</td>
<td>USLPhysics</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Awareness of the issue of alternative conceptions in chemistry</td>
<td>Aware</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M2</td>
<td>Subject specialism in chemistry</td>
<td>ChemSpec</td>
<td>Same as for Research Question C1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Study of upper-second-level chemistry</td>
<td>USLChem</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Level of study of upper-second-level mathematics</td>
<td>USLMath</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Previous grade achieved in third-level chemistry module</td>
<td>PrevChemGrade</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Motivation</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Learning strategies</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The MSLQ scales were adapted to increase their appropriateness for use in the research study. In two cases, one statement was removed from the original MSLQ scale as it was considered inappropriate to the context. The statement *when I have the opportunity in this class, I choose course assignments that I can learn from even if they don’t guarantee a good grade* was removed from the Intrinsic Goal Orientation scale as in most institutions in Ireland a student cannot choose their assignments in chemistry. The statement *considering the difficulty of this course, the teacher, and my skills, I think I will do well in this class* was removed from the Self-Efficacy for Learning and Performance scale because the students had been asked to respond with their last third-level chemistry module in mind. Therefore, their grade was already known to them, thus, removing the element of anticipation. All other scales remained intact. A general change was made to every statement on the scale to increase its appropriateness, the term ‘this class’ or ‘this course’ was changed to ‘a class’ or ‘the class’; this was because data was collected during a non-chemistry course time and PSSTs were asked to apply each statement to their last chemistry module.

These changes, though minor, may affect the reliability of the instrument. Therefore, a reliability analysis was carried out. Given that each scale is unidimensional, Cronbach alpha and KR20 statistical tests are appropriate (Schmitt 1996). Pintrich et al. (1991) utilised the Cronbach alpha and descriptive statistics in their original assessment of the MSLQ and, therefore, these strategies have also been utilised here. Table 4.2 shows the scales included, number of statements within each scale, and reliability measures arising from this study.

| Table 4.2 Reliability of the adapted Motivated Strategies for Learning Questionnaire |
|---------------------------------|-----------------|--------|-------------|--------|
| **Scale Name**                  | **No. Statements** | **Mean** | **Standard Deviation** | **Alpha** |
| **Motivation Scales**           |                  |         |                          |          |
| Intrinsic Goal Orientation      | 3                | 4.54    | 1.19                    | 0.61     |
| Extrinsic Goal Orientation      | 4                | 5.00    | 1.02                    | 0.55     |
| Control of Learning Beliefs     | 4                | 5.07    | 1.00                    | 0.54     |
| Self-Efficacy for Learning and Performance | 7                | 4.03    | 1.04                    | 0.86     |
| **Learning Strategy Scales**    |                  |         |                          |          |
| Rehearsal                       | 4                | 4.81    | 1.37                    | 0.70     |
| Elaboration                     | 6                | 4.82    | 1.17                    | 0.80     |
| Organisation                    | 4                | 4.81    | 1.17                    | 0.71     |
| Critical Thinking               | 5                | 3.21    | 1.17                    | 0.79     |
| Metacognitive Self-regulation   | 12               | 4.09    | 0.930                   | 0.74     |
| Peer Learning                   | 3                | 3.76    | 1.41                    | 0.70     |
| Help Seeking                    | 4                | 3.85    | 1.28                    | 0.60     |

Seven of the eleven scales have a Cronbach alpha value of 0.7 or above indicating that these scales have acceptable reliability (Cohen et al. 2007, p. 506). Two scales have Cronbach alpha values of .60-.69 indicating that they are minimally reliable. However, Extrinsic Goal Orientation and Control of Learning Beliefs have alpha-values below this and may need to be interpreted with caution.
4.2 DEVELOPMENT OF PRIMARY RESEARCH TOOL
The quantitative strand of Phase 1 involved the development, piloting and administration of an alternative conceptions diagnostic instrument with PSSTs in Ireland. The purpose of the instrument was primarily to answer Research Question C1. That is, to determine the prevalence of alternative conceptions about fundamental chemistry concepts among Irish PSSTs and to assess whether this is affected by a number of different variables\(^\text{107}\). As Research Question C1 involves investigating the relationship between a number of independent and dependent variables, a quantitative instrument is the most appropriate research tool. Quantitative instruments have been used in past research to investigate learners’ alternative conceptions\(^\text{108}\). Therefore, a quantitative instrument can be used for this purpose. The instrument was designed according to Treagust’s (1988; 1995) three stage design process\(^\text{109}\). Stage 1 involved defining the content area of the study. Stage 2 involved identifying alternative conceptions and suitable diagnostic items from the literature. Stage 3 involved piloting the instrument with a group of PSSTs and revising the instrument. Further information about the development process will be provided in this section.

(a) Stage 1: Defining the Content Area
As mentioned in Section 2.1\(^\text{110}\), the upper-second-level chemistry syllabus was considered to be an appropriate framework to categorise learners’ alternative conceptions in chemistry; it was also used to decide upon the content of the instrument. It includes the revision of concepts included in the chemistry portion of the lower-second-level science syllabus (which all science teachers are qualified to teach) and concepts necessary to prepare experimental materials for teaching that syllabus. The third-level general chemistry courses that have been studied by the majority of PSSTs also teach the content of the upper-second-level syllabus. The conceptual areas of the syllabus were first placed on a flow chart in order of increasing complexity. Three of the most basic areas of the syllabus were selected for inclusion in the instrument: particulate nature of matter (PNM), chemical bonding, and, stoichiometry. The complex conceptual area of chemical equilibrium was also selected for inclusion. Each of these four content areas of the upper-second-level syllabus was then defined with a list of conceptual statements and a selection of these statements were included in the instrument. The statements that were assessed for the content area of PNM\(^\text{111}\) may be seen in Table 4.3.

\(^{107}\) These were previously outlined in Table 4.1.
\(^{108}\) This was previously discussed in Section 2.4(a).
\(^{109}\) This process was outlined in Section 2.4(a).
\(^{110}\) This section details the method used to review the literature in the fundamental areas of chemistry. This is the method also used to delimit the content area of the study.
\(^{111}\) The list of statements related to the other conceptual areas may be seen in Appendix D.
Table 4.3 List of statements defining the area of particulate nature of matter for the instrument

<table>
<thead>
<tr>
<th>Statement No.</th>
<th>Statements Describing the Particulate Nature of Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Composition of Matter</td>
</tr>
<tr>
<td>PNM-1a</td>
<td>A pure substance can be made up of a single type of compound or a single type of element. α⁹</td>
</tr>
<tr>
<td>PNM-1b</td>
<td>A mixture is always composed of two or more different substances (two or more elements, two or more compounds, or elements and compounds). α⁵</td>
</tr>
<tr>
<td>PNM-1c</td>
<td>Homogeneous mixtures have a uniform (or random) composition. α³</td>
</tr>
<tr>
<td>PNM-1d</td>
<td>Heterogeneous mixtures have a non-uniform (or non-random) composition. α³</td>
</tr>
<tr>
<td>PNM-1e</td>
<td>An element is composed of a single type of atom of an element. These atoms can be unbonded or bonded to form all the same type of molecule. α⁵</td>
</tr>
<tr>
<td>PNM-1f</td>
<td>A compound is the chemical combination, in a specific ratio, of two or more different elements. α⁶</td>
</tr>
<tr>
<td>PNM-1g</td>
<td>A compound is represented by the chemical symbols of the elements which make up the compound. Subscripts depict the specific ratio in which the elements are combined. α⁶</td>
</tr>
<tr>
<td></td>
<td>Properties of Matter</td>
</tr>
<tr>
<td>PNM-2a</td>
<td>All matter has mass. This mass is always conserved. α⁵</td>
</tr>
<tr>
<td>PNM-2b</td>
<td>A single particle of a substance has all the same chemical properties of the substance but does not have the same physical properties. α⁶</td>
</tr>
<tr>
<td>PNM-2c</td>
<td>Higher ionisation energies (i.e. increasingly difficult to remove an electron) result from higher effective nuclear charge and comparatively low repulsion between the electrons of the outermost shell. ⁶</td>
</tr>
<tr>
<td></td>
<td>Arrangement and Movement of Particles in Matter</td>
</tr>
<tr>
<td>PNM-3a</td>
<td>The particles of a solid can be arranged in either a regular or irregular pattern. The particles vibrate in place but cannot break free from the arrangement as they do not have sufficient energy. α⁵</td>
</tr>
<tr>
<td>PNM-3b</td>
<td>The particles of a liquid can move more than those of a solid (as they have more kinetic energy) but they cannot break away entirely from all the other particles. α⁵</td>
</tr>
<tr>
<td>PNM-3c</td>
<td>The particles of a gas can move freely and break away from each other (as they have more kinetic energy than either a liquid or a solid). α⁵</td>
</tr>
<tr>
<td></td>
<td>Effect of Physical Changes on the Composition and Properties of Matter</td>
</tr>
<tr>
<td>PNM-4a</td>
<td>Changing the state of matter in a closed system has no effect on the mass of the substance but can have an effect on the volume of the substance. ⁶</td>
</tr>
<tr>
<td>PNM-4b</td>
<td>Changing the state of matter has no effect on the chemical composition of the substance. ⁶</td>
</tr>
<tr>
<td></td>
<td>Effect of Chemical Changes on the Composition and Properties of Matter</td>
</tr>
<tr>
<td>PNM-5a</td>
<td>During a chemical change in a closed system, the number of atoms is conserved. α⁵</td>
</tr>
<tr>
<td>PNM-5b</td>
<td>In balanced chemical equations, a compound substance is represented by the chemical symbols of the elements which make up the compound. Subscripts depict the specific ratio in which the elements are combined. Coefficients represent the proportions is which substances react and are formed. α⁵</td>
</tr>
</tbody>
</table>

[^indicates the concept was included in the α-version and ⁹ indicates it was included in the β-version]

Statements regarding the conceptual areas of rates of reaction (specifically regarding the rate-determining step) and organic chemistry (specifically regarding the identification of structural isomers) were also included in the α-instrument. At the time that the α-instrument was created, a decision had not yet been made about whether the more complex areas of equilibrium, rates of reactions, or organic chemistry should be assessed by the instrument. However, it was later decided that only equilibrium would be assessed.
(b) Stage 2: Researching Learners’ Conceptions and Developing the $\alpha$-instrument

Given the body of research in this area, it was decided that common alternative conceptions and diagnostic items could be identified based on a search of the literature. This method and the findings of this review have previously been presented in Chapter 2. NVivo, a qualitative analysis computer software program, was used to catalogue learners’ alternative conceptions and diagnostic questions. In two cases, suitable diagnostic questions could not be identified and questions were developed. For example, Figure 4.1 shows a diagnostic question about the structure of ionic compounds that was developed for the $\beta$-instrument.

![Figure 4.1 A question on the $\beta$-instrument designed by the current author](image)

Other questions were adapted from those in the research literature. Typically, these adaptations were minor. For example, Figure 4.3 shows a diagnostic question developed and validated by Sanger (2000). The question assesses learners’ understanding of the following propositions outlined in Table 4.3: PNM-1a, PNM-1b, PNM-1c, PNM-1d, PNM-1e, PNM-1f, PNM-3a, PNM-3b, and PNM-3c. Figure 4.2 shows the adapted question used in the $\beta$-instrument. A number of simple formatting changes were made to make the question consistent with the format of the instrument. Diagrams 2 and 5 of Figure 4.3 were adapted, by removing some of the particles, to ensure that they could be more easily interpreted as the gas phase. After the instrument had been piloted, further revisions involved clearly delineating the three separate sections of the instrument and reducing the stem and response method to increase the clarity of the item. For other items of the instrument, a distractor was added to ensure the consistency in the format of the instrument\(^{112}\).

The $\alpha$-instrument comprised twenty-three items and this was later revised to form a twenty-item $\beta$-instrument based on feedback from science education researchers, interviews with the M1 Sample and a reliability analysis of the $\alpha$-instrument. The conceptual areas included in the $\beta$-instrument, the number of questions in each conceptual area, and the source of the diagnostic questions are shown in Table 4.4.

\(^{112}\) The format of multiple-choice items was one correct response option and four distractors.
The following drawings contain representations of atoms and molecules. Classify each of these drawings (labeled 1–5) according to the three characteristics listed below. You should classify all five drawings for each category.

State of matter
- solid
- liquid
- gas

Physical composition of matter
- pure substance
- heterogeneous mixture
- homogeneous mixture

Chemical composition of matter
- elements
- compounds
- both

In the diagrams below (labeled 1–5), the atoms of different elements are represented by the symbols:
- ◯
- ▲

(a) Each diagram represents one of the following:
- A. a solid
- B. a liquid
- C. a gas

In the box beneath each diagram, write one letter to say what you think it represents.

1  2  3  4  5

(b) Each diagram also represents one of the following:
- A. one or more elements
- B. one or more compounds
- C. mixture of elements and compounds

In the box beneath each diagram, write one letter to say what you think it represents.

1  2  3  4  5

(c) Each diagram also represents one of the following:
- A. a pure substance
- B. a heterogeneous mixture
- C. a homogeneous mixture

In the box beneath each diagram, write one letter to say what you think it represents.

1  2  3  4  5

Figure 4.2 The adapted Sanger (2000) question used in the β-instrument

Figure 4.3 Sanger's (2000) diagnostic question assessing learners' understanding of the chemical and physical composition of matter.
Table 4.4 The conceptual areas and source of diagnostic questions used in the α-instrument

<table>
<thead>
<tr>
<th>Conceptual Area</th>
<th>Number of Items</th>
<th>Source of Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNM</td>
<td>8</td>
<td>Sanger (2000); Mulford and Robinson (2002); Yezierski and Birk (2006); one author-developed item</td>
</tr>
<tr>
<td>Chemical Bonding</td>
<td>5</td>
<td>Peterson and Treagust (1989); Mulford and Robinson (2002); Jensen (2007); two author-developed questions</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>4</td>
<td>Gower et al. (1977); Claesgens and Stacy (2003); Sheehan (2010); One author-developed question</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>3</td>
<td>Krause et al. (2004); Tyson et al. (1999); Robinson and Nurrenburn (2011)</td>
</tr>
</tbody>
</table>

(c) Stage 3: Piloting and Revision to Develop β-instrument
During this stage, the α-instrument was administered to the Pilot Sample, who were described in Section 3.9(c). Based on the data collected, a reliability analysis was carried out which informed revision of the instrument. The interviews carried out with the M1 Sample for the purpose of answering Research Question M1, also served to validate the instrument and inform its revision. Braun and Clarke’s (2006) method of inductive thematic analysis was used to analyse the data and a report was created for each item. The reliability analysis for the α-instrument and the decision-making process involved in revising the instrument to produce the final β-instrument are provided in Appendix E. This section focuses upon the procedures involved in the reliability analysis, and the analysis of the final β-instrument.

PROCEDURES TO DETERMINE RELIABILITY
Reliability and internal consistency of criterion-referenced instruments in the research literature is often measured using the Cronbach alpha test or the Kuder-Richardson test (KR-20). It has previously been reported that analysis of criterion-referenced instruments using norm-referenced methods is inappropriate and provides erroneous results (Cox and Vargas 1966). The Cronbach alpha test is based on two assumptions: that the test is norm-referenced and unidimensional (Schmitt 1996). Neither of these assumptions hold true for the instrument used in this study. Therefore, the following item-analysis methods were used:

- the difficulty of each item was assessed using a statistic P-chart (as described by Posrie (2010)),
- the extreme groups method (also known as the upper-lower groups method) was used to determine the discrimination index for each item, and
- a phi-coefficient correlation analysis was carried out to provide further insight into the discrimination of each item.
**Item Difficulty Index**

The statistic $P$ was used as a measure of item difficulty. This is calculated based on the proportion of participants who answer an item correctly; the greater the $P$ value, the higher the proportion of respondents answering the item correctly and the easier the item. The range for this value is between 0 and +1, with a value of +1 indicating that every respondent answered correctly. Extreme values are to be avoided. However, as Ding *et al.* (2006) point out, this does not necessarily mean that an instrument cannot include items with extremes of difficulty; the average difficulty index value of all items is often used as an indication of the difficulty of the instrument. The range 0.30-0.70 is commonly deemed acceptable (Allen and Yen 2002, pp. 120-123). Posrie (2010) points out that, as a criterion-referenced instrument is designed to measure the specific knowledge and skills of a particular group, the statistic $P$ "will vary according to the ability level of the group". Posrie (2010) then sets out an appropriate method of determining the statistic $P$ value for a specific group. This method involves the creation of a control $P$ chart based on the lower and upper confidence levels (in this case a 99% confidence interval has been used). The lower confidence level ($LCL$), also known as the minimum difficulty, is calculated according to Equation 1 below. The upper confidence level ($UCL$), or maximum difficulty, is calculated according to Equation 2.

\[
LCL = \bar{p} - 3 \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \tag{Equation 1}
\]

\[
UCL = \bar{p} + 3 \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \tag{Equation 2}
\]

Where:
- $LCL$ is the lower confidence level or minimum difficulty of the instrument,
- $UCL$ is the upper confidence level or maximum difficulty of the instrument,
- $\bar{p}$ is the average difficulty of the instrument item, and
- $n$ is the sample size.

**Extreme Groups Discrimination Index**

This is one measure of the discriminatory power of each item in an instrument. This method involves the analysis of the differences between the extreme upper and lower groups with reference to their ability to solve a certain item. An item with a high discrimination index ($DI$) means that participants with greater understanding will usually answer this item correctly while those students with poorer understanding will not answer this item correctly. The

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technique has been shown to be the most appropriate extreme groups method (Posrie 2010). This technique involves classifying 70% of all participants into pass and fail groups according to the group mean. In other words, the upper group would account for the top 35% of performers and the lower group the bottom 35% of performers\(^{113}\).

The value for the item \(DI\) can range from -1 to +1, with a value of +1 indicating that all in the upper group answer the item correctly and in the lower group answer it incorrectly. An item is typically considered to provide good discrimination if \(DI \geq 0.3\) (Ding et al. 2006). Items with a discrimination index in the range 0-0.3 are not necessarily bad items, but a majority of the items should have a \(DI\) above 0.3 to ensure that the instrument can distinguish between participants with and without conceptual understanding of the content of the instrument. The mean item discrimination index can be used as a measure of the discriminating power of the instrument (Ding et al. 2006). The discrimination index is calculated as according to Equations 3-5 (Posrie 2010).

\[
DI = P_U - P_L
\]

\[
P_U = \frac{X_U}{n_U} \quad P_L = \frac{X_L}{n_L}
\]

Where:

- \(DI\) is the discrimination index for the item,
- \(P\) is the proportion of the group answering the item correctly,
- \(X\) is the item score of participants in the relevant group,
- \(n\) is the number of participants in the relevant group, and
- \(Subscripts: U\) refers to the upper group and \(L\) refers to the lower group.

\[\text{Equation 3}\]

\[\text{Equations 4 and 5}\]

**Correlation Analysis Method**

This method examines the correlation of item score and the overall score in the instrument. This is widely accepted as an appropriate discrimination index (Hsu 1971; Shannon and Cliver 1987; Posrie 2010). If an item is positively correlated with the overall instrument score then it measures the same factor as the instrument and contributes to the instrument reliability (Posrie 2010). The phi-coefficient, \(\phi\), must be used with two dichotomous variables; the correlation between the score on an item (marked correct or incorrect) and

---

\(^{113}\) It was intended to use the r\(\text{70}\) technique in this study, however, only the upper 28% and the lower 28% of performers could be isolated due to a cluster of PSSTs with the same scores around the centre point.
whether PSSTs were determined to have mastery in the content of the instrument (marked mastery or non-mastery) was assessed in this study. For this instrument, a score of 40% or higher was selected as representing PSSTs’ sufficient mastery of basic chemistry concepts. This figure was selected as 50% of the concepts included in the β-instrument, are relevant to the chemistry portion of the lower-second-level science syllabus: an area which must be taught by all science teachers regardless of their discipline. A significant and positive correlation indicates that the item contributes to mastery levels according to the instrument.

**RELIABILITY AND VALIDITY OF THE B-INSTRUMENT**

The difficulty index as measured by the statistic $P$ for each item of the β-instrument is shown in Figure 4.4. The average difficulty of the instrument is 0.37. Item 3c appears to be particularly difficult for PSSTs. Items 3a, 3b and 3c are all based on the same stem and diagrams (shown previously in Figure 4.3); Items 3a and 3b are of easy and moderate difficulty, respectively. However, Item 3c is very difficult according to the ability of the PSSTs. This suggests that the issue with this item may be poor understanding of the concepts (in this case mixtures) rather than an issue with the item itself. There were seven items (35%) that were difficult according to PSSTs’ ability and six that were easy (30%) according to their ability. The remaining seven items (35%) were well-suited to their ability.

The values for the discrimination index for the β-instrument are provided in Table 4.5. Fifteen of the twenty items have an acceptable or good index, and two have a marginal index (Items 3a and 17). However, Items 3c, 8 and 13 do not have acceptable discrimination indices. Item 13 greatly improved from the version in the α-instrument, from an index of
0.03 to one of 0.19. It is suggested that Item 3c, as previously mentioned, does not perform well as a result of PSSTs’ lack of understanding of mixtures. During the interviews with the M1 Sample, PSSTs did understand the stem and response options to Item 8; however, the difficulty arose as an algorithmic response could not be applied to the item. The average discrimination for the β-instrument is 0.37 which is in the acceptable range.

### Table 4.5 Results of the extreme groups discrimination index for the β-instrument

<table>
<thead>
<tr>
<th>Item No.</th>
<th>DI</th>
<th>Item No.</th>
<th>DI</th>
<th>Item No.</th>
<th>DI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.36</td>
<td>6</td>
<td>0.31</td>
<td>13</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>0.55</td>
<td>7</td>
<td>0.45</td>
<td>14</td>
<td>0.31</td>
</tr>
<tr>
<td>3a</td>
<td>0.31</td>
<td>8</td>
<td>0.08</td>
<td>15</td>
<td>0.22</td>
</tr>
<tr>
<td>3b</td>
<td>0.55</td>
<td>9</td>
<td>0.49</td>
<td>16</td>
<td>0.44</td>
</tr>
<tr>
<td>3c</td>
<td>0.09</td>
<td>10</td>
<td>0.46</td>
<td>17</td>
<td>0.23</td>
</tr>
<tr>
<td>4</td>
<td>0.39</td>
<td>11</td>
<td>0.47</td>
<td>18</td>
<td>0.32</td>
</tr>
<tr>
<td>5</td>
<td>0.58</td>
<td>12</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Average DI 0.37**

The results of the ϕ correlation analysis are shown in Table 4.6. Sixteen of the twenty items have a moderate association or better with mastery on the instrument. However, Items 1, 3c, and 13 have a weak association and Item 8 has a negligible association. All items correlate with mastery on the instrument at the .001 level of probability with the exception of Item 3c which correlates at the .01 level and Item 8 which does not correlate with mastery. The results associated with Item 8 are likely to be due to a poor understanding of the concept of the mole as a counting unit for the reasons noted above.

### Table 4.6 Results of the ϕ correlation analysis for the β-instrument

<table>
<thead>
<tr>
<th>Item No.</th>
<th>ϕ</th>
<th>Item No.</th>
<th>ϕ</th>
<th>Item No.</th>
<th>ϕ</th>
<th>Item No.</th>
<th>ϕ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.19***</td>
<td>4</td>
<td>0.28***</td>
<td>9</td>
<td>0.30***</td>
<td>14</td>
<td>0.22***</td>
</tr>
<tr>
<td>2</td>
<td>0.35***</td>
<td>5</td>
<td>0.42***</td>
<td>10</td>
<td>0.29***</td>
<td>15</td>
<td>0.20***</td>
</tr>
<tr>
<td>3a</td>
<td>0.24***</td>
<td>6</td>
<td>0.22***</td>
<td>11</td>
<td>0.34***</td>
<td>16</td>
<td>0.28***</td>
</tr>
<tr>
<td>3b</td>
<td>0.32***</td>
<td>7</td>
<td>0.29***</td>
<td>12</td>
<td>0.39***</td>
<td>17</td>
<td>0.23***</td>
</tr>
<tr>
<td>3c</td>
<td>0.12**</td>
<td>8</td>
<td>0.01</td>
<td>13</td>
<td>0.17***</td>
<td>18</td>
<td>0.23***</td>
</tr>
</tbody>
</table>

*Note: * p < .05, ** p < .01, *** p < .001*

Overall, the instrument has an acceptable difficulty index with an average of 0.37. Certain items are easier than the minimum difficulty level with others more difficult than the maximum difficulty level. The discrimination indices of items are generally above the acceptable level according to both the extreme groups and ϕ-correlation methods. However, Items 3c and 8 are consistently problematic. Interviews with the M1 Sample suggest that PSSTs experienced no difficulties in understanding the meanings of the respective item stems or response options. These interviews will be discussed further in Chapter 7 in the context of addressing Research Question M1.
4.3 QUANTITATIVE DATA ANALYSIS PROCEDURES

(a) Software
All quantitative data discussed in this thesis were inputted to and analysed with the software program IBM SPSS Statistics version 22 (IBM Corp. 2013). However, the previous versions 18, 19 and 20 (IBM Corp. 2010; IBM Corp. 2011; IBM Corp. 2012) were also used over the course of the study. In coding PSSTs’ responses, missing responses were coded as such and not included in the subsequent analysis. Descriptive and inferential statistics were carried out on the data using this software. Certain statistics, which will be discussed later in this section, were calculated using Excel and the equations associated with these will be provided.

(b) Descriptive Analysis
A descriptive analysis was carried out on all variables. The descriptive statistics used to summarise the dependent variables with respect to the independent variables involved the comparison of measures of central tendency, dispersion and location between independent variable categories (e.g. male and female). Measures of central tendency are ways to determine the centre of distribution: the mode is the most frequently occurring score, the mean is the average score, and the median is the middle score above and below which there are the same number of scores (Field 2009, pp. 20-23). Measures of dispersion and location quantify the spread of scores in the data: the range is the difference between the largest and smallest scores, quartiles are the three values that split the data into four equal parts (Field 2009, pp. 23-24), and the standard deviation is a measure of the error between the mean and the actual scores\(^{114}\) (Field 2009, p. 37). Box plots were also used to compare data between groups.

Another aspect of the descriptive analysis was determining whether data within groups was normally distributed\(^{115}\). Histograms and Probability-Probability (P-P) plots were created to visually inspect the distribution of data. Skewness and kurtosis were also examined. The values for skewness (measuring the symmetry of the histogram) and kurtosis (measuring the ‘pointiness’ of the histogram) should ideally be zero in normally distributed data (Field 2009, p. 138). Converting the values of skewness and kurtosis to \(z\)-scores reveals whether these scores are significantly different from a normal distribution for the dataset and contribute to deciding whether a dataset is normally distributed (Field 2009, p. 138). The \(z\)-scores were calculated according to Equations 6 and 7 (Field 2009, p. 139).

\(^{114}\) Standard deviation is not a direct measure of the error between the mean and actual scores; the direct measure is variance. However, variance provides a value that is the square of dataset units. Standard deviation is more useful to report as it can be directly compared to other values such as the mean.

\(^{115}\) This was to ensure that data met this assumption for the later inferential parametric testing.
\[ Z_{\text{skewness}} = \frac{S}{SE_{\text{skewness}}} \]  
\[ Z_{\text{kurtosis}} = \frac{K}{SE_{\text{kurtosis}}} \]

Where:
- \( Z \) is the z-score,
- \( S \) is the value for skewness,
- \( K \) is the value for kurtosis, and
- \( SE \) is the standard error of skewness or kurtosis

A z-score of greater than: 1.96 is significant at \( p < .05 \), 2.58 is significant at \( p < .01 \), and 3.29 is significant at \( p < .001 \). However, when samples are large (i.e. greater than 200), the standard errors are small and small deviations from the normal distribution are significant (Field 2009, p. 139). Therefore, the distribution of the data collected from the Pilot and C1 Samples were determined based on both the z-scores and an examination of the shape of the distribution using histograms and probability plots. For each independent variable, a table such as the one shown below (Table 4.7) was created to summarise the findings. Summary tables for all variables in the study may be found in Appendix G.

<table>
<thead>
<tr>
<th>Table 4.7 Data distribution findings for PSSTs following concurrent and consecutive STE models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PNM</strong></td>
</tr>
<tr>
<td><strong>Concurrent (n = 323)</strong></td>
</tr>
<tr>
<td>Z-score skewness</td>
</tr>
<tr>
<td>Z-score kurtosis</td>
</tr>
<tr>
<td>Histogram</td>
</tr>
<tr>
<td>Q-Q Plot</td>
</tr>
<tr>
<td>Normality</td>
</tr>
<tr>
<td><strong>Consecutive (n = 144)</strong></td>
</tr>
<tr>
<td>Z-score skewness</td>
</tr>
<tr>
<td>Z-score kurtosis</td>
</tr>
<tr>
<td>Histogram</td>
</tr>
<tr>
<td>Q-Q Plot</td>
</tr>
<tr>
<td>Normality</td>
</tr>
</tbody>
</table>

Note: * \( p < .05 \), ** \( p < .01 \), *** \( p < .001 \), ✓ appearance acceptable, x some deviation from normal.

The same process was used in determining the normality of data arising from the C2-M2 Sample. However, in this case significant z-scores were always taken to indicate non-normal data (given the smaller sample size). Furthermore, the Shapiro-Wilk test (denoted by the statistic \( W \)) was used to assess the normality of data for this small sample. This test assesses
whether the distribution deviates significantly from a comparable normal distribution (Field 2009, p. 145). The null hypothesis is that it does not; therefore, where the test produced a significant result the data was always considered to be non-normally distributed.

(c) Inferential Statistics
The inferential tests used in this study were selected based on the work of Field (2009). A decision tree, produced by Field (2009, p. 822), was used to ensure that appropriate statistical tests were consistently selected. The portions of this tree that were used in analysing the quantitative data in this study have been reproduced in Figure 4.5. The purpose of the various statistical tests used in this study will be discussed in this section. The methods used to assess the various assumptions of these tests will be outlined. Where calculations were carried out outside of the SPSS environment, the equations used are also provided.

INVESTIGATING THE SIGNIFICANCE OF RELATIONSHIPS BETWEEN CATEGORICAL VARIABLES
The relationship between two categorical variables was assessed using the Pearson $\chi^2$ test. This test creates a number of groups that are represented in cells in a contingency table; for example if the relationship being assessed is between two binary categorical variables, there will be four cells in the contingency table. The test compares the frequencies that actually occur in any category with the frequencies that would occur by chance (Field 2009, p. 688-689). The test has two assumptions: 1) data should be independent, and 2) expected frequencies should be greater than a value of 5 (Field 2009, p. 691-692). In the context of Pearson’s $\chi^2$ test, independence of data refers to the assumption that each value in each cell of the contingency table arises from a single entity. This assumption was met in all cases within this study. The assumption that the expected frequencies in each cell of the contingency table should be greater than 5 can become problematic when the sample size is small or when there are very few participants in a particular category. It is acceptable for expected frequencies of less than 5 to occur in no more than 20% of cells on the contingency table (Field 2009, p. 692). The sample size was small in Phase 2 of this study and in some cases, this assumption was violated. Throughout Chapters 5 and 6, violations of this assumption are highlighted and it is recommended that results arising from these few cases be treated with caution. Where the result of a Pearson $\chi^2$ test was significant, $z$-scores were used (in the manner previously outlined) to interpret which cells were significantly different from others as recommended by Field (2009, p. 692).
Figure 4.5 Decision tree for the selection of appropriate inferential statistical tests (Field 2009, p. 822)
COMPARISON TESTS TO DETERMINE SIGNIFICANCE OF DIFFERENCES IN CENTRAL TENDENCY

As seen in Figure 4.5, prior to carrying out any statistical test a number of assumptions must first be assessed. There are two main types of statistical tests: parametric and non-parametric. The assumptions associated with all parametric tests in this area (i.e. the comparison tests to be discussed) (Fields 2009, p. 359) are the:

- normal distribution of data within groups,
- homogeneity of variance between groups,
- independence of observations, and
- dependent variables are continuous.

The normality of data within groups was assessed prior to selecting a statistical test according to the methods outlined in the previous section. Homogeneity of variance refers to the need for a similar variance of the outcome variable between the various levels of the independent variable. This was assessed using Levene’s test (Fields 2009, pp. 149-150). Parametric tests can be robust to violations of the assumption of homogeneity of variance where there are equal sample sizes (Fields 2009, p. 360). That is not the case in this study. However, SPSS produces a second adjusted statistical result in cases where this assumption has been violated; this is the value which will be reported where it is relevant. Independence of observations in this context refers to the assumption that the data from individual participants does not affect the data associated with other participants (Fields 2009, p. 133). This assumption is met by all data in this study as participants’ responses were unknown to each other during data collection. Finally, the assumption that dependent variables are continuous refers to data being measured at the interval or ratio level (Fields 2009, p. 133). This is the case for all dependent variables in this study which have been previously outlined in Table 4.1. In all cases throughout Chapters 5 and 6, the associated verification of parametric test assumptions is provided in the Appendices, which will be referred to in these chapters.

Where the independent variable was categorical with two categories (e.g. male and female), either an Independent t-test or a Mann-Whitney test was carried out. The independent t-test was used where the data within groups was normally distributed. Where this assumption was violated by one or both groups a Mann-Whitney test was carried out. Where the independent variable was categorical with more than two categories (e.g. 1st year, 2nd year, 3rd year and 4th year for the ConcYear variable), either an Independent One-Way ANOVA or Kruskal Wallis test was carried out. The One-Way ANOVA was utilised where all data within groups was normally distributed; otherwise, a Kruskal Wallis test was carried out. When a One-Way
ANOVA produces a significant result, tests to assess which groups are significantly different from others (i.e. post-hoc tests) can be carried out within the SPSS ANOVA function. This automatically corrects Type I errors\(^\text{116}\). However, this is not done automatically for the Kruskal Wallis test. In this study, a significant Kruskal Wallis result was followed up with Mann-Whitney post-hoc tests as recommended by Field (2009, pp. 565-566). The usual critical significance value of .05 cannot be used due to the increased risk of Type I errors. Therefore, a Bonferroni adjustment was manually applied. This involves calculating the true critical significance value by dividing .05 by the number of tests carried out, as shown in Equation 8 (Fields 2009, pp. 565-566).

\[
\text{Critical significance value} = \frac{.05}{\text{No. of Tests}}
\]  

Equation 8

All combinations of post-hoc tests cannot be carried out as this results in a critical significance value that is too restrictive. Therefore, the descriptive data associated with each group was re-examined in these cases, which informed the selection of appropriate Mann-Whitney tests.

**DETERMINING THE EFFECT SIZES**

Four effect sizes have been used throughout this study. Cohen’s \(d\) and a \(z\)-score conversion were used to assess the size of effects associated with the comparison tests described in the previous section. Two effect sizes were also related to Pearson \(\chi^2\) tests; Cramer’s \(V\) is a standardised effect size measure and the odds ratio is a more easily interpretable measure. Various effect size measures cannot be interpreted using the same guidelines. Therefore, the guidelines associated with interpreting each effect size and the method of calculating effect sizes, where relevant, will be presented.

Cohen’s \(d\) effect size was used with parametric tests. It was also used throughout the literature review to calculate the effect sizes within published research articles. Cohen’s \(d\) was calculated in this study according to Equations 9 and 10. Within the literature review, published articles occasionally provided information about standard errors but not standard deviations. In these circumstances, the standard deviation for each group was calculated using Equation 11. The values of Cohen’s \(d\) effect size are interpreted according to Cohen’s (1988, pp. 24-27) recommendations: 0.20 is a small effect size, 0.50 is a medium effect size, and 0.80 is a large effect size.

\(^{116}\) Type I errors occur where significance is attributed to a statistical test when there is no genuine significance. The probability of these errors occurring increases as more statistical tests are carried out on the same set of experimental data (Fields 2009, p. 348).
\[ d = \frac{\bar{x}_a - \bar{x}_b}{SD_{pooled}} \]  
\[ SD_{pooled} = \frac{(n_a - 1)SD_a^2 + (n_b - 1)SD_b^2}{n_a + n_b} \]  
\[ SD = SE\sqrt{n} \]

Where:
- \( d \) is Cohen’s \( d \) effect size,
- \( \bar{x} \) is the mean of the group,
- \( SD \) is the standard deviation,
- \( n \) is the number of participants in the group,
- \( SE \) is the standard error, and
- Subscripts: \( a \) refers to one group (usually the experimental group) and \( b \) is the group to be compared (usually a control group).

A non-parametric effect size was also required for data that was non-normally distributed. Fields (2009, p. 550) recommends a \( z \)-score conversion into an effect size (denoted \( r \)) according to Equation 12. This \( z \)-score conversion is interpreted as follows: a value of .10 is a small effect size, .30 is medium and .50 is a large effect size (Fields 2009, pp. 56-57).

\[ r = \frac{Z}{\sqrt{N}} \]

Where:
- \( r \) is non-parametric effect size,
- \( Z \) is the \( z \)-score for the statistical test, and
- \( N \) is the total number of participants on which the \( z \)-score is based.

An effect size associated with Pearson’s \( \chi^2 \) test is Cramer’s \( V \) which is produced within the relevant SPSS function. This correlation coefficient is interpreted as recommended by Rea and Parker (1992, p. 203):
- .00 - .09 is a negligible association,
- .10 - .19 is a weak association,
- .20 - .39 is a moderate association,
- .40 - .59 is a relatively strong association,
- .60 - .79 is a strong association, and
- .80 – 1.00 is a very strong association.
The odds ratio has also been utilised where Pearson’s $\chi^2$ test involves a 2 x 2 contingency table. First, the odds\textsuperscript{117} of one dependent variable condition occurring are calculated for both independent variable conditions according to Equation 13. Then the odds ratio is calculated according to Equation 14 (Fields 2009, pp. 699-700). This is easily interpretable as the value of the odds ratio reflects how much higher the odds are of a dependent condition occurring in one independent condition or the other\textsuperscript{118}.

$$odds_{1v} = \frac{\text{no. exhibiting dependent condition}}{\text{no. not exhibiting dependent condition}}$$  
Equation 13

$$odds\ ratio = \frac{odds_{1v1}}{odds_{1v2}}$$  
Equation 14

Where:
- $odds_{1v1}$ = the odds of the dependent condition under one category of the independent variable, and
- $odds_{1v2}$ = the odds of the dependent condition under the other category of the independent variable.

Finally, it is important to consider the statistical power associated with the comparison tests outlined in the previous section for the C1 Sample and C2-M2 Sample. According to Cohen (1988, pp. 36-37), there is .85 probability of detecting a genuine effect as significant at the .05 level in the C1 Sample ($n = 467$) where there is a small effect size and .95 probability or greater of detecting a medium or large effect size. Therefore, the statistical power of the tests to be carried out on the C1 Sample is sufficiently high (meeting the lower criterion of a .80 probability). For the C2-M2 Sample ($n = 52$), there is a .93 probability of detecting a large effect size as significant at the .05 level but only a .50-.70 probability of detecting a medium effect size as significant and a .08-.17 probability of detecting a small effect size as significant at this level. Therefore, it is unlikely that the statistical tests will produce a significant result for lower effect sizes for this sample due to a lack of statistical power.

**Regression Analysis**

A multiple regression analysis was carried out to further investigate the findings related to Research Question C1. An explanation of multiple regression and the reason for its use in this study will first be outlined, along with the particular method of regression used and how

\textsuperscript{117} The odds are the probability that the condition will occur divided by the probability that it won’t occur.

\textsuperscript{118} For example, taking ‘student status’ as the independent variable and ‘happy’ as the dependent condition, after the odds ratio has been calculated one will be able to say something along the lines of the odds of non-students being happy were 2.34 times higher than odds of students being happy.
the results are reported. There are many assumptions associated with multiple regression, which impact on the generalisability of regression models. These assumptions will be highlighted and the methods used to investigate them in this study will be presented. Finally, the method of assessing the accuracy of regression models will be discussed.

Multiple regression involves fitting a straight-line model to the data such that a dependent variable can be predicted from a number of independent/predictor variables (Fields 2009, p. 198). The resulting model takes the form of the straight-line equation shown in Equation 15.

\[ Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_n X_{ni} + \epsilon_i \]

Equation 15

Where:
- \( Y \) = outcome variable,
- \( \beta_0 \) = constant (i.e. \( Y \) intercept),
- \( X \) = predictor variable,
- \( \beta \) = coefficient of predictor variable,
- \( \epsilon_i \) = the difference between the predicted and observed value for \( Y \), and
- Subscripts: \( i \) refers to the \( i^{th} \) participant, \( 1 \) refers to the first predictor variable, \( 2 \) refers to the second predictor variable, and \( n \) refers to the \( n^{th} \) predictor variable.

The purpose of carrying out a regression analysis in this study was not with a view to creating a model that predicts the relevant dependent variable, but with a view to assessing which independent variables significantly contribute to predicting the outcome when the effects of all other variables are held constant. The coefficients in Equation 15 are a measure of this (Fields 2009, p. 238). They are a direct measure of the effect of the predictor variable on the dependent variable when the predictor variable is categorical. Where a predictor is continuous the standardised coefficients can be used to determine the effect on the dependent variable as they are a measure of change in the relative standard deviations (Fields 2009, pp. 239-240).

A forced entry regression method has been used in this study. This method involves entering all the predictor variables into the model simultaneously. This method was selected as entering the variables at different stages would result in a model that is influenced by random variation in the data (Fields 2009, pp. 212-213). Furthermore, in other methods of regression (such as hierarchical regression) the researcher influences the model by selecting the order in which variables should be added to the model. Such a method would require strong evidence from previous research about the variables which are of greatest influence on the dependent variable (Fields 2009, p. 212). There is no such evidence of a hierarchy of the importance of
variables within previous research in this area. It was also decided to retain all variables in the regression models. This decision was made as the purpose was primarily to assess which of the variables contributed significantly to the regression models.

The regression models will be reported by providing the following information (Field 2009, pp. 233-240):

- \( F \)-ratio; this compares the ability of the model to predict the outcome with the ability of the mean score to predict the outcome (as done in parametric comparison tests). It is a measure of the improvement in prediction of the dependent variable relative to the inaccuracy of the model.

- \( R^2 \); this is a measure of the variance within the data set for which the model derived from the sample accounts.

- \( R^2_{\text{adjusted}} \); this is a measure of the variance in the data set that would be accounted for were the model derived from the population.

- Regression coefficients (\( \beta \)) and standardised regression coefficients (\( \beta_{\text{standardised}} \)); these are measures of the effect of the predictor variable on the dependent variable when the effects of all other variables are held constant.

Meeting the assumptions related to multiple regression is necessary for generalising the resulting model to the wider population\(^\text{119}\). However, a model can be accurate to the sample, though not generalisable to the population, where certain assumptions are violated (Field 2009, p. 251). There are several assumptions (Fields 2009, pp.220-221) associated with multiple regression including that:

1. all predictor variables should be continuous or binary categorical,
2. all predictors should have some variation in their value,
3. predictors should not be correlated with external variables,
4. the values of the outcome variable should be independent,
5. the errors should be independent,
6. the errors should be normally distributed,
7. there should be no perfect multicollinearity between predictor variables,
8. the residuals arising from predictors should exhibit homoscedasticity (i.e. similar variance in the residuals at each level of the predictor variables),
9. the data can be represented using a linear model, i.e. the assumption of linearity.

\(^{119}\) A summary of the adherence to assumptions of every regression carried out as part of this study is provided in Appendix H.
Assumptions 1-4 relate to the nature of the variables included in the model. In this study, the majority of independent variables, outlined in Table 4.1, are binary categorical. However, two variables have more than two categories, i.e. *ConcYear* and *ConsecDegree*. In order to include these in the regression models, dummy variables were created according to the dummy coding procedure outlined by Field (2009, pp. 253-258). Dummy coding involves creating a number of binary categorical variables to represent the various groups. One group must be treated as a reference group. For *ConcYear*, PSSTs in their 1<sup>st</sup> year of study were selected as the reference group (denoted *Year 1*); those in every other year have more advanced study of third-level science and chemistry, therefore, those in 1<sup>st</sup> year were selected as the reference group given that one would expect every other year to have a better conceptual understanding.<sup>120</sup> For *ConsecDegree*, PSSTs with a 2.2 degree classification (denoted *2.2 Degree*) in their previous science degree were selected as the reference group. The process of dummy coding ensures that all the categorical variables are binary. For some regression models, a score in a conceptual area of the diagnostic instrument was included as a predictor variable. For example, in creating a model to predict scores in chemical bonding, score in PNM was included as a predictor given that the concepts within chemical bonding are founded upon PNM concepts. Scores in the diagnostic instrument are continuous variables. Therefore, Assumption 1 is met by all regression models. Assumption 2 is also met by all models in the study.<sup>121</sup> As it was decided to retain all predictor variables in the regression model, Assumption 3 was also met. Assumption 4, in the context of multiple regression, refers to the need for each value of the dependent variable in the model to come from an individual entity (Fields 2009, p. 221). This assumption is met by all data in the study.

Assumptions 5 and 6 relate to the residual terms arising from the model (i.e. the differences between observed and predicted values). Independence of errors (sometimes called autocorrelation) refers to a lack of correlation between residual terms and can be tested using the Durbin-Watson test. The value of this test statistic can vary between 0 and 4. A value of 2 indicates that the residuals are not correlated. Field (2009, pp. 220-221) states that values less than 1 and greater than 3 may indicate that the residuals are correlated. Within this study, values were never more than 2.40 and never less than 1.91. Typically (in nine of twelve cases), the Durbin-Watson statistic was within 0.10 of a value of 2.00. Therefore, this assumption was met by all models in the study. In the context of multiple regression, the parametric

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<sup>120</sup> PSSTs in their 4<sup>th</sup> year of study could also have been selected as a reference. However, those in 1<sup>st</sup> year were chosen as they were the larger of the two groups.

<sup>121</sup> The variance in the data set will be presented as part of a descriptive statistics analysis at the beginning of Chapter 5.
assumption of normally distributed data refers to the distribution of the standardised residuals and not to the data arising from predictor variables (Fields 2009, p. 221). The distribution of the standardised residuals was assessed by examination of histograms, probability plots and the Shapiro-Wilk test for normality. The Shapiro-Wilk statistic was non-significant for all models reported in Chapter 5. Therefore, Assumptions 5 and 6 were met for all regression models presented in this study.

Assumption 7, a lack of perfect multicollinearity between predictor variables, refers to a lack of linear relationships between the predictor variables (Fields 2009, p. 223). A correlation matrix was created using the Pearson correlation coefficient. Perfect collinearity occurs when there is a very strong correlation between variables, i.e. above 0.80. The correlation matrices for models in this study are presented in Chapter 5. There were no correlations close to this level. Other collinearity diagnostics were also investigated: namely the variance inflation factor (VIF) and the tolerance statistic. The VIF and tolerance statistic assess whether there is a strong linear relationship between variables (Fields 2009, p. 224). VIF values of 10 or greater may indicate multicollinearity; the closer the VIF is to a value of 1, the less evidence there is of multicollinearity. The average VIF for a model should be close to a value of 1. In this study the average values were never greater than 1.70. Finally, a tolerance statistic of less than a value of .1 may indicate multicollinearity; no tolerance values were less than or close to this value. Therefore, Assumption 7 was met by all models presented in Chapter 5.

The assumption of homoscedasticity (Assumption 8) refers to a similarity of variance in the residuals at each level of the predictor variables (Fields 2009, p. 220). Assumption 9 refers to the linearity of the relationship modelled in the regression analysis. These two assumptions are investigated by examining plots of the standardised residual against the standardised predicted value. Linearity is indicated by a random array of data points evenly dispersed about the zero point. Non-linearity is indicated by any curve in the plot. Heteroscedasticity is indicated in these plots if there appears to be funnelling of the data (Field 2009, pp. 247-249). In this study, none of the plots associated with the regression models in Chapter 5 were found to be non-linear or heteroscedastic. Therefore, Assumptions 8 and 9 were met by all regression models presented in this study.

122 This correlation coefficient is interpreted the same way as Cramer’s V (e.g. a value greater than 0.80 indicates a very strong correlation).
The accuracy of a regression model refers to how well the model fits the observed data. A model that does not fit the data well is indicated by the presence of outliers or influential cases which are unduly influencing it. The presence of outliers or influential cases was assessed as recommended by Fields (2009, pp. 214-219). This included investigating the presence of:

- outliers, by assessing whether the standardised residuals (theses are z-scores) violated the expectations of normal data (i.e. none should have an absolute value greater than 3.29, no more than 1% should have an absolute value above 2.58, and no more than 5% should have an absolute value greater than 1.96),
- influential cases, by examining Cook’s distance, Mahalanobis distance and the centred leverage value. Cook’s distance should be no greater than a value of 1, Mahalanobis distance should be no greater than 25, and the centred leverage value should have a value no greater than twice the average leverage value (the latter being calculated according to \((k + 1)/n\) where \(k\) is the number of predictor variables and \(n\) is the sample size),
- influential cases, by examining the values of DFBeta; this is the difference between an estimate of a parameter using all cases and excluding one value from all cases. The absolute value for a DFBeta estimate should be no greater than 1.

Neither outliers nor influential cases were identified in any of the regression models presented in this study. The accuracy of the model can also be assessed by cross-validating it. A model should have similar predictive power across different samples if it is accurate (Fields 2009 p. 221-222). This is investigated by comparing the values of \(R^2\) and \(R^2_{\text{adjusted}}\). The more accurate a model, the closer the \(R^2_{\text{adjusted}}\) value is to the unadjusted \(R^2\) value.

**CONCLUSION**

Each of quantitative research tools and their development, where relevant, have been discussed and their use and purpose within each stage of research provided. The MSLQ and alternative conceptions diagnostic instrument have undergone reliability analyses and been found to be sufficiently reliable for use in the study. The SER and SuBATOMIC Website Surveys did not undergo a reliability analysis as the purpose of these surveys was primarily to contribute to informing the development of the SuBATOMIC blended learning programme. However, the SER Survey was used at the conclusion of the study as an exploratory tool and the results arising from this tool should be interpreted as such. The details of the data analysis procedures associated with each type of variable in the study ensure that the data arising from the study can be accurately and reliably interpreted. The
results arising from this data analysis are relevant to Research Questions C1 and M2. In addressing Research Question C1, there is sufficient statistical power to detect the statistical significance of small, medium and large effect sizes. However, in addressing Research Question M2, there is only sufficient statistical power to consistently detect the statistical significance of large effect sizes. The purpose of this section was to provide the reader with the background information necessary to assess the reliability and validity of the data collection and analysis procedures. The results associated with Research Question C1 will be presented in Chapter 5 and those associated with Research Question M2 will be presented in Chapter 6. Throughout these chapters reference will be made, where necessary, to certain concepts and procedures that have been outlined in the preceding sections as well as to those Appendices that present the analyses related to assessing test assumptions.
Chapter 5  Results of Phase 1

Does the model of STE (concurrent or consecutive) on which PSSTs are enrolled have an effect on the prevalence of alternative conceptions about fundamental chemistry concepts, taking into account other variables such as subject specialism, year of study (for those on the concurrent model), degree classification (for those on the consecutive model), and previous second-level school experiences?

The quantitative results of Phase 1 focus on addressing Research Question C1 above. Descriptive statistics will first be provided for each outcome variable (i.e. particulate nature of matter (PNM) score, chemical bonding score, stoichiometry score, equilibrium score and total score in the diagnostic instrument). This is followed by simple comparison tests to assess whether data relating to the different variables in the study are significantly different. In order to investigate which variables have an effect on the prevalence of alternative conceptions taking the other variables into account, a regression analysis was performed. These models will be presented. Finally, the specific alternative conceptions of PSSTs involved in this study will be provided.

This chapter will demonstrate that previous experience of upper-second-level chemistry is, overall, the most important variable that had an effect on the conceptual understanding of PSSTs. Their decision to specialise in chemistry is, surprisingly, not a variable of importance in PSSTs’ conceptual understanding of chemistry. PSSTs’ STE model proves to have an interesting effect, in that it is, generally, not a variable of importance in relation to understanding of PNM, stoichiometry or equilibrium concepts. However, it is a variable of importance in relation to understanding of chemical bonding concepts. These results will also demonstrate that concurrent PSSTs’ year of study is a variable of importance in certain areas. This effect will be shown to be counterintuitive; PSSTs in their 1st year of study on a concurrent STE programme demonstrate better understanding of chemistry concepts than those in other years of study.

5.1 DESCRIPTIVE STATISTICS

The focus of the descriptive statistics section is upon examining the measures of central tendency, location and dispersion of data for each of the outcome variables of the diagnostic instrument. This detail is provided for the outcome variables\textsuperscript{123} for the full data set and for the outcome variables differentiated by the categories of each independent variable\textsuperscript{124}.

\textsuperscript{123} That is, the total score in the diagnostic instrument and the scores in the conceptual areas of PNM, chemical bonding, stoichiometry and equilibrium.

\textsuperscript{124} These variables have been previously outlined in Section 4.1.
Examining the measures of central tendency and dispersion allows for a simple comparison between groups arising from each variable in terms of the mean, standard deviation, etc. These values are presented in tabular format and are also referred to within the text. Measures of location of the data are presented in the form of range and quartile values in tabular format and a visualisation of these measures is provided using box plots.

The outcome variables will be explored according the categories arising from each of the independent variables. Therefore, each outcome will be investigated according to the following variables and groupings:

- **Model of STE**: concurrent PSSTs and consecutive PSSTs,
- **concurrent year of study**: 1st, 2nd, 3rd and 4th year PSSTs on concurrent STE programmes,
- **consecutive degree classification**: PSSTs on consecutive STE programmes achieving 1.1, 2.1 or 2.2 degree classifications,
- **gender**: male and female PSSTs,
- **chemistry specialism**: PSSTs with and without a specialism in chemistry,
- **upper-second-level chemistry**: PSSTs who did and did not study upper-second-level chemistry,
- **level of study of upper-second-level mathematics**: PSSTs who studied lower- and higher-level mathematics at upper-second-level,
- **upper-second-level physics**: PSSTs who did and did not study upper-second-level physics, and
- **awareness of alternative conceptions**: PSSTs who indicate that they are aware or are not aware of the issue of alternative conceptions in chemistry.

(a) **PSSTs’ Performance in the Alternative Conceptions Diagnostic Instrument**

The measures of central tendency, dispersion and location of data arising from all PSSTs involved in the study \((n = 467)\) are provided in Table 5.1. The mean total score achieved by PSSTs was relatively low \((M = 37.35\%)\) considering that half of the marks (10 marks) were related to concepts studied at lower-second-level (35%) or to concepts necessary to make up chemical solutions for use in the laboratory (15%). The most poorly answered area of the instrument was equilibrium. The next most poorly answered area was chemical bonding.

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125 Recall from Section 1.2(b) that *A1 level* in NI and *honours level* in ROI are categorised here as ‘higher-level’ and *AS level* in NI and *ordinary level* in ROI are categorised here as ‘lower-level’.
= 36.40%) followed by stoichiometry (M = 40.50%). The highest proportion of correct responses was in the conceptual area of PNM (M = 47.86%).

Table 5.1 Central tendency, dispersion and location in each conceptual area for all PSSTs (n = 467)

<table>
<thead>
<tr>
<th></th>
<th>Mean (Max)</th>
<th>S.D.</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
<th>Quartiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNM</td>
<td>3.35 (8)</td>
<td>1.59</td>
<td>4.00</td>
<td>4</td>
<td>7</td>
<td>Q1 2.00 Q2 4.00 Q3 5.00</td>
</tr>
<tr>
<td>Chemical Bonding</td>
<td>1.82 (5)</td>
<td>1.15</td>
<td>2.00</td>
<td>2</td>
<td>5</td>
<td>Q1 1.00 Q2 2.00 Q3 3.00</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>1.62 (4)</td>
<td>0.92</td>
<td>2.00</td>
<td>2</td>
<td>4</td>
<td>Q1 1.00 Q2 2.00 Q3 2.00</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>0.52 (3)</td>
<td>0.70</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>Q1 0.00 Q2 0.00 Q3 1.00</td>
</tr>
<tr>
<td>Total Score</td>
<td>7.47 (20)</td>
<td>2.96</td>
<td>8.00</td>
<td>8</td>
<td>17</td>
<td>Q1 5.00 Q2 8.00 Q3 9.00</td>
</tr>
</tbody>
</table>

The distribution of scores for each conceptual area in the instrument may be seen in Figure 5.1. In each of the conceptual areas, some PSSTs obtained a score of zero-marks. The highest proportion of these scores was in the area of equilibrium. There were relatively few maximum scores achieved in any area of the instrument and the highest proportion of these was in PNM. The majority of scores are located centrally in PNM, chemical bonding and stoichiometry. However, the majority of scores for equilibrium were zero-marks.

The distribution of total scores obtained by PSSTs in the diagnostic instrument is displayed in Figure 5.2. The maximum possible score in the instrument was 20 marks; none of the PSSTs achieved this score. Almost half of PSSTs (49.89%) achieved less than 40% (i.e. less than 8 marks) in the instrument and a further 14.13% achieved exactly 40% (8 marks).

\[126\] In all cases, this was due to incorrect responses rather than non-response, the latter being coded differently in SPSS and excluded from all analyses as outlined in Section 4.3.
Figure 5.1 The distribution of scores obtained by PSSTs in each of the conceptual areas of the diagnostic instrument (top-left: PNM; top-right: chemical bonding; bottom-left: stoichiometry; bottom-right: equilibrium).
Figure 5.2 The distribution of total scores obtained by PSSTs in the diagnostic instrument

(b) Achievement in Particulate Nature of Matter

The variables associated with the largest difference in mean scores for PNM were: previous upper-second-level experience of chemistry and mathematics, and STE model. Table 5.2 shows the descriptive statistics for the area of PNM. PSSTs who studied chemistry at upper-second-level achieved higher mean and median scores \((M = 3.89, SD = 1.52, Mdn = 4.00)\) than those who had not studied chemistry \((M = 3.15, SD = 1.58, Mdn = 3.00)\). Similarly, PSSTs who had studied mathematics at the higher-level in upper-second-level education achieved higher mean and median scores \((M = 3.75, SD = 1.66, Mdn = 4.00)\) than those who studied it at the lower-level \((M = 3.16, SD = 1.42, Mdn = 3.00)\). Figure 5.3 confirms the relative location of scores identified by these simple mean and median comparisons. In relation to model of STE, the consecutive group achieved a higher mean score in PNM \((M = 3.99, SD = 1.63)\) than the concurrent group \((M = 3.35, SD = 1.53)\). Figure 5.3 shows that the data is located one score higher for the consecutive group.

Upper-second-level physics, awareness of the issue of alternative conceptions in chemistry, and the degree classification awarded to consecutive PSSTs are also associated with mean differences. Study of upper-second-level physics is associated with a higher mean PNM score \((M = 4.26, SD = 1.82)\) compared with not having studied the subject \((M = 3.83, SD = 1.52)\). However, both groups achieved the same median score \((Mdn = 4.00)\). The box plots in Figure 5.3 reveal that, although the location of the data is quite similar, the third quartile of data for the group who had studied physics is dispersed over a wider, higher range of scores.
Table 5.2 Central tendency, dispersion and location for scores in PNM differentiated according to the groups arising from each of the variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups within variable</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEModel</td>
<td>Concurrent (n = 323)</td>
<td>3.35</td>
<td>1.53</td>
<td>3.00</td>
<td>3</td>
<td>7</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive (n = 144)</td>
<td>3.99</td>
<td>1.63</td>
<td>4.00</td>
<td>4</td>
<td>7</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td>ConcYear</td>
<td>Concurrent 1st years (n = 97)</td>
<td>3.41</td>
<td>1.44</td>
<td>3.00</td>
<td>4</td>
<td>7</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 2nd years (n = 100)</td>
<td>3.29</td>
<td>1.67</td>
<td>3.00</td>
<td>3</td>
<td>7</td>
<td>2.00</td>
<td>3.00</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 3rd years (n = 85)</td>
<td>3.25</td>
<td>1.49</td>
<td>3.00</td>
<td>3</td>
<td>7</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 4th years (n = 41)</td>
<td>3.54</td>
<td>1.50</td>
<td>4.00</td>
<td>3 &amp; 4</td>
<td>6</td>
<td>2.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td>ConsecDegree</td>
<td>Consecutive degree classification 1.1 (n = 30)</td>
<td>4.07</td>
<td>1.70</td>
<td>4.00</td>
<td>4</td>
<td>7</td>
<td>4.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive degree classification 2.1 (n = 75)</td>
<td>3.85</td>
<td>1.66</td>
<td>4.00</td>
<td>4 &amp; 5</td>
<td>7</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive degree classification 2.2 (n = 15)</td>
<td>4.33</td>
<td>1.54</td>
<td>4.00</td>
<td>3 - 6</td>
<td>5</td>
<td>3.00</td>
<td>4.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Gender</td>
<td>Male (n = 135)</td>
<td>3.58</td>
<td>1.57</td>
<td>4.00</td>
<td>4</td>
<td>7</td>
<td>2.00</td>
<td>4.00</td>
<td>5.00</td>
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<tr>
<td></td>
<td>Female (n = 331)</td>
<td>3.52</td>
<td>1.58</td>
<td>3.00</td>
<td>3</td>
<td>7</td>
<td>2.00</td>
<td>3.00</td>
<td>5.00</td>
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<td>ChemSpec</td>
<td>Chemistry specialism (n = 143)</td>
<td>3.82</td>
<td>1.60</td>
<td>4.00</td>
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<td>7</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
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<td></td>
<td>No chemistry specialism (n = 199)</td>
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<td>7</td>
<td>2.00</td>
<td>4.00</td>
<td>5.00</td>
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<td>USLChem</td>
<td>No study USL chemistry (n = 210)</td>
<td>3.15</td>
<td>1.58</td>
<td>3.00</td>
<td>3</td>
<td>7</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>Study USL chemistry (n = 245)</td>
<td>3.89</td>
<td>1.52</td>
<td>4.00</td>
<td>4</td>
<td>7</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td>USLMath</td>
<td>Lower level study USL mathematics (n = 167)</td>
<td>3.16</td>
<td>1.42</td>
<td>3.00</td>
<td>3</td>
<td>6</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
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<td>4</td>
<td>7</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
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<td>No study USL physics (n = 319)</td>
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<td>4</td>
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<td>3.00</td>
<td>4.00</td>
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</tr>
<tr>
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<td>4 &amp; 6</td>
<td>7</td>
<td>3.00</td>
<td>4.00</td>
<td>6.00</td>
</tr>
<tr>
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<td>Not aware alternative conceptions (n = 187)</td>
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<td>7</td>
<td>2.00</td>
<td>3.00</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Aware alternative conceptions (n = 265)</td>
<td>3.80</td>
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<td>4</td>
<td>7</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
</tbody>
</table>
Figure 5.3 Performance in the conceptual area PNM across all variable categories [Note that darker and lighter shades represent the locations of the 2nd and 3rd quartile groups, respectively]
PSSTs with an awareness of the issue of alternative conceptions achieved higher mean and median scores ($M = 3.80, SD = 1.62$, $Mdn = 4.00$) than those without this awareness ($M = 3.42, SD = 1.55$, $Mdn = 3.00$). Examining the degree classifications for those on consecutive STE programmes ($n = 144$) reveals that those who were awarded a 2.2 classification achieved the highest mean score ($M = 4.33, SD = 1.54$), followed by those who were awarded a 1.1 degree classification ($M = 4.07, SD = 1.70$), and a 2.1 degree classification ($M = 3.85, SD = 1.66$). However, the median scores of these three groups were identical ($Mdns = 4.00$). Small mean differences are associated with the year of study for concurrent PSSTs and whether or not they had chosen to specialise in chemistry. These mean differences were lower than 0.30 marks. Finally, a negligible mean difference was associated with gender.

**(c) Achievement in Chemical Bonding**

The data related to central tendency, location and dispersion of data in the area of chemical bonding are presented in Table 5.3 and Figure 5.4. The largest mean differences were associated with upper-second-level experience of chemistry and model of STE. However, unlike the case in PNM, the level of study of upper-second-level mathematics was associated with a negligible difference. PSSTs on concurrent STE programmes achieved higher mean and median scores ($M = 1.99, SD = 1.12$, $Mdn = 2.00$) than those on consecutive STE programmes ($M = 1.44, SD = 1.12$, $Mdn = 1.00$). The box plots for these two groups in Figure 5.4 confirm this difference. PSSTs who had studied chemistry at upper-second-level achieved higher mean, though not median, scores ($M = 2.02, SD = 1.12$) than those who had not studied chemistry ($M = 1.58, SD = 1.13$).

Mean differences were associated with consecutive degree classification, concurrent year of study and PSSTs’ specialism. Isolating the consecutive group ($n = 144$) to examine the mean differences associated with degree classifications, reveals that those who were awarded a 1.1 degree classification achieved higher mean and median scores ($M = 1.63, SD = 1.07$, $Mdn = 2.00$) than those who were awarded either a 2.1 ($M = 1.49, SD = 1.15$, $Mdn = 1.00$) or a 2.2 ($M = 1.27, SD = 1.10$, $Mdn = 1.00$) degree classification. Figure 5.4 shows that the second quartile for the 2.2 classification group is located lower than the second quartile for the other two groups. Examining the mean differences associated with year of study for concurrent PSSTs ($n = 323$), reveals that those in their 1st year of study achieved a higher mean score ($M = 2.19, SD = 1.22$) than those in either their 2nd ($M = 1.84, SD = 1.11$) or 3rd ($M = 1.89, SD = 0.99$) years of study. Those in their 1st year also achieved a higher mean score than those in their 4th year ($M = 2.10, SD = 1.09$). However, this difference was less than 0.10 marks.
Table 5.3 Central tendency, dispersion and location for scores in chemical bonding differentiated according to the groups arising from each of the variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups within variable</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
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<td>1.12</td>
<td>2.00</td>
<td>2</td>
<td>5</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive (n = 144)</td>
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<td>2</td>
<td>4</td>
<td>0.75</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>ConcYear</td>
<td>Concurrent 1st years (n = 97)</td>
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<td>1.22</td>
<td>2.00</td>
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<td>5</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 2nd years (n = 100)</td>
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<td>2.00</td>
<td>2</td>
<td>5</td>
<td>1.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 3rd years (n = 85)</td>
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<td>0.99</td>
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<td>4</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
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<td></td>
<td>Concurrent 4th years (n = 41)</td>
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<td>2.00</td>
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<td>ConsecDegree</td>
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<td></td>
<td>Consecutive degree classification 2.2 (n = 15)</td>
<td>1.27</td>
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<tr>
<td>Gender</td>
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<tr>
<td></td>
<td>Female (n = 331)</td>
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<td>2.00</td>
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<tr>
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</tr>
<tr>
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<td>1.00</td>
<td>2.00</td>
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</tr>
<tr>
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<td>2.00</td>
<td>3.00</td>
</tr>
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<td>No study USL physics (n = 319)</td>
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<td>1.00</td>
<td>1.00</td>
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</tr>
<tr>
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<td>Not aware alternative conceptions (n = 187)</td>
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<td>1.20</td>
<td>2.00</td>
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<td>5</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
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<td></td>
<td>Aware alternative conceptions (n = 265)</td>
<td>1.93</td>
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<td>5</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>
Figure 5.4 Performance in the conceptual area chemical bonding across all variable categories
All four years of study achieved the same median score \( (Mdn = 2.00) \). The box plots in Figure 5.4, demonstrate that the location of scores is very similar for each of the year groups with the exception of those in their 3rd year of study. In relation to PSSTs’ specialism, those who had a chemistry specialism achieved a slightly higher mean score \( (M = 2.01, SD = 0.99) \) than those who did not \( (M = 1.71, SD = 1.21) \). However, both groups achieved the same median score \( (Mdn = 2.00) \) and display no difference in the location of scores.

Finally, the mean differences related to awareness of alternative conceptions, upper-second-level study of mathematics and physics, and gender were negligible. The median values were the same for the groups arising from each of the variables and Figure 5.4 shows that the location of data is similar. Exact values for these variables may be seen in Table 5.3.

(d) Achievement in Stoichiometry

The largest differences in mean scores in the area of stoichiometry were associated with: the degree classification among the consecutive group, PSSTs’ experience of upper-second-level chemistry, and PSSTs’ specialism. Isolating the consecutive group \( (n = 144) \) from the rest of the participants, those who had been awarded a degree classification of 1.1 for their previous science degree achieved higher mean and median scores \( (M = 1.97, SD = 0.78, Mdn = 2.00) \) than those who had been awarded either a 2.1 \( (M = 1.53, SD = 1.02, Mdn = 1.00) \) or a 2.2 \( (M = 1.07, SD = 0.92, M = 1.00) \) classification. The box plots displayed in Figure 5.5 confirm that the location of scores is highest for the group with a 1.1 classification, followed by those with a 2.1 classification and a 2.2 classification. Examining the mean differences related to upper-second-level experience of chemistry for the full PSST cohort \( (n = 467) \) reveals that those who had studied upper-second-level chemistry achieved higher mean and median scores \( (M = 1.81, SD = 0.87, Mdn = 2.00) \) than those who had not studied chemistry \( (M = 1.39, SD = 0.91, Mdn = 1.00) \). In contrast to the area of PNM and chemical bonding, PSSTs’ choice to specialise in chemistry (or not) is also associated with a difference in mean scores. Those with a chemistry specialism achieved higher mean and median scores \( (M = 1.87, SD = 0.87, Mdn = 2.00) \) in stoichiometry than those who did not have a chemistry specialism \( (M = 1.47, SD = 0.89, Mdn = 1.00) \). The findings in relation to the PSSTs’ specialism and experience of upper-second-level chemistry are presented in Table 5.4 and Figure 5.5.

PSSTs’ experience of upper-second-level mathematics and physics are also associated with differences in mean scores. Those who had studied mathematics at higher-level achieved higher mean and median scores \( (M = 1.72, SD = 0.91, Mdn = 2.00) \) than those who had studied the subject at lower-level \( (M = 1.46, SD = 0.91, Mdn = 1.00) \).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups within variable</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
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<td>1.65</td>
<td>0.89</td>
<td>2.00</td>
<td>2</td>
<td>4</td>
<td>1.00</td>
<td>2.00</td>
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</tr>
<tr>
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<tr>
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<td>4</td>
<td>1.00</td>
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<tr>
<td><strong>USLPhys</strong></td>
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<td>1.42</td>
<td>1.03</td>
<td>1.00</td>
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<tr>
<td><strong>Aware</strong></td>
<td>Not aware alternative conceptions ($n = 187$)</td>
<td>1.58</td>
<td>0.93</td>
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<td>4</td>
<td>1.00</td>
<td>2.00</td>
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<td>Aware alternative conceptions ($n = 265$)</td>
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<td>4</td>
<td>1.00</td>
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</tr>
</tbody>
</table>
Figure 5.5 Performance in the conceptual area stoichiometry across all variable categories
Similarly, those who had studied physics at upper-second-level achieved higher mean and median scores ($M = 1.67, SD = 0.90, Mdn = 2.00$) than those who had not studied physics ($M = 1.42, SD = 1.03, Mdn = 1.00$). Isolating the concurrent group ($n = 323$) to examine the mean scores associated with concurrent year of study, reveals that there was virtually no mean or median difference associated with PSSTs being in their 2nd ($M = 1.60, SD = 0.84, Mdn = 2.00$), 3rd ($M = 1.60, SD = 0.90, Mdn = 2.00$) or 4th ($M = 1.61, SD = 0.80, Mdn = 2.00$) years of study. However, those in their 1st year of study achieved a higher mean score ($M = 1.76, SD = 0.95, Mdn = 2.00$) than any other year group. Figure 5.5 confirms that the location of data is higher for the 1st year group than the other year groups.

Finally, there was very little difference in mean scores for stoichiometry associated with model of STE, gender, or awareness of alternative conceptions in chemistry. There was no median difference associated with these variables ($Mdns = 2.00$). Figure 5.5 confirms that the location of data is identical for each of the groups arising from these variables.

(e) Achievement in Equilibrium

Items related to equilibrium were poorly answered by all PSSTs resulting in very low mean differences between all groups as may be seen in Table 5.5. This is also confirmed by the box plots in Figure 5.6 which show that the data was similarly located in all cases. However, the largest differences in mean scores were associated with upper-second-level experience of chemistry and physics. Those who had studied chemistry achieved a higher mean score ($M = 0.66, SD = 0.77$) than those who had not studied chemistry ($M = 0.33, SD = 0.50$), and those who had studied physics achieved a higher mean score ($M = 0.71, SD = 0.84$) than those who had not studied physics ($M = 0.46, SD = 0.62$). There was no difference in median scores associated with study of chemistry ($Mdns = 0.00$) and the box plots in Figure 5.6 confirm that the data is similarly located. However, those who studied physics achieved a higher median score ($Mdn = 1.00$) than those who had not studied the subject ($Mdn = 0.00$).

Isolating the consecutive group ($n = 144$), the degree classification for their science degree was associated with differences in mean scores. Those with a 1.1 award achieved higher mean and median scores ($M = 0.72, SD = 0.75, Mdn = 1.00$) than those with a 2.1 award ($M = 0.53, SD = 0.78, Mdn = 0.00$) or a 2.2 award ($M = 0.43, SD = 0.51, Mdn = 0.00$). Isolating the concurrent group ($n = 323$), PSSTs’ concurrent year of study was also associated with differences in mean scores. Those in their 1st year of study achieved a higher mean, though not median, score ($M = 0.62, SD = 0.76, Mdn = 0.00$) than those in their 2nd ($M = 0.47, SD = 0.67, Mdn = 0.00$), 3rd ($M = 0.38, SD = 0.56, Mdn = 0.00$) or 4th ($M = 0.46, SD = 0.64, Mdn = 0.00$) years of study.
Table 5.5 Central tendency, dispersion and location for scores in equilibrium differentiated according to the groups arising from each of the variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups within variable</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STEModel</strong></td>
<td>Concurrent ((n = 323))</td>
<td>0.49</td>
<td>0.67</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive ((n = 144))</td>
<td>0.60</td>
<td>0.77</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>ConcYear</strong></td>
<td>Concurrent 1(^{st}) years ((n = 97))</td>
<td>0.62</td>
<td>0.76</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 2(^{nd}) years ((n = 100))</td>
<td>0.47</td>
<td>0.67</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 3(^{rd}) years ((n = 85))</td>
<td>0.38</td>
<td>0.56</td>
<td>0.00</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 4(^{th}) years ((n = 41))</td>
<td>0.46</td>
<td>0.64</td>
<td>0.00</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>ConsecDegree</strong></td>
<td>Consecutive degree classification 1.1 ((n = 30))</td>
<td>0.72</td>
<td>0.75</td>
<td>1.00</td>
<td>1</td>
<td>3</td>
<td>0.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive degree classification 2.1 ((n = 75))</td>
<td>0.53</td>
<td>0.78</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td></td>
<td>Consecutive degree classification 2.2 ((n = 15))</td>
<td>0.43</td>
<td>0.51</td>
<td>0.00</td>
<td>0</td>
<td>1</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td>Male ((n = 135))</td>
<td>0.67</td>
<td>0.81</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Female ((n = 331))</td>
<td>0.46</td>
<td>0.63</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>ChemSpec</strong></td>
<td>Chemistry specialism ((n = 143))</td>
<td>0.59</td>
<td>0.72</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>No chemistry specialism ((n = 199))</td>
<td>0.49</td>
<td>0.67</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>USLChem</strong></td>
<td>No study USL chemistry ((n = 210))</td>
<td>0.33</td>
<td>0.50</td>
<td>0.00</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Study USL chemistry ((n = 245))</td>
<td>0.66</td>
<td>0.77</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>USLMath</strong></td>
<td>Lower level study USL mathematics ((n = 167))</td>
<td>0.42</td>
<td>0.59</td>
<td>0.00</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Higher level study USL mathematics ((n = 259))</td>
<td>0.57</td>
<td>0.74</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>USLPhys</strong></td>
<td>No study USL physics ((n = 319))</td>
<td>0.46</td>
<td>0.62</td>
<td>0.00</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Study USL physics ((n = 133))</td>
<td>0.71</td>
<td>0.84</td>
<td>1.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Aware</strong></td>
<td>Not aware alternative conceptions ((n = 187))</td>
<td>0.51</td>
<td>0.68</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Aware alternative conceptions ((n = 265))</td>
<td>0.55</td>
<td>0.74</td>
<td>0.00</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Figure 5.6 Performance in the conceptual area equilibrium across all variable categories
Unlike in previous conceptual areas of the diagnostic instrument, gender was associated with a difference in mean scores, with male PSSTs achieving a higher mean score ($M = 0.67$, $SD = 0.81$) than female PSSTs ($M = 0.46$, $SD = 0.63$). There was no difference in median scores between male and female PSSTs ($Mdn = 0.00$).

Upper-second-level experience of mathematics and PSSTs’ model of STE also resulted in small mean differences between groups; the differences were 0.15 and 0.11 marks, respectively. Those who had studied upper-second-level mathematics at higher-level achieved a higher mean score ($M = 0.57$, $SD = 0.74$) than those who had studied mathematics at lower-level ($M = 0.42$, $SD = 0.59$). PSSTs studying on consecutive STE programmes achieved a higher mean score ($M = 0.60$, $SD = 0.77$) than those studying on concurrent programmes ($M = 0.49$, $SD = 0.67$). There was no difference in median scores associated with upper-second-level experience of mathematics or STE model ($Mden = 0.00$).

There were some further small mean differences associated with PSSTs’ specialism and awareness of alternative conceptions in chemistry. Again, there were no differences in median scores associated with either of these variables.

(f) **Total Score on the Diagnostic Instrument**

As may be seen in Table 5.6, the largest difference in mean total scores was associated with upper-second-level chemistry experience; those who had studied chemistry achieved mean and median scores ($M = 8.36$, $SD = 2.88$, $Mdn = 8.00$) that were approximately 2.0 marks higher than the mean and median achieved by those who had not studied chemistry ($M = 6.37$, $SD = 2.64$, $Mdn = 6.00$). The higher location of data for the group who had studied chemistry may also be seen in Figure 5.7.

Mean differences of approximately one mark were associated with the areas of: degree classification for the consecutive group, previous experience of upper-second-level mathematics and physics, and PSSTs’ specialism. Isolating the consecutive group ($n = 144$) to examine the differences associated with degree classification, reveals that those who had been awarded a 1.1 classification for their previous science degrees achieved higher mean and median scores ($M = 8.30$, $SD = 2.44$, $Mdn = 9.00$) than those with either a 2.1 classification ($M = 7.32$, $SD = 3.41$, $Mdn = 7.00$) or a 2.2 classification ($M = 7.00$, $SD = 2.95$, $Mdn = 7.00$). PSSTs who had studied higher-level mathematics achieved a mean score ($M = 7.86$, $SD = 3.09$) that was 1.09 marks higher than the group who had studied the subject at lower-level ($M = 6.77$, $SD = 2.70$). The higher-level mathematics group also achieved a higher median score ($Mdn = 8.00$) than the lower-level mathematics group ($Mdn = 7.00$).
Table 5.6 Central tendency, dispersion and location for total score in the diagnostic instrument differentiated according to the groups arising from each of the variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups within variable</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEModel</td>
<td>Concurrent (n = 323)</td>
<td>7.46</td>
<td>2.87</td>
<td>8.00</td>
<td>8</td>
<td>17</td>
<td>5.00</td>
<td>8.00</td>
<td>9.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive (n = 144)</td>
<td>7.50</td>
<td>3.17</td>
<td>7.00</td>
<td>6 &amp; 8</td>
<td>15</td>
<td>5.00</td>
<td>7.00</td>
<td>10.00</td>
</tr>
<tr>
<td>ConcYear</td>
<td>Concurrent 1st years (n = 97)</td>
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<td>3.00</td>
<td>8.00</td>
<td>9</td>
<td>15</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 2nd years (n = 100)</td>
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<td>5 &amp; 8</td>
<td>16</td>
<td>5.00</td>
<td>7.00</td>
<td>9.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 3rd years (n = 85)</td>
<td>7.12</td>
<td>2.71</td>
<td>7.00</td>
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<td>13</td>
<td>5.00</td>
<td>7.00</td>
<td>9.00</td>
</tr>
<tr>
<td></td>
<td>Concurrent 4th years (n = 41)</td>
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<td>10</td>
<td>11</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
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<tr>
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<td>Consecutive degree classification 1.1 (n = 30)</td>
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<td>8 &amp; 9</td>
<td>10</td>
<td>7.75</td>
<td>9.00</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive degree classification 2.1 (n = 75)</td>
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<td>3.41</td>
<td>7.00</td>
<td>6</td>
<td>15</td>
<td>5.00</td>
<td>7.00</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>Consecutive degree classification 2.2 (n = 15)</td>
<td>7.00</td>
<td>2.95</td>
<td>7.00</td>
<td>7</td>
<td>10</td>
<td>5.00</td>
<td>7.00</td>
<td>9.00</td>
</tr>
<tr>
<td>Gender</td>
<td>Male (n = 135)</td>
<td>7.72</td>
<td>3.20</td>
<td>7.00</td>
<td>6</td>
<td>16</td>
<td>5.00</td>
<td>7.00</td>
<td>10.00</td>
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<tr>
<td></td>
<td>Female (n = 331)</td>
<td>7.34</td>
<td>2.82</td>
<td>8.00</td>
<td>8</td>
<td>15</td>
<td>5.00</td>
<td>8.00</td>
<td>9.00</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>Chemistry specialism (n = 143)</td>
<td>8.27</td>
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<td>8.00</td>
<td>10</td>
<td>15</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>No chemistry specialism (n = 199)</td>
<td>7.20</td>
<td>2.93</td>
<td>7.00</td>
<td>8</td>
<td>15</td>
<td>5.00</td>
<td>7.00</td>
<td>9.00</td>
</tr>
<tr>
<td>USLChem</td>
<td>No study USL chemistry (n = 210)</td>
<td>6.37</td>
<td>2.64</td>
<td>6.00</td>
<td>5</td>
<td>13</td>
<td>5.00</td>
<td>6.00</td>
<td>8.00</td>
</tr>
<tr>
<td></td>
<td>Study USL chemistry (n = 245)</td>
<td>8.36</td>
<td>2.88</td>
<td>8.00</td>
<td>8</td>
<td>15</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
</tr>
<tr>
<td>USLMath</td>
<td>Lower level study USL mathematics (n = 167)</td>
<td>6.77</td>
<td>2.70</td>
<td>7.00</td>
<td>6</td>
<td>13</td>
<td>5.00</td>
<td>7.00</td>
<td>8.00</td>
</tr>
<tr>
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<td>Higher level study USL mathematics (n = 259)</td>
<td>7.86</td>
<td>3.08</td>
<td>8.00</td>
<td>5, 8 &amp; 9</td>
<td>17</td>
<td>5.00</td>
<td>8.00</td>
<td>10.00</td>
</tr>
<tr>
<td>USLPhys</td>
<td>No study USL physics (n = 309)</td>
<td>7.02</td>
<td>3.04</td>
<td>7.00</td>
<td>6</td>
<td>12</td>
<td>5.00</td>
<td>7.00</td>
<td>9.00</td>
</tr>
<tr>
<td></td>
<td>Study USL physics (n = 127)</td>
<td>7.98</td>
<td>3.31</td>
<td>8.00</td>
<td>8</td>
<td>15</td>
<td>5.50</td>
<td>8.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Aware</td>
<td>Not aware alternative conceptions (n = 187)</td>
<td>7.25</td>
<td>3.05</td>
<td>7.00</td>
<td>8</td>
<td>15</td>
<td>5.00</td>
<td>7.00</td>
<td>9.00</td>
</tr>
<tr>
<td></td>
<td>Aware alternative conceptions (n = 265)</td>
<td>7.93</td>
<td>2.83</td>
<td>8.00</td>
<td>8</td>
<td>17</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
</tr>
</tbody>
</table>
Figure 5.7 Overall performance in the diagnostic instrument across all variable categories.
The study of upper-second-level physics was associated with mean score differences: those who had studied physics achieved higher mean and median scores ($M = 7.98, SD = 3.31$, $Mdn = 8.00$) than those who had not studied physics ($M = 7.02, SD = 3.04$, $Mdn = 7.00$). The mean and median scores for those with a specialism in chemistry ($M = 8.27, SD = 2.80$, $Mdn = 8.00$) were also approximately one mark higher than the scores for those not specialising in the subject ($M = 7.20, SD = 2.92$, $Mdn = 7.00$). In each of these cases, the box plots shown in Figure 5.7 confirm the relative location of scores.

Small mean differences were associated with: concurrent year of study, awareness of alternative conceptions in chemistry, and gender. Isolating the concurrent group ($n = 323$) to examine the differences associated with year of study, demonstrates that 1st year ($M = 7.94, SD = 3.00$, $Mdn = 8.00$) and 4th year PSSTs ($M = 7.71, SD = 2.81$, $Mdn = 8.00$) achieved higher mean and median scores than either 2nd year ($M = 7.18, SD = 2.87$, $Mdn = 7.00$) or 3rd year PSSTs ($M = 7.12, SD = 2.71$, $Mdn = 7.00$). An awareness of the issue of alternative conceptions in chemistry was associated with a mean difference of 0.68 marks and a median difference of 1.00 marks, with PSSTs who had an awareness of alternative conceptions achieving the higher mean and median scores ($M = 7.93, SD = 3.31$, $Mdn = 8.00$). The relative location of data associated with concurrent year of study and awareness of alternative conceptions is confirmed in Figure 5.7. Gender is also associated with a mean and median difference. In this case, males PSSTs achieved a mean score ($M = 7.72, SD = 3.20$) that was 0.38 marks higher than that achieved by female PSSTs ($M = 7.34, SD = 2.82$). However, female PSSTs achieved the higher median score by 1.00 marks ($Mdn = 8.00$).

The model of STE followed by PSSTs was associated with a negligible difference in mean scores of 0.04 marks favouring the consecutive group ($M = 7.50, SD = 3.17$). However, there was a median difference of 1.00 marks favouring the concurrent PSSTs ($Mdn = 8.00$).
SUMMARY OF MAIN POINTS OF INTEREST

Previous upper-second-level experience of chemistry was consistently associated with the largest mean differences in each conceptual area of the instrument. Previous upper-second-level experience of mathematics, although often not associated with the largest mean differences, was associated with mean differences in PNM, stoichiometry, and total scores on the diagnostic instrument. Some other notable mean differences were also associated with the following variables and conceptual areas:

- STE Model in the areas of PNM and chemical bonding. PSSTs in consecutive programmes achieved the higher mean score in PNM and PSSTs in concurrent programmes achieved the higher mean score in chemical bonding;
- previous upper-second-level experience of physics in the areas of PNM, equilibrium, and total scores. Those who studied physics achieved higher mean scores;
- awareness of alternative conceptions in the area of PNM. Those who were aware of this issue achieved a higher mean score than those who were not aware of the issue;
- degree classification awarded to consecutive PSSTs for their previous science degree in all areas. These mean differences were not consistent – sometimes favouring those with 2.2 classifications and other times favouring those with 1.1 classifications;
- year of study for PSSTs on concurrent programmes in the area of chemical bonding. This mean difference favoured those in their 1st year over all other years of study;
- PSSTs’ specialism in the area of PNM and total scores on the diagnostic instrument. Those with a specialism in chemistry achieved the higher mean score.
5.2 COMPARISON TESTS TO DETERMINE SIGNIFICANCE OF DIFFERENCES IN CENTRAL TENDENCY

The assumptions associated with the comparison tests were investigated as detailed in Section 4.3(b). These findings may be found in Appendix G. The significance of mean and median differences associated with the model of STE were first compared for the full cohort; the variable STEModel refers to this comparison. The significance associated with the STE model was also assessed between only the 4th year concurrent PSSTs and the consecutive cohort. Those in their 4th year of study on a concurrent programme and on consecutive programmes have similar amounts of third-level education, ensuring that like was compared with like; the variable STEModel(Y4Conc) refers to this comparison.

(a) Particulate Nature of Matter

Table 5.7 shows the findings of the comparison tests in PNM. As shown in Section 5.1(b), the largest mean differences were associated with previous experience of upper-second-level chemistry and mathematics, and model of STE. The mean differences associated with experience of upper-second-level chemistry \((t(453) = 5.07, p < .001, d = .48)\) and mathematics \((t(391.53) = 3.96, p < .001, d = .38)\) were significant at the .001 level of probability. The effect sizes were medium and small-medium, respectively. Those who studied chemistry achieved a significantly higher mean score than those who had not studied chemistry, and those who had studied higher-level mathematics achieved a higher mean score than those who had studied it at the lower-level. The mean difference between consecutive and concurrent PSSTs was significant \((t(469) = 4.13, p < .001, d = .41)\) at the .001 level of probability. This effect size was medium. PSSTs on consecutive programmes achieved a significantly higher mean score than those on concurrent programmes. However, comparing the consecutive PSSTs with those PSSTs in their 4th year of a concurrent STE programme, reveals a non-significant difference in mean scores for PNM \((t(183) = 1.61, ns, d = .28)\).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Test</th>
<th>Relevant Statistic (df)</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEModel</td>
<td>Independent t-test</td>
<td>(t = 4.13(469)^{***})</td>
<td>(d = .41)</td>
</tr>
<tr>
<td>STEModel (Y4Conc)</td>
<td>Independent t-test</td>
<td>(t = 1.61(183))</td>
<td>(d = .28)</td>
</tr>
<tr>
<td>ConsecYear</td>
<td>One-Way ANOVA</td>
<td>(F = 0.43(3, 319))</td>
<td></td>
</tr>
<tr>
<td>ConsecDegree</td>
<td>Kruskal Wallis</td>
<td>(H = 1.40 (2))</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Independent t-test</td>
<td>(t = 0.34 (464))</td>
<td>(d = .04)</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>Independent t-test</td>
<td>(t = 1.35 (340))</td>
<td>(d = .15)</td>
</tr>
<tr>
<td>USLChem</td>
<td>Independent t-test</td>
<td>(t = 5.07(453)^{***})</td>
<td>(d = .48)</td>
</tr>
<tr>
<td>USLMath</td>
<td>Independent t-test</td>
<td>(t = 3.96(391.53)^{***})</td>
<td>(d = .38)</td>
</tr>
<tr>
<td>USLPhys</td>
<td>Independent t-test</td>
<td>(t = 1.08(450))</td>
<td>(d = .08)</td>
</tr>
<tr>
<td>Aware</td>
<td>Independent t-test</td>
<td>(t = 2.54(450)^*)</td>
<td>(d = .24)</td>
</tr>
</tbody>
</table>

Note: * \(p < .05\), ** \(p < .01\), *** \(p < .001\), \(^{\dagger}\) adjusted \(t\)-value due to violation of homogeneity of variance, effect size \(d\) is Cohen’s \(d\), df are degrees of freedom.
PSSTs’ awareness of alternative conceptions in chemistry was also associated with a significant mean difference ($t(450) = 2.54, p < .05, d = .24$) at the .05 level of probability. The effect size was small. PSSTs with an awareness of this issue achieved a significantly higher mean score than those without an awareness of this issue. The mean differences in PNM related to other variables were not significant.

(b) Chemical Bonding

The results of the independent t-tests, One-Way ANOVA, and Kruskal Wallis test for the area of chemical bonding are presented in Table 5.8. The largest mean differences in this area were associated with upper-second-level experience of chemistry and model of STE. The concurrent group achieved a higher mean score than the consecutive group. This mean difference was found to be significant ($t(463) = 4.93, p < .001, d = .49$) at the .001 level of probability. The effect size was medium. The mean score achieved by the consecutive group was also compared to that achieved by the 4th year concurrent PSSTs. Again the difference was significant ($t(181) = 3.35, p < .01, d = .60$): this time at the .01 level of probability. This indicates that the 4th year concurrent PSSTs achieved a significantly higher mean score than was achieved by the consecutive group. The effect size was medium-large.

The mean difference associated with upper-second-level chemistry was also found to be significant ($t(438.25) = 4.23, p < .05, d = .39$) at the .05 level of probability and with small-medium effect size. The mean score achieved by PSSTs with upper-second-level chemistry was significantly higher than the mean score achieved by those who had not studied chemistry. PSSTs’ specialism was associated with a significant mean difference ($t(333.55) = 2.57, p < .05, d = .27$). Those with a specialism in chemistry achieved a significantly higher mean score than those without it. Again, the effect size was small-medium. There were no significant mean differences in chemical bonding related to any of the other variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Test</th>
<th>Relevant Statistic (df)</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
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<td>Independent t-test</td>
<td>$t = 4.93(463)^{***}$</td>
<td>$d = .49$</td>
</tr>
<tr>
<td>STEModel (Y4Conc)</td>
<td>Independent t-test</td>
<td>$t = 3.35(181)^{**}$</td>
<td>$d = .60$</td>
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<td>ConcYear</td>
<td>One-Way ANOVA</td>
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<td>ConsecrDegree</td>
<td>Kruskal Wallis</td>
<td>$H = 1.15 (2)$</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Independent t-test</td>
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<td>$d = .03$</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>Independent t-test</td>
<td>$t = 2.57(333.55)^*$</td>
<td>$d = .27$</td>
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<td>Independent t-test</td>
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<td>$d = .39$</td>
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<td>Independent t-test</td>
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<td>USLPhys</td>
<td>Independent t-test</td>
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<td>$d = .18$</td>
</tr>
<tr>
<td>Aware</td>
<td>Independent t-test</td>
<td>$t = 1.38(448)$</td>
<td>$d = .13$</td>
</tr>
</tbody>
</table>

Note: * $p < .05$, ** $p < .01$, *** $p < .001$, t adjusted t-value due to violation of homogeneity of variance, effect size $d$ is Cohen’s $d$, df are degrees of freedom.
From Section 5.1(d), the largest differences in mean scores in the area of stoichiometry were associated with: degree classification among the consecutive group, PSSTs’ experience of upper-second-level chemistry, and PSSTs’ subject specialism. A Kruskal Wallis test reveals that the differences in stoichiometry scores related to the degree classification of consecutive PSSTs were significant ($H(2) = 9.36, p < .01$) at the .01 level of probability. As detailed in Table 5.9, post hoc comparisons were carried out using Mann-Whitney $U$ tests. There was a significant difference in scores between PSSTs who had been awarded a 1.1 degree classification and a 2.2 degree classification ($U = 95.00, z = 2.96, p < .01, r = .45$), with the former achieving the higher score. The effect size is medium.

The higher mean score achieved by PSSTs who studied upper-second-level chemistry compared with those who had not studied it was significant ($t(449) = 5.12, p < .001, d = .49$), as was the higher mean score achieved by those with a chemistry specialism when compared to those who did not ($t(311.48) = 4.16, p < .001, d = .46$). In both cases, the significance was at the .001 level of probability and the effect size was medium.

Finally, a significant mean difference was also related to PSSTs’ experience of upper-second-level mathematics ($t(420) = 2.81, p < .01, d = .29$). Those who studied at higher-level achieved a significantly higher mean score than those who had studied lower-level. This effect size was small-medium.
(d) Equilibrium

According to the descriptive statistics presented in Section 5.1(e), the largest differences in equilibrium scores were associated with upper-second-level experience of chemistry and physics. As all data related to equilibrium were non-normally distributed, only non-parametric tests were carried out. The results of these tests are shown in Table 5.10.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Test</th>
<th>Relevant Statistic</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
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<td>r = .06</td>
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<tr>
<td>STEModel (Y4Conc)</td>
<td>Mann-Whitney</td>
<td>U = 2543.50</td>
<td>r = .07</td>
</tr>
<tr>
<td>ConsecYear</td>
<td>Kruskal Wallis</td>
<td>H = 4.35(3)</td>
<td></td>
</tr>
<tr>
<td>ConsecDegree</td>
<td>Kruskal Wallis</td>
<td>H = 2.62 (2)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Mann-Whitney</td>
<td>U = 18284.50*</td>
<td>r = .11</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>Mann-Whitney</td>
<td>U = 12437.00</td>
<td>r = .07</td>
</tr>
<tr>
<td>USLChem</td>
<td>Mann-Whitney</td>
<td>U = 18666.50**</td>
<td>r = .22</td>
</tr>
<tr>
<td>USLMath</td>
<td>Mann-Whitney</td>
<td>U = 18330.00</td>
<td>r = .09</td>
</tr>
<tr>
<td>USLPhys</td>
<td>Mann-Whitney</td>
<td>U = 17177.00*</td>
<td>r = .11</td>
</tr>
<tr>
<td>Aware</td>
<td>Mann-Whitney</td>
<td>U = 23048.50</td>
<td>r = .00</td>
</tr>
</tbody>
</table>

Note: * p < .05, ** p < .01, *** p < .001, effect size r is non-parametric z-score conversion, df are degrees of freedom.

The higher scores achieved by those who had studied upper-second-level chemistry compared with those who had not studied the subject were found to be significantly different ($U = 18666.50, p < .01, r = .22$). The same was true of the higher scores achieved by those who had studied physics compared with those who had not studied physics ($U = 17177.00, p < .05, r = .11$). One other area of significance was also identified: male PSSTs achieved significantly higher scores in equilibrium than female PSSTs ($U = 18284.50, p < .05, r = .11$). The effect sizes associated with these mean differences are small.

(e) Total Score in the Diagnostic Instrument

PSSTs who had studied chemistry at upper-second-level achieved a mean score that was approximately two marks higher than that achieved by those who had not studied chemistry. This accounts for the largest mean difference in total scores on the diagnostic instrument. This difference was significant ($t(453) = 7.63, p < .001, d = .71$) at the .001 level of probability and with medium-large effect size.

A number of other variables were associated with mean differences of approximately one mark: degree classification for the consecutive group, previous experience of upper-second-level mathematics and physics, and PSSTs’ specialism. However, the comparison tests demonstrate that the differences associated with consecutive degree classification are non-significant ($H(2) = 4.16, ns$) as are the differences associated with upper-second-level experience of physics ($t(450) = 0.85, ns$). The higher mean score achieved by those who had studied mathematics at the higher level compared to the lower level was significant ($t(424) =$
The higher mean score achieved by PSSTs who had a specialism in chemistry compared to those who did not have a chemistry specialism was also significant ($t(340) = 3.40, p < .01, d = .37$). This was significant at the .01 level of probability and with small-medium effect size.

Table 5.11 Results of mean/median comparisons for the total score in the diagnostic instrument

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Test</th>
<th>Relevant Statistic (df)</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEModel</td>
<td>Independent t-test</td>
<td>$t = 0.14(465)$</td>
<td>$d = .01$</td>
</tr>
<tr>
<td>STEModel (Y4Conc)</td>
<td>Independent t-test</td>
<td>$t = 0.38(183)$</td>
<td>$d = .07$</td>
</tr>
<tr>
<td>ConcYear</td>
<td>One-Way ANOVA</td>
<td>$F = 1.73(3, 319)$</td>
<td></td>
</tr>
<tr>
<td>ConsecDegree</td>
<td>Kruskal Wallis</td>
<td>$H = 4.16 (2)$</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Independent t-test</td>
<td>$t = 1.25(223.38)$</td>
<td>$d = .13$</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>Independent t-test</td>
<td>$t = 3.40(340)**$</td>
<td>$d = .37$</td>
</tr>
<tr>
<td>USLChem</td>
<td>Independent t-test</td>
<td>$t = 7.63(453)***$</td>
<td>$d = .71$</td>
</tr>
<tr>
<td>USLMath</td>
<td>Independent t-test</td>
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</tr>
<tr>
<td>USLPhys</td>
<td>Independent t-test</td>
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<td>$d = .09$</td>
</tr>
<tr>
<td>Aware</td>
<td>Independent t-test</td>
<td>$t = 2.43(450)*$</td>
<td>$d = .23$</td>
</tr>
</tbody>
</table>

Note: * $p < .05$, ** $p < .01$, *** $p < .001$, $t$ adjusted $t$-value due to violation of homogeneity of variance, $d$ is Cohen’s $d$, df are degrees of freedom.

Finally, PSSTs’ awareness of alternative conceptions was also associated with a significant difference in mean scores ($t(450) = 2.43, p < .05, r = .23$), favouring those with an awareness of this issue. This had a small effect size. There were no other areas associated with significant mean differences for total score in the diagnostic instrument. The results of all comparison tests may be seen in Table 5.11.

**SUMMARY OF MAIN POINTS OF INTEREST**

PSSTs’ upper-second-level experiences of chemistry and mathematics were most consistently associated with significant differences in PSSTs’ scores. Those who had studied chemistry achieved significantly higher scores than those who had not studied chemistry in all areas of the diagnostic instrument. Studying mathematics at the higher level, compared with at the lower level, was associated with a significantly higher score for two conceptual areas and total score in the instrument. Upper-second-level physics was associated with a significant difference in scores, favouring those who had studied the subject, for the conceptual area of equilibrium. PSSTs’ specialism was associated with a significant difference in scores for the area of chemical bonding and total score in the diagnostic instrument. However, STE model was also associated with a significant difference in the area of chemical bonding, favouring those who were studying on concurrent STE programmes. From Section 3.9(c), more of those on concurrent programmes have a specialism in chemistry and, therefore, the significance associated with these two variables may potentially be only truly associated with a single variable.
5.3 **REGRESSION ANALYSIS**

The purpose of carrying out a regression analysis was not to develop models which are to be used to predict scores for all PSSTs, but rather to investigate which variables contribute significantly to prediction *when all other variables are held constant*. This allows the findings of the comparison tests to be further investigated. Full details of the regression models will be provided, as described in Section 4.3(c). For each outcome variable, a model was first derived from the concurrent PSST cohort and the consecutive PSST cohort. These two types of regression model were created to determine the effect of concurrent year of study and consecutive degree classification for these two groups. Depending on the findings of these models in each area (i.e. PNM, chemical bonding, etc.), a regression model was then derived either from: 1) the full PSST cohort or 2) the combination of consecutive PSSTs and concurrent PSSTs in their final year of study. The former cohort was used in cases where no differences were associated with year of study among the concurrent PSSTs. The latter cohort was used in cases where PSSTs’ stage of progress through their concurrent STE programme did have an influence on their performance in an area of the diagnostic instrument; this was to ensure that ‘like’ was compared with ‘like.’

All variables, with the exception of ConcYear and ConsecDegree, were included in regression models derived from any combination of consecutive and concurrent PSSTs. The variable PNM was included as a predictor variable for the chemical bonding regression model as the concepts included in chemical bonding are founded upon the PNM concepts. The variables PNM and ChemBond were included as predictor variables in the stoichiometry model for the same reason. For the concurrent regression models, the variable STEModel was removed and dummy variables 128 for ConcYear were included. Similarly, for the consecutive regression models, STEModel was removed and dummy variables for ConsecDegree were included. The assumptions of regression were investigated as outlined in Section 4.3(c) and the models presented in this chapter adhere to these assumptions. The models were found to be accurate for this sample and generalisable to the PSST population 129. However, the models reveal that the majority of variance in the data is unaccounted for and, therefore, other variables need to be added to the models were they to be used to effectively predict PSSTs’ performance. Equilibrium is an exception to this regression analysis, as it proved unsuitable for multiple

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128 The dummy variables were created as described in Section 4.3(c).
129 Accuracy for the sample is determined by the absence of outliers and cases of undue influence. Generalisability is determined by each model’s adherence to the multiple regression assumptions. The data relating to this aspect of the models is provided in Appendix H.
regression or logistic regression. An alternative analysis was carried out on this area based on a more in-depth investigation using the Kruskal Wallis and Mann-Whitney tests.

(a) Correlation Analysis
A correlation analysis was carried out as part of the assumption-testing. This analysis will be briefly presented as it highlights some differences between the groups. The focus is on the relationships associated with STE Model, concurrent year of study, and consecutive degree classification. As may be seen in Table 5.12, there was a significant relationship between PSSTs’ model of STE and their subject specialism \((r = .34, p < .001)\), awareness of alternative conceptions \((r = .11, p < .05)\), previous upper-second-level experience of chemistry \((r = .10, p < .05)\) and physics \((r = .14, p < .01)\). Based on the odds ratio, the odds of those that were studying on a consecutive STE programme having:

- a chemistry specialism were 4.50 times lower than that for concurrent PSSTs,
- an awareness of the issue of alternative conceptions in chemistry were 1.60 times higher than the odds for those studying on a concurrent programme,
- studied upper-second-level chemistry were 1.56 times higher than the odds for those on a concurrent STE programme, and
- studied upper-second-level physics were 1.95 times higher than the odds for those in a concurrent STE programme.

Table 5.12 Pearson correlation values for variables among full PSST cohort (n = 467)

<table>
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<th>STEModel</th>
<th>Gender</th>
<th>ChemSpec</th>
<th>USLChem</th>
<th>USLMath</th>
<th>USLPhys</th>
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<tbody>
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<td>Gender</td>
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<td>.02</td>
<td>.14**</td>
<td>.11*</td>
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<td>.01</td>
<td>.11*</td>
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<td>.01</td>
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<td>.08</td>
<td>.23**</td>
<td>.12*</td>
<td>.01</td>
<td>.04</td>
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</table>

Note: * p < .05, ** p < .01.

Table 5.13 shows that there was a significant relationship between PSSTs’ concurrent year of study, awareness of alternative conceptions, and upper-second-level physics and mathematics experience. Based on the odds ratio, the odds of those that were:

- in their 3rd year of study having an awareness of alternative conceptions in chemistry were 3.14 times higher than the odds for those in their 1st, 2nd, or 4th year of study,
- in their 3rd year of study having studied upper-second-level physics were 1.89 times higher than the odds for those in their 1st, 2nd, or 4th year of study, and
- in their 4th year of study having studied higher-level mathematics were 2.19 times higher than the odds for those in their 1st, 2nd, or 3rd year of study.
Table 5.13 Pearson correlation for variables among concurrent PSSTs (n = 323)

<table>
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<th>ChemSpec</th>
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Note: * p < .05, ** p < .01.

The Pearson r values in Table 5.14 show that there was no significant relationship between the degree classification awarded to consecutive PSSTs for their previous science degree and any of the other variables included in the study. This brief presentation of some between-group differences demonstrates that some factors are not consistent across groups. The regression analysis allows for an assessment of how much a variable contributes to predicting scores in outcome variables when all other variables are held constant.

Table 5.14 Pearson correlation values for variables among consecutive PSSTs (n = 144)

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<td>.03</td>
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</tr>
<tr>
<td>Aware</td>
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<td>.13</td>
<td>.04</td>
<td>.02</td>
<td>.02</td>
<td>.04</td>
<td>.11</td>
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<tr>
<td>Y1vY2</td>
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<td>.04</td>
<td>.07</td>
<td>.14</td>
<td>.17</td>
<td>.04</td>
<td>.52**</td>
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<td>Y1vY4</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Note: ** p < .01

(b) Regression Analysis for Consecutive Pre-service Science Teachers

The regression model derived from consecutive PSSTs for PNM, explained a significant amount of the variance in their scores, $F(8,104) = 5.77, p < .05$, $R^2 = .15$, $R^2_{adj} = .08$. The model accounts for 15% of variance in PNM scores. Had the model been derived from the population rather than a sample it would account for 7% less variance in PNM scores.$^{130}$ Table 5.15 describes the regression equation. Only upper-second-level chemistry ($t(104) = 2.66, p < .01$) contributed significantly to the model; PSSTs who studied chemistry achieve 0.86 more marks than if they had not studied chemistry. PSSTs who studied higher-level mathematics will achieve 0.67 more marks than those who studied lower-level mathematics. However, this did not contribute significantly to the model. PSSTs’ degree classification also does not contribute significantly to the model. However, the negative sign of the regression coefficient indicates lower scores for the reference group, i.e. those with a 2.2 classification.

$^{130}$ Recall from Section 4.3(c), that the $R^2$ and $R^2_{adj}$ values provide this information.
The regression model arising from consecutive PSSTs for chemical bonding explained a significant amount of the variance in consecutive PSSTs’ scores, $F(9,102) = 2.76, p < .05, R^2 = .17, R^2_{adjusted} = .10$. The data describing the regression equation are presented in Table 5.16. PSSTs’ scores in PNM contribute significantly to the model ($t(102) = 2.14, p < .05$). For each increment of 1.67 achieved in PNM, consecutive PSSTs achieve an additional 0.24 marks in the area of chemical bonding. Study of upper-second-level chemistry also contributes significantly to the model ($t(102) = 2.10, p < .05$). Where a PSST has studied upper-second-level chemistry, the model predicts that they will achieve 0.48 marks more than if they had not studied chemistry. The model confirms the non-significant finding in relation to consecutive degree classification from the comparison tests: consecutive PSSTs’ degree classification does not contribute significantly to the model predicting scores in chemical bonding.

<table>
<thead>
<tr>
<th>Constant</th>
<th>$\beta$</th>
<th>$SE$</th>
<th>$\beta_{Standardised}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
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<td>0.35</td>
<td>.02</td>
</tr>
<tr>
<td>ChemSpec</td>
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<td>0.39</td>
<td>.01</td>
</tr>
<tr>
<td>USLChem</td>
<td>0.86</td>
<td>0.33</td>
<td>.25**</td>
</tr>
<tr>
<td>USLMath</td>
<td>0.67</td>
<td>0.35</td>
<td>.20</td>
</tr>
<tr>
<td>USLPhys</td>
<td>0.17</td>
<td>0.34</td>
<td>.05</td>
</tr>
<tr>
<td>Aware</td>
<td>0.30</td>
<td>0.31</td>
<td>.09</td>
</tr>
<tr>
<td>2.2 vs 2.1 Degree</td>
<td>-0.56</td>
<td>0.36</td>
<td>-.17</td>
</tr>
<tr>
<td>2.2 vs 1.1 Degree</td>
<td>-0.41</td>
<td>0.45</td>
<td>-.10</td>
</tr>
</tbody>
</table>

Note: $R^2 = .15, ** p < .01$.

The regression model for scores in stoichiometry explains a significant amount of the variance in consecutive PSSTs’ scores, $F(10,98) = 2.64, p < .01, R^2 = .26, R^2_{adjusted} = .19$. The model accounts for 26% of variance in stoichiometry scores for the consecutive sample. The data describing the regression equation are presented in Table 5.17.

<table>
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<tr>
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<tr>
<td>ChemSpec</td>
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<td>.09</td>
</tr>
<tr>
<td>USLChem</td>
<td>0.48</td>
<td>0.23</td>
<td>.20*</td>
</tr>
<tr>
<td>USLMath</td>
<td>0.23</td>
<td>0.24</td>
<td>.10</td>
</tr>
<tr>
<td>USLPhys</td>
<td>-0.05</td>
<td>0.23</td>
<td>-.02</td>
</tr>
<tr>
<td>Aware</td>
<td>-0.03</td>
<td>0.21</td>
<td>-.01</td>
</tr>
<tr>
<td>PNM</td>
<td>0.14</td>
<td>0.07</td>
<td>.21*</td>
</tr>
<tr>
<td>2.2 vs 2.1 Degree</td>
<td>0.22</td>
<td>0.24</td>
<td>.10</td>
</tr>
<tr>
<td>2.2 vs 1.1 Degree</td>
<td>0.11</td>
<td>0.30</td>
<td>.04</td>
</tr>
</tbody>
</table>

Note: $R^2 = .17, * p < .05$.

131 Note that raw scores predicted from continuous variables are derived from $\beta_{Standardised}$ as discussed by Fields (2009, p. 239) and described in Section 4.3(c).
Table 5.17 Regression coefficients for the stoichiometry model derived from consecutive PSSTs

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
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<th>$\beta$ Standardised</th>
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<tr>
<td>Gender</td>
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<td>0.02</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>0.20</td>
<td>0.22</td>
<td>0.09</td>
</tr>
<tr>
<td>USLChem</td>
<td>0.35</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td>USLMath</td>
<td>-0.08</td>
<td>0.20</td>
<td>-0.04</td>
</tr>
<tr>
<td>USLPhys</td>
<td>0.25</td>
<td>0.19</td>
<td>0.13</td>
</tr>
<tr>
<td>Aware</td>
<td>0.06</td>
<td>0.17</td>
<td>0.03</td>
</tr>
<tr>
<td>PNM</td>
<td>0.02</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>ChemBond</td>
<td>0.30</td>
<td>0.08</td>
<td>0.35***</td>
</tr>
<tr>
<td>2.2 vs 2.1 Degree</td>
<td>0.15</td>
<td>0.20</td>
<td>0.08</td>
</tr>
<tr>
<td>2.2 vs 1.1 Degree</td>
<td>0.50</td>
<td>0.25</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Note: $R^2 = .26$, *** $p < .001$.

Only scores in chemical bonding contribute significantly to predicting consecutive PSSTs’ scores in stoichiometry ($t(98) = 3.70, p < .001$). For each increment of 1.14 achieved in chemical bonding, consecutive PSSTs achieve an additional 0.34 marks in stoichiometry. Of the non-significantly contributing variables, the dummy variable comparing the 2.2 to 1.1 degree classifications contributes the most ($t(98) = 1.95, ns$), followed by PSSTs’ study of upper-second-level chemistry ($t(98) = 1.86, ns$). PSSTs with a degree classification of 1.1 are predicted to achieve a score that is 0.50 marks higher than if they had a 2.2 degree classification. PSSTs who had studied upper-second-level chemistry are predicted to achieve a score that is 0.35 marks higher than if they had not studied chemistry.

The regression model for consecutive PSSTs’ total scores in the instrument explains a significant amount of the variance, $F(8,104) = 33.76, p < .001$, $R^2 = .24$, $R^2_{\text{adjusted}} = .18$. The data describing the regression equation for consecutive PSSTs are presented in Table 5.18.

Table 5.18 Regression coefficients for the model for predicting total score of consecutive PSSTs

<table>
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<tr>
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<th>$\beta$</th>
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</tr>
</thead>
<tbody>
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<td>Constant</td>
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<td>1.13</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.57</td>
<td>0.62</td>
<td>-0.08</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>-0.51</td>
<td>0.70</td>
<td>-0.07</td>
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<tr>
<td>USLChem</td>
<td>2.50</td>
<td>0.58</td>
<td>.39***</td>
</tr>
<tr>
<td>USLMath</td>
<td>1.12</td>
<td>0.61</td>
<td>.17</td>
</tr>
<tr>
<td>USLPhys</td>
<td>0.49</td>
<td>0.61</td>
<td>.08</td>
</tr>
<tr>
<td>Aware</td>
<td>-0.67</td>
<td>0.55</td>
<td>-0.11</td>
</tr>
<tr>
<td>2.2 vs 2.1 Degree</td>
<td>-0.50</td>
<td>0.63</td>
<td>-0.08</td>
</tr>
<tr>
<td>2.2 vs 1.1 Degree</td>
<td>0.02</td>
<td>0.79</td>
<td>.00</td>
</tr>
</tbody>
</table>

Note: $R^2 = .24$. * $p < .05$, ** $p < .01$, *** $p < .001$.

PSSTs’ study of upper-second-level chemistry contributes significantly to the model ($t(104) = 4.34, p < .001$). The model predicts that a consecutive PSST who has studied chemistry will achieve a total score that is 2.50 marks higher than if they had not studied upper-second-level chemistry. However, PSSTs’ consecutive degree classification is not a significant predictor of performance in the instrument.
(c) Regression Analysis for Concurrent Pre-service Science Teachers

A regression model was developed from the concurrent PSST group to investigate whether, with all other variables held constant, year of study can contribute to predicting PSSTs’ scores in each area of the diagnostic instrument and their total scores. The data describing the regression equation to predict scores in PNM for concurrent PSSTs are presented in Table 5.19. The regression model, explained a significant amount of the variance in concurrent PSSTs’ scores, $F(9,172) = 5.21, p < .05, R^2 = .11, R^2_{adj} = .06$. The model accounts for 11% of variance in PNM scores for the sample. Had the model been derived from the population rather than a sample it would account for 5% less variance in PNM scores. This indicates that the model is not as accurate for the PSST population as it is for this sample.

Only upper-second-level chemistry ($t(172) = 1.96, p = .05$) and level of study of upper-second-level mathematics ($t(172) = 2.17, p < .05$) contributed significantly to the model. Where a PSST has studied chemistry at upper-second-level, the model predicts that they will achieve 0.54 more marks in the area of PNM than if they had not studied chemistry. The model also predicts that if a PSST has studied higher-level mathematics at upper-second-level, they will achieve 0.55 more marks in PNM than if they had studied lower-level mathematics. PSSTs’ year of study in their concurrent programme does not contribute significantly to the model. However, in comparing each of the years of study with the 1st year of study, the negative sign of the $\beta$-value indicates that being in the 1st year of study results in a higher prediction of scores in PNM than being in any of the other three years of study.

![Table 5.19](image)

The regression model for chemical bonding explained a significant amount of the variance, $F(10,171) = 3.75, p < .001, R^2 = .18, R^2_{adj} = .13$. The data describing the regression equation are presented in Table 5.20. Concurrent PSSTs’ scores in PNM contribute significantly to the model ($t(171) = 3.96, p < .001$). For each increment of 1.55 achieved in PNM, concurrent PSSTs achieve an additional 0.31 marks in chemical bonding. However, concurrent PSSTs’ year of study contributes more significantly to the regression model than PNM score. The model predicts that a PSST in the 1st year of study will achieve a chemical bonding score that
is a minimum of 0.80 marks higher than if the PSST were in any of the successive years of study. This result seems counter-intuitive. It is particularly interesting given that, although the correlation analysis demonstrated significant relationships between year of study and three other variables, these relationships were in favour of those in their 3rd or 4th years of study. This is likely the reason why this relationship was not observed in the comparison testing presented in Section 5.2. There was no significant mean difference associated with concurrent year of study according to the comparison tests. However, the regression analysis reveals that, with all other variables held constant, concurrent year of study does contribute significantly to predicting concurrent PSSTs’ scores in chemical bonding.

Table 5.20 Regression coefficients for the chemical bonding model derived from concurrent PSSTs

<table>
<thead>
<tr>
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<th>$\beta$</th>
<th>$SE_\beta$</th>
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<tbody>
<tr>
<td>Constant</td>
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<tr>
<td>Gender</td>
<td>0.18</td>
<td>0.18</td>
<td>0.08</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>-0.12</td>
<td>0.18</td>
<td>-0.06</td>
</tr>
<tr>
<td>USLChem</td>
<td>0.09</td>
<td>0.18</td>
<td>0.04</td>
</tr>
<tr>
<td>USLMath</td>
<td>-0.10</td>
<td>0.17</td>
<td>-0.05</td>
</tr>
<tr>
<td>USLPhys</td>
<td>0.05</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>Aware</td>
<td>0.33</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>PNM</td>
<td>0.20</td>
<td>0.05</td>
<td>0.29***</td>
</tr>
<tr>
<td>Year 1 vs Year 2</td>
<td>-0.80</td>
<td>0.26</td>
<td>-0.35**</td>
</tr>
<tr>
<td>Year 1 vs Year 3</td>
<td>-0.92</td>
<td>0.26</td>
<td>-0.43***</td>
</tr>
<tr>
<td>Year 1 vs Year 4</td>
<td>-0.87</td>
<td>0.28</td>
<td>-0.32**</td>
</tr>
</tbody>
</table>

Note: $R^2 = .18$, ** $p < .01$, *** $p < .001$.

The regression model for stoichiometry explained a significant amount of the variance, $F(11,170) = 3.01, p < .01, R^2 = .16, R^2_{adjusted} = .11$. The model accounts for 16% of variance for the concurrent sample. Table 5.21 provides data describing the model. Only scores in PNM contribute significantly to the model ($t(170) = 2.87, p < .01$). For each increment of 1.55 in PNM, concurrent PSSTs achieve an additional 0.18 marks in stoichiometry.

Table 5.21 Regression coefficients for the stoichiometry model derived from concurrent PSSTs

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
<th>$SE_\beta$</th>
<th>$\beta_{Standardised}$</th>
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</thead>
<tbody>
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<td>Constant</td>
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<td>-0.08</td>
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<td>Gender</td>
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<td>0.14</td>
<td>-0.12</td>
</tr>
<tr>
<td>ChemSpec</td>
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<td>0.14</td>
<td>0.11</td>
</tr>
<tr>
<td>USLChem</td>
<td>0.19</td>
<td>0.14</td>
<td>0.06</td>
</tr>
<tr>
<td>USLMath</td>
<td>0.11</td>
<td>0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>USLPhys</td>
<td>0.09</td>
<td>0.15</td>
<td>-0.04</td>
</tr>
<tr>
<td>Aware</td>
<td>-0.07</td>
<td>0.13</td>
<td>-0.04</td>
</tr>
<tr>
<td>PNM</td>
<td>0.12</td>
<td>0.04</td>
<td>0.22**</td>
</tr>
<tr>
<td>ChemBond</td>
<td>0.08</td>
<td>0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>Year 1 vs Year 2</td>
<td>0.03</td>
<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>Year 1 vs Year 3</td>
<td>0.03</td>
<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>Year 1 vs Year 4</td>
<td>0.07</td>
<td>0.22</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: $R^2 = .16$, ** $p < .01$.

132 E.g., the odds of having studied higher-level USL mathematics were 2.19 times higher for 4th years.
Of the non-significant variables, upper-second-level chemistry \((t(170) = 1.31, \text{ns})\) and PSSTs' scores in chemical bonding \((t(170) = 1.29, \text{ns})\) contribute the most to the model. However, concurrent PSSTs' year of study contributes a negligible amount to the regression model.

The regression model derived from the concurrent PSSTs for total scores explains a significant amount of the variance in the data, \(F(9,172) = 3.73, p < .001, R^2 = .16, R^2_{\text{adjusted}} = .11\). The data describing the resulting regression equation are presented in Table 5.22.

| Table 5.22 Regression coefficients for the model for predicting total score of concurrent PSSTs |
|---------------------------------|---------------|-----------------|-----------------|
| **Constant**                    | 8.72          | 0.89            | .00             |
| **Gender**                      | 0.03          | 0.47            | -.01            |
| **ChemSpec**                    | -0.03         | 0.48            | -.22*           |
| **USLChem**                     | 1.23          | 0.48            | .14             |
| **USLMath**                     | 0.76          | 0.44            | .00             |
| **USLPhys**                     | 0.00          | 0.52            | .00             |
| **Aware**                       | 0.88          | 0.45            | .16*            |
| **Year 1 vs Year 2**            | -1.49         | 0.68            | -.25*           |
| **Year 1 vs Year 3**            | -2.13         | 0.68            | -.37**          |
| **Year 1 vs Year 4**            | -1.26         | 0.73            | -.18            |

Note: \(R^2 = .16, * p < .05, ** p < .01\).

PSSTs’ study of upper-second-level chemistry contributes significantly to the model \((t(172) = 2.59, p < .05)\). However, concurrent year of study makes a more significant contribution to the model. If a PSST is in his/her 1\(^{st}\) year of study, he/she is predicted to achieve a total score that is 1.49 marks or 2.13 marks higher than if the PSST were in either the 2\(^{nd}\) or 3\(^{rd}\) year of study, respectively. PSSTs in the 1\(^{st}\) year of study are also predicted to achieve a higher score than if they were in the 4\(^{th}\) year of study, however, this is not a significant contribution to the model. Having examined each of the conceptual areas in the instrument, this result likely stems primarily from performance in chemical bonding and PNM; both of the regression analyses in these areas produced models that predicted higher scores for those in their 1\(^{st}\) year of study than for those in the successive years of study. Given this, concurrent year of study is considered an important factor for performance in the areas of PNM, chemical bonding, and total scores in the diagnostic instrument. This will be reflected in the regression analyses involving both consecutive and concurrent PSSTs by comparing only 4\(^{th}\) year concurrent PSSTs with consecutive PSSTs as this is the best approximation of comparing ‘like’ with ‘like’ across these two models. The concurrent year of study was shown to have no significant predictive power in the area of stoichiometry, and furthermore, the non-significant differences in this model were entirely negligible. Therefore, the entire concurrent PSST cohort will be compared with the consecutive cohort in this area, in order to maintain the maximum predictive power of the resulting model.
(d) Regression Analysis for Consecutive and Concurrent Pre-service Teachers
In the area of PNM, it was found that the model arising from the consecutive and concurrent PSST cohort explained a significant amount of the variance in PSSTs’ scores, $F(7,139) = 3.27, p < .01, R^2 = .14, R^2_{adj} = .10$. The model accounts for 14% of variance in PNM scores for the sample. Had the model been derived from the population rather than a sample it would account for 4% less variance in PNM scores. The data describing the regression equation to predict scores in PNM are presented in Table 5.23.

Table 5.23 Regression coefficients for the PNM model for consecutive and 4th year concurrent PSSTs

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
<th>SE $\beta$</th>
<th>$\beta$ Standardised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.71</td>
<td>0.48</td>
<td>.08</td>
</tr>
<tr>
<td>Gender</td>
<td>0.28</td>
<td>0.30</td>
<td>.08</td>
</tr>
<tr>
<td>STEModel</td>
<td>0.06</td>
<td>0.33</td>
<td>.02</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>-0.16</td>
<td>0.33</td>
<td>-.05</td>
</tr>
<tr>
<td>USLChem</td>
<td>0.95</td>
<td>0.28</td>
<td>.29***</td>
</tr>
<tr>
<td>USLMath</td>
<td>0.58</td>
<td>0.29</td>
<td>.18*</td>
</tr>
<tr>
<td>USLPhys</td>
<td>0.20</td>
<td>0.30</td>
<td>.06</td>
</tr>
<tr>
<td>Aware</td>
<td>0.17</td>
<td>0.27</td>
<td>.05</td>
</tr>
</tbody>
</table>

Note: $R^2 = .14$, *p < .05, ***p < .001.

Only upper-second-level chemistry ($t(148) = 3.35, p < .001$) and level of study of upper-second-level mathematics ($t(148) = 2.00, p < .05$) contributed significantly to the model. In other words, where a PSST has studied chemistry at upper-second-level, the model predicts that he/she will achieve 0.95 more marks in PNM than if he/she had not studied chemistry. The model also predicts that if a PSST has studied higher-level mathematics, he/she will achieve 0.58 more marks in PNM than if he/she had studied lower-level mathematics. The model of STE is one of the poorest predictors of performance.

The findings in relation to upper-second-level chemistry and mathematics are consistent with the results of the comparison tests carried out in Section 5.2(a). However, a significant mean difference was identified in Section 5.2(a) related to PSSTs’ STE model ($p < .001$) and their awareness of alternative conceptions ($p < .05$). These variables did not contribute significantly to the regression model. The significance that was identified in the comparison tests may have been due to the fact that those on consecutive courses were more likely to have studied chemistry at upper-second-level: when study of upper-second-level chemistry is held constant, PSSTs’ model of STE does not make a significant contribution to predicting their scores in PNM. The same may be the case with PSSTs’ awareness of alternative conceptions, which had a significant relationship with upper-second-level study of chemistry.

The regression model arising from the consecutive and concurrent PSST cohort explained a significant amount of the variance in their scores in chemical bonding, $F(8,137) = 4.027, p < .001, R^2 = .19, R^2_{adj} = .15$. The model accounts for 19% of variance in chemical bonding...
scores for the sample. Had the model been derived from the population rather than a sample, it would account for 4% less variance in PNM scores. The data describing the regression equation for this model are presented in Table 5.24.

Table 5.24 Regression coefficients for the chemical bonding model for consecutive and 4th year concurrent PSSTs

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<th>SE β</th>
<th>βStandardised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
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<td>0.38</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
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<td>.08</td>
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<td>STEMModel</td>
<td>0.84</td>
<td>0.24</td>
<td>.30***</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>-0.04</td>
<td>0.24</td>
<td>-.02</td>
</tr>
<tr>
<td>USLChem</td>
<td>0.38</td>
<td>0.21</td>
<td>.16</td>
</tr>
<tr>
<td>USLMath</td>
<td>0.11</td>
<td>0.21</td>
<td>.05</td>
</tr>
<tr>
<td>USLPhys</td>
<td>-0.09</td>
<td>0.21</td>
<td>-.04</td>
</tr>
<tr>
<td>Aware</td>
<td>0.08</td>
<td>0.19</td>
<td>.03</td>
</tr>
<tr>
<td>PNM</td>
<td>0.18</td>
<td>0.06</td>
<td>.25**</td>
</tr>
</tbody>
</table>

Note: $R^2 = .19$, ** $p < .01$, *** $p < .001$.

PSSTs’ choice of a concurrent or consecutive STE programme contributed significantly ($t(147) = 3.577, p < .001$) to the model. PSSTs on concurrent STE programmes are predicted to achieve a score that is 0.84 marks higher than those on consecutive programmes. The only other predictor to contribute significantly to the model is PSSTs’ score in PNM ($t(147) = 2.99, p < .01$). For each 1.61 increment in PNM score, PSSTs are predicted to achieve an additional 0.29 marks in chemical bonding. Of the non-significant variables, upper-second-level study of chemistry contributes the most to the model ($t(147) = 1.82, ns$). The model predicts that PSSTs who studied chemistry will achieve a score that is 0.38 marks higher than those who had not studied chemistry. It is interesting that PSSTs’ chosen model of STE is the most significant predictor of scores in chemical bonding, while their decision to specialise in chemistry contributes a negligible amount to the model.

These findings confirm the results of the comparison tests in Section 5.2(b) associated with PSSTs’ STE model. The comparison tests also demonstrated significant mean differences associated with chemistry specialism and upper-second-level chemistry. However, these variables do not significantly contribute to predicting PSSTs’ scores. The higher odds of those on concurrent STE programmes having a specialism in chemistry do not explain concurrent PSSTs’ higher scores. Furthermore, those on consecutive programmes were more likely to have studied upper-second-level chemistry: when this variable is held constant, a larger difference between the scores of those on concurrent and consecutive STE programmes is revealed. The mean difference between the two groups was 0.55 marks. The regression analysis reveals a difference of 0.84 marks in predicted chemical bonding scores.

The stoichiometry regression model for all PSSTs explained a significant amount of the variance in scores, $F(9,281) = 6.41, p < .001, R^2 = .17, R^2_{adjusted} = .14$. The model accounts for
17% of variance in stoichiometry scores for the sample. Had the model been derived from the population rather than a sample it would account for 3% less variance in stoichiometry scores. The data describing the regression equation are presented in Table 5.25.

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>SE</th>
<th>β Standardised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.02</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>0.09</td>
<td>0.11</td>
<td>.05</td>
</tr>
<tr>
<td>STEM Model</td>
<td>0.03</td>
<td>0.12</td>
<td>.02</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>0.21</td>
<td>0.12</td>
<td>.12</td>
</tr>
<tr>
<td>USL Chem</td>
<td>0.26</td>
<td>0.11</td>
<td>.15*</td>
</tr>
<tr>
<td>USL Math</td>
<td>0.06</td>
<td>0.11</td>
<td>.04</td>
</tr>
<tr>
<td>USL Phys</td>
<td>0.15</td>
<td>0.12</td>
<td>.08</td>
</tr>
<tr>
<td>Aware</td>
<td>0.00</td>
<td>0.10</td>
<td>.00</td>
</tr>
<tr>
<td>PNM</td>
<td>0.07</td>
<td>0.03</td>
<td>.13*</td>
</tr>
<tr>
<td>Chem Bond</td>
<td>0.17</td>
<td>0.05</td>
<td>.22***</td>
</tr>
</tbody>
</table>

Note: $R^2 = .17$, * p < .05, *** p < .001.

Of the demographic variables, only upper-second-level chemistry ($t$(281) = 2.38, $p < .05) contributed significantly to the model: where a PSST has studied chemistry, the model predicts he/she will achieve 0.26 more marks in stoichiometry than if he/she had not studied chemistry. PSSTs’ scores in the areas of PNM ($t$(281) = 2.18, $p < .05) and chemical bonding ($t$(281) = 3.61, $p < .001) also contributed significantly to the model. This indicates that: for each PNM increment of 1.62 marks, the score in stoichiometry is 0.21 marks higher, and for each 1.15 increment in score in chemical bonding, the score in stoichiometry is predicted to increase by 0.25 marks. Chemistry specialism contributes the most of the non-significant predictors ($t$(281) = -1.82, *ns), followed by study of upper-second-level physics ($t$(281) = 1.26, *ns). The prediction related to the other variables is negligible.

The comparison tests carried out in Section 5.2(c) demonstrated a significant mean difference associated with upper-second-level study of chemistry. The regression analysis confirms that PSSTs’ study of chemistry contributes significantly to predicting stoichiometry scores. The comparison tests also revealed a significant mean difference associated with PSSTs’ specialism and level of study of upper-second-level mathematics. The regression analysis shows that these do not contribute significantly to prediction of scores. Chemistry specialism and level of study of upper-second-level mathematics had a significant relationship with upper-second-level chemistry according to the correlation analysis. Those with a chemistry specialism were more likely to have studied upper-second-level chemistry and those who had studied upper-second-level chemistry were more likely to have also studied mathematics at the higher level. The regression analysis reveals that, when the effect of upper-second-level chemistry is held constant, chemistry specialism and level of study of upper-second-level mathematics do not contribute significantly to predicting PSSTs’ scores.
For total scores on the diagnostic instrument, the regression model for the consecutive and concurrent PSST cohort explained a significant amount of the variance in scores, $F(7,139) = 4.88, p < .001, R^2 = .20, R^2_{\text{adjusted}} = .16$. The model accounts for 20% of variance in total scores. The data describing the regression equation for this model are presented in Table 5.26.

Table 5.26 Regression coefficients for the model for predicting total score derived from consecutive and 4th-year concurrent PSSTs

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
<th>$SE\ \beta$</th>
<th>$\beta_{\text{Standardised}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6.34</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>0.09</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>STEMModel</td>
<td>1.30</td>
<td>0.61</td>
<td>0.18*</td>
</tr>
<tr>
<td>ChemSpec</td>
<td>0.22</td>
<td>0.61</td>
<td>0.03</td>
</tr>
<tr>
<td>USLChem</td>
<td>2.32</td>
<td>0.52</td>
<td>0.37***</td>
</tr>
<tr>
<td>USLMath</td>
<td>0.89</td>
<td>0.53</td>
<td>0.15</td>
</tr>
<tr>
<td>USLPhys</td>
<td>0.50</td>
<td>0.56</td>
<td>0.08</td>
</tr>
<tr>
<td>Aware</td>
<td>0.41</td>
<td>0.49</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Note: $R^2 = .16$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Study of upper-second-level chemistry contributed most significantly to the model ($t(148) = 4.47, p < .001$). A PSST who has studied chemistry is predicted to achieve a score that is 2.32 marks higher in the instrument than if he/she had not studied chemistry. PSSTs’ model of STE also contributes significantly to the model ($t(148) = 2.14, p < .05$). The model predicts that PSSTs who study on the concurrent model, as opposed to the consecutive model, will achieve a score that is 1.30 marks higher. The remaining variables do not contribute significantly. Of these non-significant contributors, PSSTs’ level of study of upper-second-level mathematics contributes the most ($t(148) = 1.68, \text{ns}$). Studying mathematics at higher-level rather than lower-level results in a prediction that is 0.89 marks higher.

The comparison tests, presented in Section 5.2(e), demonstrated a highly significant difference in mean scores associated with upper-second-level chemistry and level of study of upper-second-level mathematics (both p-values < .001). The regression analysis confirms the importance of previous experiences of chemistry in predicting PSSTs’ total scores in the instrument. The comparison tests also found significant mean differences associated with chemistry specialism and awareness of alternative conceptions. However, the regression analysis reveals that, with the effects of other variables held constant, these are not significant predictors of PSSTs’ performance. Finally, the comparison tests did not attribute any significance to mean differences associated with STE model. However, with variables such as upper-second-level chemistry held constant, the regression analysis reveals that STE model is indeed a significant predictor of total score, in favour of concurrent PSSTs. Having examined all areas of the instrument individually, one can conclude that this higher score is primarily the result of better understanding of chemical bonding.
(e) Equilibrium Analysis

Data related to equilibrium were not appropriate for multiple regression analysis as the standardised residuals were non-normally distributed. Logistic regression could also not be carried out given that this method of regression is based on the $\chi^2$ distribution and, therefore, group size is a factor. Including even a small number of variables would result in group sizes being too small. Based on the comparison tests presented in Section 5.2(d), the only demographic variables that were associated with a significant difference in scores were gender and upper-second-level study of chemistry and physics. Therefore, eight new categories were created based on these three variables:

- males that did not study either chemistry or physics, $n = 32$ (MaleNeither),
- males that did not study chemistry and did study physics, $n = 23$ (MalePhysics),
- males that studied chemistry and did not study physics, $n = 40$ (MaleChemistry),
- males that studied both chemistry and physics, $n = 28$ (MaleBoth),
- females that did not study either chemistry or physics, $n = 114$ (FemaleNeither),
- females that did not study chemistry and did study physics, $n = 29$ (FemalePhysics),
- females that studied chemistry and did not study physics, $n = 124$ (FemaleChemistry),
- females that studied both chemistry and physics, $n = 45$ (FemaleBoth).

![Figure 5.8 Performance in equilibrium differentiated by gender and upper-second-level study of chemistry and physics](image)

133 This is due to the generally poor performance in equilibrium resulting in relatively few PSSTs achieving scores of 2 or 3 marks in this area.
A Kruskal Wallis test found a significant difference between these groups, $H(7) = 36.28, p < .001$. A post hoc analysis was necessary using Mann Whitney $U$ tests. All possible tests could not be carried out as the Bonferroni adjustment would be too restrictive. Therefore, the box plot shown in Figure 5.8 was examined and the following conclusions drawn:

- studying physics appears to have little association with the performance of female PSSTs in equilibrium. The spread of data for female PSSTs who had studied physics is similar to that of their peers who had not studied the subject. However, the study of physics does appear to be associated with some differences for male PSSTs as those who studied both physics and chemistry achieved a higher median and spread of data than those who studied chemistry only;

- gender is not associated with differences where neither males nor females studied upper-second-level chemistry. Median values are identical between males and females who 1) studied neither chemistry nor physics, or 2) studied physics only. However, there may be some association between gender and scores when chemistry has been studied. For example, male PSSTs who studied chemistry achieved a higher median score than female PSSTs who studied chemistry;

- study of upper-second-level chemistry appears to be associated with differences in scores. Those who studied chemistry achieved higher medians and/or spread of data than their peers who were identical in gender and experience of upper-second-level physics. However, female PSSTs who had not studied physics are an exception, as there is no difference in scores between female PSSTs who studied neither chemistry nor physics, and female PSSTs who studied chemistry only.

Based on this visual analysis of Figure 5.8, it was decided to carry out the post hoc tests identified in Table 5.27. The Bonferroni adjustment resulted in a critical value for significance of .01\textsuperscript{134}.

**Table 5.27 Result of the post-hoc Mann Whitney $U$ tests**

<table>
<thead>
<tr>
<th>Groups Compared</th>
<th>$U$</th>
<th>Significance</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MaleNeither MaleChemistry</td>
<td>455.00</td>
<td>.017</td>
<td>.28</td>
</tr>
<tr>
<td>MalePhysics MaleBoth</td>
<td>196.00</td>
<td>.010</td>
<td>.36</td>
</tr>
<tr>
<td>FemalePhysics FemaleBoth</td>
<td>424.50</td>
<td>.006</td>
<td>.34</td>
</tr>
<tr>
<td>MaleChemistry FemaleChemistry</td>
<td>2130.00</td>
<td>.132</td>
<td>.12</td>
</tr>
<tr>
<td>MaleBoth FemaleBoth</td>
<td>457.50</td>
<td>.035</td>
<td>.25</td>
</tr>
<tr>
<td>MaleChemistry MaleBoth</td>
<td>440.00</td>
<td>.112</td>
<td>.19</td>
</tr>
</tbody>
</table>

\textsuperscript{134} This value is rounded up from .008.
The study of both upper-second-level chemistry and physics resulted in significantly higher scores compared with the study of physics only. This was the case for both male and female PSSTs and the associated effect sizes were small-medium. From Figure 5.8, it was observed that, among female PSSTs, there was no difference associated with the study of both chemistry and physics and the study of chemistry only. From Table 5.27, this is also the case for male PSSTs. Male PSSTs who studied chemistry did outperform those who studied neither subject. Although this effect was found to be non-significant, the Bonferroni adjustment is widely acknowledged as conservative135 (Fields 2009, p.373); the significance is so close to the Bonferroni critical value as to be worthy of consideration. There was no significant difference associated with gender as the level of probability associated with these comparisons was well above the critical value of .01. These results demonstrate that it is the study of chemistry at upper-second-level that is of greater importance than either the study of upper-second-physics or the gender of PSSTs.

**SUMMARY OF MAIN FINDINGS FROM REGRESSION ANALYSIS**

Previous experience of upper-second-level chemistry is the most important of all educational variables in contributing to PSSTs’ understanding of the concepts included in this study. It contributes to PSSTs’ performance in PNM, stoichiometry, equilibrium, and total scores on the diagnostic instrument. It appears to be more important for consecutive PSSTs than concurrent PSSTs, as it was the most powerful predictor of performance for the consecutive group in almost every area analysed using regression, while it was only a significant predictor of performance for the concurrent PSSTs in PNM and total scores. Previous upper-second-level experience of mathematics was also a significant predictor of performance in the PNM portion of the diagnostic instrument, and previous upper-second-level experience of physics appears to make some contribution to scores in equilibrium – though this is less conclusive given the less rigorous investigation in this area.

The consistent contribution of previous upper-second-level experiences to the regression models – often as the most powerful predictors of performance – is made particularly interesting given the lack of predictive power associated with variables such as PSSTs’ decision to specialise, or not, in chemistry. Those with a chemistry specialism have experienced far more extensive study in chemistry than those who do not have a specialism in the subject. This is even truer for PSSTs following the consecutive STE model than for

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135 The trade-off for reducing the chance of Type I errors (observing significance where there is none) is an increase in the chance of Type II errors (rejecting an effect as significant when, in fact, it is significant).
those following the concurrent model. Yet PSSTs’ subject specialism was not a predictor of performance. It was generally one of the poorest predictors of performance.

The findings in relation to previous upper-second-level experience are also particularly interesting in light of the impact of progressing through a concurrent STE programme. PSSTs’ year of study was not associated with any difference in performance in the area of stoichiometry (and no such association was noted in the area of equilibrium either), and the impact was counterintuitive for PNM, chemical bonding, and total scores on the diagnostic instrument; PSSTs in their first year of study outperform those in subsequent years of study. Finally, the model of STE being followed by PSSTs was the most powerful predictor of performance in chemical bonding, and it was also a significant predictor of performance in total scores in the instrument, with the latter likely arising from the former. PSSTs on concurrent STE programmes are predicted to have fewer alternative conceptions about fundamental chemical bonding concepts than those on consecutive STE programmes.

5.4 ALTERNATIVE CONCEPTIONS OF PRE-SERVICE SCIENCE TEACHERS

The previous analyses focused on the variables which have the greatest impact on PSSTs’ overall achievement in each area of the diagnostic instrument. In this section, the specific alternative conceptions of PSSTs will be discussed. Alternative conceptions identified among more than 10% of PSSTs based on their responses to the instrument will be provided. A comparison of the responses provided in individual questions based on the demographic variables that were found to have the greatest impact on PSSTs’ performance will be discussed where significant differences were identified.

(a) Particulate Nature of Matter

The alternative conceptions identified among more than 10% of PSSTs are presented in Table 5.28. Over 70% of PSSTs selected responses that were consistent with the conceptions that: (a) atoms are not conserved after a mixture reacts in a closed container (73.88%) and (b) only elements, and not compounds, are pure substances (71.95%). Between 30% and 50% of PSSTs selected responses consistent with the conceptions that: (a) a random arrangement of atoms is indicative of a heterogeneous mixture (47.75%), (b) all mixtures are heterogeneous mixtures (30.19%), (c) the coefficient of a compound in a chemical equation is a multiplier of the number of atoms in a compound (38.12%), and (c) a single atom exhibits all of the properties of the macroscopic substance (38.54%).
Table 5.28 Alternative conceptions of PSSTs (n = 467) in the area of PNM

<table>
<thead>
<tr>
<th>Alternative Conceptions</th>
<th>% PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A single atom of sulfur has the same density as the macroscopic substance (as well as chemical properties).</td>
<td>12.85%</td>
</tr>
<tr>
<td>A single atom of sulfur exhibits all of the properties (chemical and physical) of the macroscopic sulfur substance.</td>
<td>38.54%</td>
</tr>
<tr>
<td>On phase change of ammonia from liquid to gas, all covalent bonds are broken.</td>
<td>12.63%</td>
</tr>
<tr>
<td>On phase change of ammonia from liquid to gas, the proximity of particles does not change.</td>
<td>14.35%</td>
</tr>
<tr>
<td>After a mixture of sulfur and oxygen react in a closed container to form the compound sulfur dioxide, atoms are not conserved.</td>
<td>73.88%</td>
</tr>
<tr>
<td>After a mixture of sulfur and oxygen react in a closed container to form the compound sulfur dioxide, the coefficient of the compound applies like a multiplier of the number of atoms in the compound.</td>
<td>38.12%</td>
</tr>
<tr>
<td>On phase change of solid iodine to gaseous iodine in a closed container, the mass of the container reduces because a gas weighs less than a solid.</td>
<td>11.35%</td>
</tr>
<tr>
<td>Spaces in the particle arrangement of a solid indicate that atoms are free to move like a liquid. No consideration is given to the regularity of atom arrangement.</td>
<td>18.42%</td>
</tr>
<tr>
<td>A heterogeneous mixture means that there are different atoms or molecules in the mixture, i.e. heterogeneous mixture is a synonym for mixture.</td>
<td>30.19%</td>
</tr>
<tr>
<td>A homogeneous mixture means that there is an ordered or non-random particle arrangement.</td>
<td>11.13%</td>
</tr>
<tr>
<td>A heterogeneous mixture means that there is a disordered or random atom arrangement.</td>
<td>47.75%</td>
</tr>
<tr>
<td>A pure substance comprises the same type of atom, i.e. only elements are pure substances.</td>
<td>71.95%</td>
</tr>
</tbody>
</table>

The scientifically-acceptable conceptions associated with each item included in the PNM section of the diagnostic instrument are provided in Table 5.29, along with the percentage of PSSTs that demonstrated sound understanding of these conceptions. The majority of PSSTs demonstrated sound understanding of PNM in the context of:

- phase change from liquid to gas,
- conservation of mass during phase change in a closed container,
- reactants and products as described by chemical equations, and
- states of matter.

Far less than half of PSSTs demonstrated sound understanding of concepts related to:

- the properties of individual atoms,
- the conservation of atoms when a reaction takes place in a closed container, and
- the meaning of the terms element and compound.

Few PSSTs understood the concepts of pure substance, and heterogeneous and homogeneous mixtures.
A single atom of sulfur has the same chemical properties as the macroscopic substance but does not have the same physical properties. 32.12%

On phase change of ammonia from liquid to gas, the distance between particles increases but the intramolecular bonds are not broken. 64.24%

After a mixture of sulfur and oxygen react in a closed container, the resulting sulfur dioxide is made up of discrete molecules and the number of atoms are conserved. 16.27%

On phase change of iodine from solid to gas in a closed container, mass is conserved. 61.03%

The coefficients in a chemical equation refer to the number of moles or the number of particles; these are the number of discrete molecules in the case of covalent molecules such as methane and carbon tetrachloride. 71.31%

Static images of solid, liquid and gas differ in proximity and arrangement of particles. 67.02%

An element is made up of all the same type of atom, whether they are unbonded or bonded. A compound is made up of two or more chemical elements that are chemically combined. 38.76%

A pure substance comprises the same type of particle (element or compound). A heterogeneous mixture is an ordered or non-random particle arrangement. A homogenous mixture is a disordered or random particle arrangement. 2.78%

The responses of PSSTs to each item included in the PNM area of the instrument were investigated with respect to their study of upper-second-level chemistry and mathematics. The results related to upper-second-level chemistry and mathematics are provided in Tables 5.30 and 5.31, respectively.

Table 5.29 Proportion of PSSTs that provided evidence of scientifically-acceptable PNM conceptions

<table>
<thead>
<tr>
<th>Scientifically-Acceptable Conceptions</th>
<th>% PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A single atom of sulfur has the same chemical properties as the macroscopic substance but does not have the same physical properties.</td>
<td>32.12%</td>
</tr>
<tr>
<td>On phase change of ammonia from liquid to gas, the distance between particles increases but the intramolecular bonds are not broken.</td>
<td>64.24%</td>
</tr>
<tr>
<td>After a mixture of sulfur and oxygen react in a closed container, the resulting sulfur dioxide is made up of discrete molecules and the number of atoms are conserved.</td>
<td>16.27%</td>
</tr>
<tr>
<td>On phase change of iodine from solid to gas in a closed container, mass is conserved.</td>
<td>61.03%</td>
</tr>
<tr>
<td>The coefficients in a chemical equation refer to the number of moles or the number of particles; these are the number of discrete molecules in the case of covalent molecules such as methane and carbon tetrachloride.</td>
<td>71.31%</td>
</tr>
<tr>
<td>Static images of solid, liquid and gas differ in proximity and arrangement of particles.</td>
<td>67.02%</td>
</tr>
<tr>
<td>An element is made up of all the same type of atom, whether they are unbonded or bonded. A compound is made up of two or more chemical elements that are chemically combined.</td>
<td>38.76%</td>
</tr>
<tr>
<td>A pure substance comprises the same type of particle (element or compound). A heterogeneous mixture is an ordered or non-random particle arrangement. A homogenous mixture is a disordered or random particle arrangement.</td>
<td>2.78%</td>
</tr>
</tbody>
</table>

Table 5.30 Pearson’s $\chi^2$ tests for PSSTs’ experience of second-level chemistry and PNM responses

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\chi^2$(df)</th>
<th>Cramer’s V</th>
<th>Variable</th>
<th>$\chi^2$(df)</th>
<th>Cramer’s V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Responses</td>
<td>7.11(4)</td>
<td>.13</td>
<td>3bDiagram5</td>
<td>8.52(2)*</td>
<td>.14</td>
</tr>
<tr>
<td>1Mark</td>
<td>1.77(1)</td>
<td>.07</td>
<td>3bMark</td>
<td>19.58(1)**</td>
<td>.21</td>
</tr>
<tr>
<td>2Responses</td>
<td>10.03(5)</td>
<td>.15</td>
<td>3cDiagram1</td>
<td>2.74(1)</td>
<td>.08</td>
</tr>
<tr>
<td>2Mark</td>
<td>12.75(1)**</td>
<td>.17</td>
<td>3cDiagram2</td>
<td>22.01(2)**</td>
<td>.22</td>
</tr>
<tr>
<td>3aDiagram1*</td>
<td>0.05(1)</td>
<td>.01</td>
<td>3cDiagram3</td>
<td>3.60(2)</td>
<td>.09</td>
</tr>
<tr>
<td>3aDiagram2*</td>
<td>0.15(1)</td>
<td>.02</td>
<td>3cDiagram4*</td>
<td>0.02(1)</td>
<td>.01</td>
</tr>
<tr>
<td>3aDiagram3*</td>
<td>0.76(1)</td>
<td>.04</td>
<td>3cDiagram5</td>
<td>1.61(2)</td>
<td>.06</td>
</tr>
<tr>
<td>3aDiagram4</td>
<td>1.47(2)</td>
<td>.06</td>
<td>3cMark</td>
<td>2.72(1)</td>
<td>.08</td>
</tr>
<tr>
<td>3aDiagram5b</td>
<td>1.47(2)</td>
<td>.06</td>
<td>4Responses</td>
<td>8.29(4)</td>
<td>.14</td>
</tr>
<tr>
<td>3aMark</td>
<td>0.08(1)</td>
<td>.01</td>
<td>4Mark</td>
<td>1.26(1)</td>
<td>.05</td>
</tr>
<tr>
<td>3bDiagram1*</td>
<td>0.06(1)</td>
<td>.01</td>
<td>5Responses*</td>
<td>24.02(4)**</td>
<td>.24</td>
</tr>
<tr>
<td>3bDiagram2</td>
<td>1.75(2)</td>
<td>.06</td>
<td>5Mark</td>
<td>25.82(1)**</td>
<td>.24</td>
</tr>
<tr>
<td>3bDiagram3</td>
<td>7.06(2)*</td>
<td>.13</td>
<td>6Responses</td>
<td>50.10(4)**</td>
<td>.34</td>
</tr>
<tr>
<td>3bDiagram4</td>
<td>16.64(2)**</td>
<td>.19</td>
<td>6Mark</td>
<td>2.22(1)</td>
<td>.07</td>
</tr>
</tbody>
</table>

Note: * p < .05, ** p < .001, *some response options were removed, * some response options were removed, *test not carried out.

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136 This phrasing has been used as the images on a pencil-and-paper instrument are static and, therefore, concepts associated with kinetic energy of particles cannot be assessed.
137 These variables were the only two investigated in this conceptual area, as they were the only two that significantly contributed to the prediction of scores in PNM - as investigated in Section 5.3.
138 This ensured that the assumption that no more than 20% of cells have an expected frequency < 5 was met. For example, in Item 3a Diagram 1, the option gas was removed as only 3 PSSTs had selected this.
139 This occurred if only one option met the assumptions, i.e. almost all PSSTs selected the same option.
Table 5.31 Pearson’s χ² tests for PSSTs’ experience of second-level mathematics and PNM responses

<table>
<thead>
<tr>
<th>Variable</th>
<th>χ²(df)</th>
<th>Cramer’s V</th>
<th>Variable</th>
<th>χ²(df)</th>
<th>Cramer’s V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1Responses</td>
<td>4.24(4)</td>
<td>.10</td>
<td>3bDiagram5</td>
<td>6.37(1)*</td>
<td>.12</td>
</tr>
<tr>
<td>Q1Mark</td>
<td>0.15(1)</td>
<td>.02</td>
<td>3bMark</td>
<td>20.39(1)**</td>
<td>.22</td>
</tr>
<tr>
<td>2Responses</td>
<td>4.39(5)</td>
<td>.11</td>
<td>3cDiagram1</td>
<td>2.24(1)</td>
<td>.07</td>
</tr>
<tr>
<td>2Mark</td>
<td>0.93(1)</td>
<td>.47</td>
<td>3cDiagram2</td>
<td>8.94(2)*</td>
<td>.15</td>
</tr>
<tr>
<td>3aDiagram</td>
<td>0.00(1)</td>
<td>.00</td>
<td>3cDiagram3</td>
<td>2.41(2)</td>
<td>.08</td>
</tr>
<tr>
<td>3aDiagram2</td>
<td>2.14(1)</td>
<td>.07</td>
<td>3cDiagram4*</td>
<td>3.47(1)</td>
<td>.09</td>
</tr>
<tr>
<td>3aDiagram3*</td>
<td>0.24(1)</td>
<td>.02</td>
<td>3cDiagram5</td>
<td>1.23(2)</td>
<td>.06</td>
</tr>
<tr>
<td>3aDiagram4b</td>
<td></td>
<td></td>
<td>3cDiagram5</td>
<td>5.64(1)*</td>
<td>.12</td>
</tr>
<tr>
<td>3aDiagram5b</td>
<td></td>
<td></td>
<td>4Responses</td>
<td>4.37(4)</td>
<td>.10</td>
</tr>
<tr>
<td>3aMark</td>
<td>0.49(1)</td>
<td>.03</td>
<td>4Mark</td>
<td>2.13(1)</td>
<td>.07</td>
</tr>
<tr>
<td>3bDiagram1</td>
<td>0.26(1)</td>
<td>.03</td>
<td>5Responses*</td>
<td>7.50(4)</td>
<td>.14</td>
</tr>
<tr>
<td>3bDiagram2</td>
<td>3.37(2)</td>
<td>.09</td>
<td>5Mark</td>
<td>5.47(1)*</td>
<td>.11</td>
</tr>
<tr>
<td>3bDiagram3</td>
<td>5.72(2)</td>
<td>.12</td>
<td>6Responses</td>
<td>21.64(4)**</td>
<td>.23</td>
</tr>
<tr>
<td>3bDiagram4</td>
<td>15.06(2)**</td>
<td>.19</td>
<td>6Mark</td>
<td>4.07(1)*</td>
<td>.10</td>
</tr>
</tbody>
</table>

Note: * p < .05, ** p < .01, *** p < .001, a * some response options were removed, b test not carried out.

Item 2 of the instrument assessed PSSTs’ understanding of conservation of matter during a phase change from solid iodine to gaseous iodine in a closed container. PSSTs who had studied upper-second-level chemistry were significantly more likely to answer this item correctly than those who had not studied it. Figure 5.9 shows the responses provided by PSSTs. Those who had studied upper-second-level chemistry were more likely to select the correct response. A higher proportion of those who had not studied upper-second-level chemistry indicated that the mass of the closed container would decrease as a gas is lighter than a solid; this difference was not significant.

![Figure 5.9 Responses provided by PSSTs to Item 2 of the diagnostic instrument](image)

Note: * refers to the correct answer, # refers to a significant difference between groups selecting this option.

140 This was not the actual question asked of PSSTs but is the overall theme of the question and response options. Where titles have been added to graphs throughout this section, they provide the theme of the item. Only the most popular response options are shown.
Those who had studied upper-second-level chemistry were significantly more likely to answer Item 3b correctly compared with those who not studied chemistry. The specific responses selected by PSSTs are provided in Figure 5.11. The responses selected for Diagrams 3, 4 and 5 were significantly different. This item is provided in Figure 5.10. More of those who had studied upper-second-level chemistry identified Diagrams 3 and 5 as mixtures of elements and compounds, and were less likely to select either of the other two options. They were also more likely to identify Diagram 4 as one or more elements and were less likely to identify it as a mixture of elements and compounds than were their peers. The same trend was identified when comparing those who had studied lower- and higher-level upper-second-level mathematics in relation to Diagrams 4 and 5: those who had studied it at higher-level were more likely to identify Diagram 4 as one or more elements and Diagram 5 as a mixture of elements and compounds than those who had studied it at the lower-level.

Figure 5.11 Responses provided by PSSTs to Item 3b of the diagnostic instrument [# refers to a significant difference between groups selecting this option, numerical values in labels, e.g. 2: Study USL Chemistry, are a reference to the diagrams in Figure 5.10]
In Item 3c, the categorisation of Diagram 2 was significantly different depending on whether or not PSSTs had studied upper-second-level chemistry. The responses provided are shown in Figure 5.12. Those who had studied chemistry were significantly more likely to correctly categorise this diagram as a pure substance and significantly less likely to categorise it as either a homogeneous or heterogeneous mixture. The same trend was seen for upper-second-level mathematics: those who had studied it at higher-level were significantly more likely to correctly categorise Diagram 2 as a pure substance (25.10%) than those that had studied mathematics at the lower-level (13.17%).

![Figure 5.12 Responses provided by PSSTs to Item 3c Diagram 2 of the diagnostic instrument [* refers to the correct answer, # refers to a significant difference between groups selecting this option]*](image)

PSSTs who had studied upper-second-level chemistry were also significantly more likely to answer Item 5 correctly than those who had not studied chemistry. Item 5 assessed PSSTs’ conceptions of reactants and products at the particulate level as described by a chemical equation. Molecular flocking as described by Kern et al. (2010) is the inappropriate connecting of all molecules of a given species. In this sense, the coefficient is being used as a multiplier of all atoms in a molecule, as depicted in Diagram A of Figure 5.13. Molecular flocking is also used to describe cases of partial flocking as depicted in Diagram D of Figure 5.13. Diagram E shows a case of elemental flocking, while Diagram B shows the reactants as discrete atoms. More of those who had studied upper-second-level chemistry (74.90%) chose responses depicting the correct number of discrete molecules than those who had not studied chemistry (64.07%). They were less likely to select responses indicating molecular flocking. The same trend was seen for study of mathematics, where those who had studied the subject at higher-level performed better than those who had studied at lower-level.

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141 The same diagrams were used in the same order for Items 3a, 3b and 3c as shown in Figure 5.10.
Item 6 of the instrument required PSSTs to select a diagram to represent the product of a reaction taking place in a closed container. They were provided with the chemical equation. Those who had studied upper-second-level chemistry were not more likely to answer this item correctly than those who had not studied chemistry. However, the specific responses selected did differ significantly with moderate association. As shown in Figure 5.14, those who had not studied chemistry were more likely to treat the coefficient as a multiplier of the number of atoms of the first element in the compound, or to treat the coefficient as a multiplier of the number of atoms of all elements in the compound.

Those who had studied upper-second-level mathematics at the higher level were significantly more likely to respond to Item 6 correctly than those who had studied at the lower level. They also differed significantly in their alternative conceptions, with those who had studied at the lower-level (49.10%) being significantly more likely to indicate that the coefficient is a multiplier of the number of atoms of all elements in a compound than those who had studied at the higher-level (31.27%).

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142 Note that only the first tier of the question is shown here. The second tier related to the products and used diagrams following the same theme.
Figure 5.14 Responses provided by PSSTs to Item 6 of the diagnostic instrument [* refers to the correct answer, # refers to a significant difference between groups selecting this option]

(b) Chemical Bonding

Table 5.32 provides the alternative conceptions consistent with the responses selected by more than 10% of PSSTs. The most common alternative conceptions in this area were that: the shared electron pair in hydrogen fluoride is best represented as being closer to hydrogen as hydrogen has a stronger attraction for the electron pair (39.40%), and the breaking of all (32.12%) or some (32.12%) bonds in a chemical reaction releases energy.

<table>
<thead>
<tr>
<th>Alternative Conceptions</th>
<th>% PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ionic compound sodium chloride is best represented by the unit cell.</td>
<td>24.84%</td>
</tr>
<tr>
<td>The ionic compound sodium chloride is best represented as a covalent bond.</td>
<td>21.84%</td>
</tr>
<tr>
<td>Breaking hydrogen-hydrogen bonds releases energy when hydrogen burns in air.</td>
<td>20.56%</td>
</tr>
<tr>
<td>Breaking oxygen-oxygen bonds releases energy when hydrogen burns in air.</td>
<td>11.56%</td>
</tr>
<tr>
<td>Breaking hydrogen-hydrogen and oxygen-oxygen bonds releases energy when hydrogen burns in air.</td>
<td>32.12%</td>
</tr>
<tr>
<td>The breaking of hydrogen-hydrogen and oxygen-oxygen bonds and the formation of hydrogen-oxygen bonds releases energy when hydrogen burns in air.</td>
<td>12.85%</td>
</tr>
<tr>
<td>Sodium hydroxide has a higher boiling point than water because sodium hydroxide contains the metallic element sodium which increases the boiling point.</td>
<td>10.06%</td>
</tr>
<tr>
<td>Sodium hydroxide has a higher boiling point then water because ionic bonding is always stronger than covalent bonding.</td>
<td>16.27%</td>
</tr>
<tr>
<td>Lone pairs cannot exist on adjacent atoms of a molecule.</td>
<td>11.35%</td>
</tr>
<tr>
<td>Nitrogen always forms triple bonds.</td>
<td>23.13%</td>
</tr>
<tr>
<td>Hydrazine can be represented as nitrogen forming either three or five bonds because it is a resonance structure with delocalised electrons.</td>
<td>22.70%</td>
</tr>
<tr>
<td>In hydrogen fluoride, the electron pair is best represented as closer to hydrogen because hydrogen has a stronger attraction for electron pair</td>
<td>39.40%</td>
</tr>
<tr>
<td>In hydrogen fluoride, the electron pair is best represented as closer to fluorine because fluorine is the larger of the two atoms.</td>
<td>22.06%</td>
</tr>
</tbody>
</table>
The proportion of PSSTs demonstrating understanding of chemical bonding concepts is provided in Table 5.33. Only one conception, relating to differences in boiling points, was understood by over half of the PSSTs. PSSTs had the poorest understanding of the shared electron pair in hydrogen fluoride.

<table>
<thead>
<tr>
<th>Scientifically-Acceptable Conceptions</th>
<th>% PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ionic compound sodium chloride is best represented as a crystal lattice structure.</td>
<td>41.33%</td>
</tr>
<tr>
<td>Forming bonds releases energy when hydrogen burns in air.</td>
<td>18.63%</td>
</tr>
<tr>
<td>Sodium hydroxide has a higher boiling point than water because the ionic bonds are stronger than the intermolecular bonds between water molecules.</td>
<td>58.24%</td>
</tr>
<tr>
<td>Nitrogen cannot form five bonds.</td>
<td>23.34%</td>
</tr>
<tr>
<td>In hydrogen fluoride, the electron pair is best represented as closer to fluorine because fluorine has a stronger attraction for the shared electron pair.</td>
<td>7.92%</td>
</tr>
</tbody>
</table>

PSSTs’ responses to chemical bonding items were investigated with respect to their model of STE. Isolating the concurrent group, responses were also investigated with respect to their year of study. PSSTs’ studying on concurrent STE programmes were significantly more likely to respond correctly to two of the five chemical bonding items than those who were studying on a consecutive programme. In each case, the responses selected were also significantly different between these two groups. The relevant statistics are provided in Table 5.34.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\chi^2$(df)</th>
<th>Cramer’s $V$</th>
<th>Variable</th>
<th>$\chi^2$(df)</th>
<th>Cramer’s $V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Responses</td>
<td>20.36(4)***</td>
<td>.21</td>
<td>13 Mark</td>
<td>0.57(1)</td>
<td>.04</td>
</tr>
<tr>
<td>11 Mark</td>
<td>16.98(1)***</td>
<td>.20</td>
<td>14 Responses</td>
<td>2.67(4)</td>
<td>.08</td>
</tr>
<tr>
<td>12 Responses</td>
<td>19.02(5)**</td>
<td>.22</td>
<td>14 Mark</td>
<td>0.85(1)</td>
<td>.04</td>
</tr>
<tr>
<td>12 Mark</td>
<td>13.29(1)***</td>
<td>.18</td>
<td>15 Responses</td>
<td>8.68(4)</td>
<td>.15</td>
</tr>
<tr>
<td>13 Responses</td>
<td>9.21(4)</td>
<td>.14</td>
<td>15 Mark</td>
<td>0.25(1)</td>
<td>.03</td>
</tr>
</tbody>
</table>

Note: ** $p < .01$, *** $p < .001$.

Item 11 required PSSTs to identify the best representation of the ionic compound sodium chloride from a series of diagrams. Figure 5.15 shows PSSTs’ responses differentiated by model of STE. Those following a concurrent programme (47.68%) were significantly more likely than PSSTs following a consecutive programme (27.08%) to identify the crystal lattice as the best representation. Those on consecutive STE programmes (31.35%) were significantly more likely than those on concurrent programmes (17.65%) to select a response consistent with the alternative conception that the bonding in sodium chloride is covalent and involves the sharing of electrons.
Figure 5.15 Responses provided by PSSTs to Item 11 of the diagnostic instrument [* refers to the correct answer, # refers to a significant difference between groups selecting this option]

Item 12 assessed PSSTs’ understanding of the best representation of the position of the shared electron pair in a hydrogen fluoride molecule. As shown in Figure 5.16, a significantly higher proportion of the concurrent group (45.82%) compared with the consecutive group (25.00%) correctly identified the best representation of the position of the electron pair as closer to fluorine, due to fluorine’s stronger attraction for the electron pair. The consecutive group were significantly more likely to select responses consistent with the alternative conceptions that:

- the electron pair is centrally located in all covalent bonds, and
- the electron pair is best represented as closer to hydrogen due to hydrogen’s stronger attraction for the electron pair.

In all other chemical bonding items (Items 13-15), a higher proportion of the concurrent group responded correctly, although these differences were not significant.
Figure 5.16 Responses provided by PSSTs to Item 12 of the diagnostic instrument [* refers to the correct answer, # refers to a significant difference between groups selecting this option]

The data from the concurrent group \((n = 323)\) was isolated to investigate the impact of year of study on performance in chemical bonding items. There was a significant difference associated with PSSTs’ mark in Item 13 \((\chi^2(3) = 11.77, p < .01, V = .19)\). This item required PSSTs to identify a response option that explained the main source of energy released when hydrogen burns in air. Those in their 1st year of study were significantly more likely to answer the item correctly than those in their 2nd year. The mark achieved by PSSTs in their 3rd and 4th years of study did not differ significantly from that achieved by the 1st and 2nd year groups; however, the 1st year group had the highest proportion of correct answers of all four groups.

There was a significant difference associated with the specific responses, shown in Figure 5.17, selected by PSSTs in each year of study \((\chi^2(3) = 24.99, p < .05, V = .15)\). PSSTs in their 1st year were less likely to indicate that energy is released by breaking hydrogen-hydrogen and oxygen-oxygen bonds. However, there were equally as likely to indicate that breaking either type of bond was responsible for the release of energy. A higher proportion of those in their 1st year answered three of the other four items correctly compared with any of the other years of study; these differences were not significant at the .05 level of probability.
The alternative conceptions in this area consistent with the responses of PSSTs are presented in Table 5.35. The most common alternative conceptions are that: the mass of a particle affects the number of particles in a mole (43.04%), and there is one mole of electrons in 12 g of carbon (59.31%).

<table>
<thead>
<tr>
<th>Alternative Conceptions above 10%</th>
<th>% of PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The type of particle affects the number of particles in a mole of a substance.</td>
<td>11.56%</td>
</tr>
<tr>
<td>The mass of a particle affects the number of particles in a mole of a substance.</td>
<td>43.04%</td>
</tr>
<tr>
<td>There is one mole of electrons in 12 g of carbon.</td>
<td>59.31%</td>
</tr>
<tr>
<td>A 1.0 M solution of ethanol means that there is 1 mL of ethanol per litre of solution.</td>
<td>15.20%</td>
</tr>
<tr>
<td>A 1.0 M solution of ethanol means that there are 46 g of ethanol per litre of water.</td>
<td>25.70%</td>
</tr>
</tbody>
</table>

The proportion of PSSTs demonstrating sound understanding of stoichiometry concepts are presented in Table 5.36. The majority of PSSTs could use a simple mole ratio (74.09%). However, fewer than half understood the meaning of a 1.0 M solution of ethanol. This concept is important for all PSSTs as they will need make solutions of various concentrations in their future role as science teachers. Furthermore, the item assessing this involved quantities of 1 L, thus, reducing the complexity of the item. Very few PSSTs (8.99%) were able to use the mole as a counting unit.

<table>
<thead>
<tr>
<th>Scientifically-Acceptable Conceptions</th>
<th>% of PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of particles in a mole of substance is unaffected by any particle property.</td>
<td>32.98%</td>
</tr>
<tr>
<td>Capable of using the mole as a counting unit.</td>
<td>8.99%</td>
</tr>
<tr>
<td>The mole ratio provided by the coefficients in a chemical equation provides information about the relative numbers of moles of each substance.</td>
<td>74.09%</td>
</tr>
<tr>
<td>A 1.0 M solution of ethanol means that there are 46 g of ethanol per litre of solution.</td>
<td>44.54%</td>
</tr>
</tbody>
</table>
PSSTs’ responses to the stoichiometry items were investigated with respect to their previous experience of upper-second-level chemistry. The results of the Pearson’s $\chi^2$ tests to investigate this are presented in Table 5.37.

Table 5.37 Pearson’s $\chi^2$ tests for second-level chemistry experience and stoichiometry responses

| Variable | $\chi^2$(df) | Cramer’s $V$ | Variable | $\chi^2$(df) | Cramer’s $V$
|----------|--------------|-------------|----------|--------------|-------------
| 7Responses | 8.92(4) | .14 | 9Responses | 23.35(3)** | .24
| 7Mark | 5.35(1)* | .11 | 9Mark | 26.09(1)*** | .25
| 8Responses | 21.72(4)*** | .23 | 10Responses | 19.99(4)** | .22
| 8Mark | 1.47(1) | .06 | 10Mark | 3.39(1) | .09

Note: * $p < .05$, ** $p < .01$, *** $p < .001$, * some response options were removed.

Those who had studied chemistry were significantly more likely than PSSTs who had not studied chemistry to respond correctly to Items 7 and 9. Item 7 investigated PSSTs’ conceptions of the factors that could influence the number of particles in a mole of a substance. Although there was no overall significant difference in the responses selected, a higher proportion of those who had studied upper-second-level chemistry selected the correct response option and a lower proportion selected responses consistent with alternative conceptions in this area as shown in Figure 5.18.

![Figure 5.18 Responses provided by PSSTs to Item 7 of the diagnostic instrument [* refers to the correct answer, # refers to a significant difference between groups selecting this option]](image)

Item 9 investigated PSSTs’ ability to use the mole ratio by identifying how much carbon dioxide is produced when one mole of propane is burned according to the equation:

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

There was a significant difference associated with every response option and PSSTs’ experience of upper-second-level chemistry. More of those who had not studied chemistry identified one mole as the correct response. This may be indicative of a conception that
reactants and products always have a 1:1 mole ratio. Those who studied chemistry were significantly more likely to correctly use the mole ratio and significantly less likely to select each of the other response options. Although neither group was more likely to answer Items 8 or 10 correctly, there was a significant difference associated with the responses selected. The purpose of Item 8 was to assess PSSTs’ ability to use the mole as a counting unit. The responses and theme of the item are shown in Figure 5.19. Those who had studied upper-second-level chemistry were far more likely to indicate that there is one mole of electrons in 12 g of carbon, even though the stem of the item had informed them that there are six electrons in a single carbon atom. This suggests that upper-second-level chemistry reinforces the idea that the number of particles in a mole is inappropriately linked to 12 g of carbon regardless of the context. Item 10 assessed PSSTs’ understanding of molarity. PSSTs were asked to identify the meaning of a 1.0 M solution of ethanol and were provided with five possible responses. PSSTs’ who had not studied upper-second-level chemistry were significantly more likely to suggest that a 1.0 M solution of ethanol means that there is 1.0 mL of ethanol in 1 L of solution.

![Figure 5.19 Responses provided by PSSTs to Item 8 of the diagnostic instrument](image)

**Figure 5.19 Responses provided by PSSTs to Item 8 of the diagnostic instrument** [* refers to the correct answer, # refers to a significant difference between groups selecting this option]

(d) Equilibrium

The alternative conceptions associated with the area of equilibrium with which more than 10% of PSSTs may have difficulty are presented in Table 5.38. The most common alternative conceptions are that:

- the concentrations of all species in a reaction mixture are equal at equilibrium (32.98%), and
- on approach to equilibrium, the concentration of a reactant increases until equilibrium is reached whereupon the concentration remains constant (28.48%).
In other conceptual areas, a number of alternative conceptions were very prevalent among PSSTs. That is not the case in the area of equilibrium. However, the area was also very poorly understood by PSSTs. It appears that PSSTs simply have a very poor understanding of concepts in this area but alternative conceptions are not the main barrier to understanding.

Table 5.38 Alternative conceptions of PSSTs (n = 467) in the area of equilibrium

<table>
<thead>
<tr>
<th>Alternative Conceptions</th>
<th>% PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On approach to equilibrium, the concentration of a reactant reduces and then increases until, at equilibrium, it becomes constant.</td>
<td>11.99%</td>
</tr>
<tr>
<td>On approach to equilibrium, the concentration of a reactant increases until, at equilibrium, it remains constants.</td>
<td>28.48%</td>
</tr>
<tr>
<td>There is no change in concentration of reactant on approach to or during equilibrium.</td>
<td>11.35%</td>
</tr>
<tr>
<td>On approach to and during equilibrium, the concentration of reactant alternates between increasing and decreasing.</td>
<td>10.92%</td>
</tr>
<tr>
<td>At chemical equilibrium, the moles of products and starting reactants are the same, as the concentrations of all species in the reaction mixture are equal at equilibrium.</td>
<td>32.98%</td>
</tr>
<tr>
<td>The concentrations of products and reactants are always equal at equilibrium and, therefore, the equilibrium constant has a value of 1.</td>
<td>10.28%</td>
</tr>
</tbody>
</table>

PSSTs had the least difficulty with the concept of the change in a reactant on approach to equilibrium. However, they had the greatest difficulty with the concept of the relative concentrations of reactants and products at equilibrium. There was also a very poor understanding of the meaning of the equilibrium constant and many responses to this item were inconsistent or illogical (22.48%).

Table 5.39 Proportion of PSSTs providing evidence of scientifically-acceptable equilibrium conceptions

<table>
<thead>
<tr>
<th>Scientifically-Acceptable Conceptions</th>
<th>% PSSTs (n = 467)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On approach to equilibrium, the concentration of reactant reduces until, at equilibrium, it remains constant.</td>
<td>29.98%</td>
</tr>
<tr>
<td>At chemical equilibrium, the no. of moles of the products will be lower than the no. of moles of starting reactants as the reactants partially decompose to form the products.</td>
<td>9.21%</td>
</tr>
<tr>
<td>The equilibrium constant associated with equation 2A ⇌ B has a value that is less than 1; this means that the reverse reaction is favoured over the forward reaction.</td>
<td>11.13%</td>
</tr>
</tbody>
</table>

Responses to equilibrium items on the instrument were investigated with respect to PSSTs’ previous experience of upper-second-level chemistry; this was shown to be the main variable impacting upon performance in this area based on the analysis carried out in Section 5.3. Table 5.40 presents the results of the statistical tests carried out.

Table 5.40 Pearson’s χ² tests for experience of second-level chemistry and equilibrium responses

<table>
<thead>
<tr>
<th>Variable</th>
<th>χ²(df)</th>
<th>Cramer’s V</th>
<th>Variable</th>
<th>χ²(df)</th>
<th>Cramer’s V</th>
</tr>
</thead>
<tbody>
<tr>
<td>16Responses</td>
<td>16.46(4)**</td>
<td>.20</td>
<td>17Mark</td>
<td>7.14(1)**</td>
<td>.14</td>
</tr>
<tr>
<td>16Mark</td>
<td>7.85(1)**</td>
<td>.14</td>
<td>18Responses</td>
<td>35.25(9)**</td>
<td>.28</td>
</tr>
<tr>
<td>17Responses</td>
<td>17.85(5)**</td>
<td>.23</td>
<td>18Mark</td>
<td>21.83(1)**</td>
<td>.24</td>
</tr>
</tbody>
</table>

Note: ** p < .01, *** p < .001.
There was statistical significance associated with study of upper-second-level chemistry and all three equilibrium items: those who had studied chemistry were more likely to respond to each item correctly than those who had not studied chemistry. The specific responses selected also differed significantly between these two groups. Figure 5.20 shows PSSTs’ responses to Item 16 on the instrument. They were asked to select a graph that best represented the change in concentration of a reactant on approach to and during equilibrium. Those who had not studied chemistry were significantly more likely than those who had studied it to select a graph showing the concentration of the reactant increasing until some level whereupon it remains constant. Both groups were equally as likely to select graphs consistent with the following alternative conceptions:

- the concentration of reactant oscillates before and during equilibrium,
- the concentration oscillates on approach to equilibrium and then remains constant,
- the concentration of reactant remains constant on approach to and during equilibrium.

![Figure 5.20 Responses provided by PSSTs to Item 16 of the diagnostic instrument](image)

The responses select by PSSTs for Item 17 are shown in Figure 5.21. This item assessed PSSTs’ understanding of the concentration of products compared to the concentration of starting reactant for a decomposition reaction. PSSTs who had studied upper-second-level chemistry were significantly more likely to correctly identify that there would be fewer moles of product than moles of starting reactant as the reactant partially decomposes. However, they were also more likely to select responses consistent with the alternative conception that the number of moles of products will be higher than the number of moles of starting reactant as the forward reaction is favoured over the reverse reaction. Although not a significant
relationship, a higher proportion of those who studied chemistry also selected responses consistent with the alternative conception that all species have the same concentration at equilibrium compared with those who had not studied the subject.

The responses to Item 18 are shown in Figure 5.22. This item asked PSSTs to identify the value of the equilibrium constant for the reaction below and the meaning of this value.

\[2A \rightleftharpoons B\]

PSSTs who studied chemistry were significantly more likely to respond correctly. PSSTs who had not studied chemistry were significantly more likely to select responses consistent with the conception that concentrations of products and reactants are equal at equilibrium.
CONCLUSION

Study of upper-second-level chemistry is the most important predictor of PSSTs’ understanding of basic chemistry concepts. This generally impacts positively on their understanding of PNM, stoichiometry, and equilibrium concepts. PSSTs who have studied chemistry and/or higher-level mathematics at upper-second-level are significantly less likely than their peers who have not studied the subject(s) to select responses consistent with the following alternative conceptions:

- the mass of a closed container will decrease when solid iodine is heated to become gaseous iodine as a gas is lighter than a solid,
- the reactants and products in a reaction can be depicted as engaging in molecular flocking,
- the coefficient of a compound is a multiplier of the number of atoms of the first element,
- the coefficient of a compound is a multiplier of the number of atoms of all elements,
- the reactants and products of a chemical reaction always have a 1:1 mole ratio,
- a 1.0 M solution of ethanol means that there is 1.0 mL of ethanol in 1 L of solution,
- on approach to chemical equilibrium, the concentration of reactant increases until some level whereupon it remains constant, and
- the concentrations of products and reactants are equal at chemical equilibrium.

However, in a few cases those who studied chemistry were more likely to select responses consistent with alternative conceptions. They were more likely to inappropriately link the number of particles in a mole to 12 g of carbon, regardless of the context or what particle is being discussed. They were also more likely than their peers who didn’t study chemistry to select responses consistent with the idea that in a reversible reaction the number of moles of products will be higher than the number of moles of starting reactant because the forward reaction is favoured over the reverse reaction. Finally, a higher proportion of these PSSTs indicated that all species have the same concentration at equilibrium.

The analysis presented in this chapter has demonstrated that PSSTs’ model of STE was an important variable for the prediction of scores in chemical bonding. PSSTs following the concurrent model were significantly less likely than their peers on consecutive courses to select responses consistent with a number of alternative conceptions including: the bonding in sodium chloride is covalent and involves sharing of an electron, the electron pair is centrally located in all covalent bonds, and hydrogen has a stronger attraction for the electron pair in hydrogen fluoride. In all chemical bonding items, concurrent PSSTs demonstrated
better understanding than consecutive PSSTs, though not necessarily significantly so. The year of study for concurrent PSSTs was shown in the regression analysis to be an important predictor of scores in chemical bonding. This better performance is primarily the result of 1st year PSSTs having a better understanding of the energetics of bonding than those in other years in study. Also, a higher proportion of those in their 1st year of study answered four of the five chemical bonding items correctly compared with any other year of study.

Overall, this strand of research demonstrates the impact of upper-second-level chemistry and, to a lesser extent, mathematics education on PSSTs’ understanding of basic chemistry concepts, and the lack of impact of PSSTs’ subject specialism or degree classification. It has also resulted in interested findings regarding the counterintuitive impact of year of study for concurrent PSSTs and the topic-specific impact of STE model. Arguably one of the more important findings of this strand of research is that there were large portions of variance for which the regression models in Section 5.3 could not account. This suggests that there are factors which are more important for the development of sound understanding of basic chemistry concepts than the educational factors included in this study.
Chapter 6  Results of Phase 2

The data analysis reported on in this chapter was carried out with the intention of addressing Research Question M1: does a blended learning programme improve PSSTs’ understanding of fundamental chemistry concepts? The data was collected during Phase 2 of the study. All those in the C2-M2 Sample\(^{143}\) were administered the research tool prior to the beginning of the SuBATOMIC blended learning programme described in Section 3.10. This research tool collected data about the PSSTs’ backgrounds, exposure to Science Education Research (SER), and their motivation and learning strategies. This data was used to formally assess the comparability of the Conventional and Blended Learning Groups, derived from the C2-M2 Sample. It was also used in a more informal capacity in developing the SuBATOMIC programme. The results of this data collection will first be presented. At the conclusion of the SuBATOMIC programme, further data was collected using the same alternative conceptions diagnostic instrument as was used in Phase 1 of the study. This data will also be presented in this chapter. The scope of the analysis is limited as a result of the small sample size involved in Phase 2 of the project. Little can be said definitively as a result of this lack of statistical power. However, the results do suggest that the blended learning experience may have been more beneficial for the conceptual understanding about fundamental chemistry concepts for those with lower initial levels of conceptual understanding.

6.1 COMPARABILITY OF CONVENTIONAL GROUP AND BLENDED LEARNING GROUP

The PSSTs who formed the Conventional and Blended Learning Groups were from the same year of study and on the same concurrent STE programme. During the course of the study, all PSSTs were to continue with their studies as normal; this included the modules on the STE programme and a Teaching Practice (TP), which PSSTs began half-way through the study. The Blended Learning Group were to experience the SuBATOMIC learning programme in addition to these conventional experiences. The two groups could then be compared at the conclusion of the study. However, the similarity of background experiences does not guarantee that the two groups are comparable at the study outset. Therefore, the groups were compared in relation to the demographic variables that were identified as factors in Phase 1 of the study. The motivation and learning strategies of the two groups, as well as their exposure to SER were also hypothesised to be potentially confounding variables. Therefore, the groups were also compared in relation to these variables.

\(^{143}\) This sample group were previously described in Section 3.9(c).
(a) Demographic Comparison
A Pearson’s $\chi^2$ test was carried out to assess whether the Conventional and Blended Learning Groups were comparable in terms of the variables that were shown to significantly contribute to the regression analyses that were carried in Phase 1 of the study. PSSTs’ subject specialism and grade achieved in the previous third-level chemistry module ($\text{PrevChemGrade}$) were also included to assess whether PSSTs in the Conventional and Blended Learning Groups differed in these areas. The results of these tests are shown in Table 6.1. There was no significant difference between the Conventional and Blended Learning Groups in terms of their subject specialism, grade achieved in their previous chemistry module, or upper-second-level experience of chemistry and mathematics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test Statistic (df)</th>
<th>Effect size (Cramer’s $V$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>3.86(1)*</td>
<td>.27</td>
</tr>
<tr>
<td>Chemistry Specialism</td>
<td>0.11(1)</td>
<td>.05</td>
</tr>
<tr>
<td>USLChem</td>
<td>1.70(1)</td>
<td>.18</td>
</tr>
<tr>
<td>USLMath</td>
<td>1.58(1)</td>
<td>.18</td>
</tr>
<tr>
<td>$\text{PrevChemGrade}$</td>
<td>0.63(2)</td>
<td>.11</td>
</tr>
</tbody>
</table>

Note: * $p < .05$, df degrees of freedom.

There was a significant difference between the groups associated with gender. The Conventional Group had a higher proportion of male PSSTs (45.45%) than the Blended Learning Group (20.00%). According to Section 5.3(e), this variable may be of some relevance in the area of equilibrium. A breakdown of the composition of the two groups within each variable is provided in Figure 6.1. A slightly higher proportion of the Blended Learning Group had studied upper-second-level chemistry and higher-level mathematics than the Conventional Group. These relationships have a weak association.

(b) Comparison of Exposure to Science Education Research
The Conventional and Blended Learning Groups were also compared in relation to their views on the importance of SER, the frequency with which they read SER, the sources of SER which they use, and the perceived barriers to accessing SER. These variables were assessed as they may affect the manner in which PSSTs participate in the study. The results of these comparisons are provided in Table 6.2.

144 PSSTs’ model of STE and concurrent year of study were not included as they are not relevant to the sample group, all of whom are concurrent 2nd year PSSTs.
145 Although gender was not an important variable in the regression models, it appeared to be a confounding variable in the area of equilibrium and it was, therefore, included.
146 In all cases the assumptions of the $\chi^2$ tests were met.
Figure 6.1 Breakdown of the composition of the Conventional (C) (n = 22) and Blended Learning (BL) (n = 30) Groups
Table 6.2 Pearson’s χ² tests assessing the comparability of the Conventional and Blended Learning Groups in relation to if and how they access Science Education Research

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test Statistic (df)</th>
<th>Effect size (Cramer’s V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of Reading SER</td>
<td>.24(2)</td>
<td>.07</td>
</tr>
<tr>
<td>Source SER: Books</td>
<td>0.00(1)</td>
<td>.00</td>
</tr>
<tr>
<td>Source SER: Popular Search Engine</td>
<td>7.12(1)**</td>
<td>.37</td>
</tr>
<tr>
<td>Source SER: Lectures</td>
<td>0.79(1)</td>
<td>.12</td>
</tr>
<tr>
<td>Source SER: Peers</td>
<td>0.46(1)</td>
<td>.10</td>
</tr>
<tr>
<td>Source SER: Databases</td>
<td>1.92(1)</td>
<td>.19</td>
</tr>
<tr>
<td>Never Searched for SER</td>
<td>.71(1)</td>
<td>.12</td>
</tr>
<tr>
<td>Source SER: Other</td>
<td>.19(1)</td>
<td>.19</td>
</tr>
<tr>
<td>Importance of SER</td>
<td>.11(1)</td>
<td>.05</td>
</tr>
<tr>
<td>Barrier to Access: Language</td>
<td>0.08(1)</td>
<td>.04</td>
</tr>
<tr>
<td>Barrier to Access: Lack of Relevance</td>
<td>4.27(1)</td>
<td>.16</td>
</tr>
<tr>
<td>Barrier to Access: No Time to Search</td>
<td>4.74(1)</td>
<td>.12</td>
</tr>
<tr>
<td>Barrier to Access: No Time to Read</td>
<td>4.41(1)*</td>
<td>.29</td>
</tr>
<tr>
<td>Barrier to Access: Don’t Know How to Find</td>
<td>2.46(1)</td>
<td>.22</td>
</tr>
<tr>
<td>Barrier to Access: None</td>
<td>4.58(1)</td>
<td>.18</td>
</tr>
</tbody>
</table>

Note: * p < .05, ** p < .01, ^ one or more cells have an expected count less than 5.

The only significant relationship identified was associated with the use of popular search engines (e.g. Yahoo, Google, etc.) to search for SER and the perception of time constraints as a barrier to accessing SER. A higher proportion of the Blended Learning Group (73.33%) used popular search engines to locate SER than was the case for the Conventional Group (36.36%). Very few PSSTs in either group identified research journals as a source of SER and none in either group identified magazines for teachers (e.g. Chemistry in Action!) as a source of SER. A higher proportion of the Blended Learning Group (50.00%) compared with the Conventional Group (22.73%) perceived time constraints as a barrier to reading SER. A breakdown of PSSTs’ responses in each of these areas is provided in Section 6.2(a) in the context of presenting their responses in these areas at the conclusion of the study.

(c) Comparison of Motivation and Learning Strategies

The scales of the Motivated Strategies for Learning Questionnaire (MSLQ) were assessed for their adherence to parametric test assumptions. Where data within the Conventional and Blended Learning Groups met these assumptions, an independent t-test was carried out to compare the two groups. Where the data associated with one or both groups did not meet these assumptions, a Mann-Whitney test was carried out. Table 6.3 presents these results.

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147 A number of the tests violated the assumption that no more than 20% of cells have an expected frequency of less than 5. This was due to a very low number of PSSTs in a category of the 2x2 contingency tables. Results identified as violating this assumption should be treated with caution.
Table 6.3 Comparisons between the Conventional and Blended Learning Groups for MSLQ scales

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Test</th>
<th>Relevant Statistic (df)</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic Goal Orientation</td>
<td>t-test</td>
<td>( t = 0.39 ) (50)</td>
<td>( d = .11 )</td>
</tr>
<tr>
<td>Extrinsic Goal Orientation</td>
<td>Mann-Whitney</td>
<td>( U = 239.50 ) (52)</td>
<td>( r = .23 )</td>
</tr>
<tr>
<td>Control of Learning Beliefs</td>
<td>Mann-Whitney</td>
<td>( U = 247.50 ) (52)</td>
<td>( r = .21 )</td>
</tr>
<tr>
<td>Self-Efficacy for Learning and</td>
<td>t-test</td>
<td>( t = 0.96 ) (50)</td>
<td>( d = .27 )</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehearsal</td>
<td>t-test</td>
<td>( t = 0.18 ) (50)</td>
<td>( d = .05 )</td>
</tr>
<tr>
<td>Elaboration</td>
<td>t-test</td>
<td>( t = 0.81 ) (50)</td>
<td>( d = .23 )</td>
</tr>
<tr>
<td>Organisation</td>
<td>t-test</td>
<td>( t = 0.54 ) (50)</td>
<td>( d = .16 )</td>
</tr>
<tr>
<td>Critical Thinking</td>
<td>t-test</td>
<td>( t = 1.31 ) (50)</td>
<td>( d = .38 )</td>
</tr>
<tr>
<td>Metacognitive Self-Regulation</td>
<td>t-test</td>
<td>( t = 0.92 ) (50)</td>
<td>( d = .26 )</td>
</tr>
<tr>
<td>Peer Learning</td>
<td>t-test</td>
<td>( t = 1.14 ) (50)</td>
<td>( d = .33 )</td>
</tr>
<tr>
<td>Help Seeking</td>
<td>t-test</td>
<td>( t = 0.61 ) (50)</td>
<td>( d = .02 )</td>
</tr>
</tbody>
</table>

Note: Effect size \( d \) is Cohen’s, \( r \) is non-parametric z-score conversion, df are degrees of freedom.

There was no significant difference associated with PSSTs’ role in the study (i.e. participating in either the Conventional or Blended Learning Groups) and any of the scales of the MSLQ. However, there are a number of variables associated with small-medium effect sizes: Extrinsic Goal Orientation, Self-Efficacy for Learning and Performance, Elaboration, Critical Thinking, Metacognitive Self-Regulation and Peer Learning. Figure 6.2 displays PSSTs’ pattern of responses within each of these scales. Although these differences are not significant, recall that with a sample this size, it is only possible to consistently detect the significance of large effect sizes.

As shown in this Figure 6.2, a higher proportion of the Conventional Group provided responses that were closer to the ‘true of me’ end of the scale for Critical Thinking, Control of Learning Beliefs and Extrinsic Goal Orientation. This indicates that they have higher perceptions of themselves as:

- applying prior knowledge to solve problems with respect to standards of excellence,
- achieving outcomes as a result of their own efforts rather than the result of external factors (e.g. the teacher), and
- participating in a task as a means to an end (e.g. grades, rewards, evaluation by others).

The Blended Learning Group provided responses that were closer to the ‘true of me’ end of the scale for: Self-Efficacy for Learning and Performance, Elaboration, Metacognitive Self-Regulation, and Peer Learning. This indicates that they have higher perceptions of themselves as:

- having the ability to accomplish a task,
- using learning strategies such as summarising, creating analogies, etc.,
- using strategies such as planning, monitoring and regulating activities, and
- collaborating with their peers.
Figure 6.2 PSSTs’ response patterns for each scale of the MSLQ (Note: C is the Conventional Group and BL is the Blended Learning Group)
There were few significant differences between the groups for the demographic variables or exposure to SER. The variables associated with significant relationships with PSSTs’ role in the study, include their gender, choice of popular search engines to locate SER, and perceptions of time constraints as a barrier to accessing SER. From Phase 1, gender is associated with differences in the area of equilibrium when combined with differences in experience of upper-second-level chemistry. The SuBATOMIC programme focused on the areas of PNM and chemical bonding and, therefore, this difference is of little concern. Furthermore, there were no significant differences between the groups in their responses to the MSLQ. As such, the two groups may be said to be generally comparable. The small sample size means that the tests do not have the statistical power to consistently detect small-medium differences and it is important to be aware of these differences. The main pre-existing advantages of the Blended Learning Group over the Conventional Group, that are associated with these small-medium differences, are their higher perceptions of themselves in relation to peer learning and metacognitive self-regulation. The main pre-existing advantages of the Conventional Group over the Blended Learning Group are their higher perceptions of themselves in relation to critical thinking and control of learning beliefs.

6.2 PERFORMANCE OF CONVENTIONAL AND BLENDED LEARNING GROUPS

The Conventional and Blended Learning Groups were compared at the conclusion of the study. All PSSTs attended conventional lectures and completed a Teaching Practice. The Blended Learning Group also experienced the SuBATOMIC programme. In addition to the diagnostic instrument, the Science Education Research Survey was also re-administered. Although the survey had not been validated, it was thought to be an interesting exploratory outcome and the results should be interpreted accordingly. The findings in this exploratory area will first be presented, followed by an investigation of the mean and median differences in each area of the diagnostic instrument associated with PSSTs’ role in the study. Finally, a primarily descriptive investigation will be presented for the conceptual areas addressed within the SuBATOMIC programme and the total score in the instrument.

(a) Exposure to Science Education Research

Table 6.4 presents the findings related to PSSTs’ reading frequency and perceptions of the importance of SER. Figures 6.3 and 6.4 display the frequency with which PSSTs read SER and the perceived importance of SER, respectively. The frequency with which PSSTs read SER prior to the study was similar for both groups. However, after the study more PSSTs in the Blended Learning Group identified themselves as sometimes reading SER (40.00%) and
as reading it often or frequently (10.00%) than in the Conventional Group (25% identified themselves as sometimes reading SER and none as often or frequently reading it).

The frequency with which those in the Conventional Group read SER does not appear to have changed during the study. The relationship between PSSTs’ role in the study and the frequency of reading SER was not significant. However, it did have a small-medium effect size. From Figure 6.5, the most popular SER sources before the study were books, popular search engines and lectures. This remains the case after the study. However, the reliance of Conventional PSSTs on books was higher than the reliance of Blended Learning PSSTs. This relationship was significant ($\chi^2(1) = 4.44, p < .05, V = .30$). Few PSSTs selected research journals as a source of SER and none identified teaching magazines as a source of SER.

Note: * p < .05, ** p < .01, ^ one or more cells have an expected count less than 5.

![Figure 6.3 Frequency of reading of Science Education Research before and after the study](image-url)
Prior to the study, the importance that PSSTs attributed to SER was similar for both groups (see Figure 6.4) with approximately 90% identifying it as very or extremely important and 10.00% identifying it as moderately important. Prior to the study, none of the PSSTs identified SER as slightly important or not important. After the study, during which time all PSSTs attended science education lectures and experienced a Teaching Practice, all PSSTs’ perceptions of the importance of SER decreased. However, this decline in perceived importance was less marked for the Blended Learning Group than the Conventional Group. Approximately 5% in both groups identified SER as slightly or not important. However, over 15% more of those in the Blended Learning Group, compared to the Conventional Group, identified SER as very or extremely important. This relationship was not significant (see Table 6.4), although it did have a small-medium effect size. There was no significant difference between the perceived barriers to accessing SER between the Blended Learning and Conventional Groups (shown in Figure 6.6). However, the Blended Learning Group was more likely to identify the language of SER as a barrier to access than the Conventional Group; this relationship had a small effect size. Fewer Blended Learning PSSTs perceived barriers to accessing SER than Conventional PSSTs. This had a small effect size.
(b) Mean and Median Differences in the Diagnostic Instrument

The results of the comparison tests between the Blended Learning and Conventional Groups in each area of the instrument are presented in Table 6.5. The Blended Learning Group achieved higher mean and median scores ($M = 3.41, \sigma = 1.45, Mdn = 3.00$) in PNM than the Conventional Group ($M = 2.71, \sigma = 1.76, Mdn = 2.00$). This mean difference was not significant. However, it is an important finding given that it did have a medium effect size and the sample size is not sufficiently large to detect significance in the case of small and medium effect sizes. The Blended Learning Group also achieved a higher mean score ($M = 1.93, \sigma = 1.16, Mdn = 2.00$) in chemical bonding than the Conventional Group ($M = 1.62, \sigma = 1.07, Mdn = 2.00$). This difference was also not significant and was associated with a small effect size. The SuBATOMIC programme focused on the areas of PNM and chemical bonding. Therefore, the finding in relation to chemical bonding is disappointing.

Table 6.5 Performance of Conventional and Blended Learning Groups in the diagnostic instrument

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Test</th>
<th>Relevant Statistic (df)</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNM</td>
<td>Independent t-test</td>
<td>$t = 1.54(48)$</td>
<td>$d = .45$</td>
</tr>
<tr>
<td>Chemical Bonding</td>
<td>Mann-Whitney</td>
<td>$U = 262.50(50)$</td>
<td>$r = .12$</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>Mann-Whitney</td>
<td>$U = 284.00(50)$</td>
<td>$r = .06$</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Mann-Whitney</td>
<td>$U = 292.50(50)$</td>
<td>$r = .04$</td>
</tr>
<tr>
<td>Total Score</td>
<td>Independent t-test</td>
<td>$t = 1.07(48)$</td>
<td>$d = .42$</td>
</tr>
</tbody>
</table>

Note: Effect size $d$ is Cohen’s $d$, $r$ is non-parametric $z$-score conversion, df are degrees of freedom.

Where data within groups met the assumptions of parametric tests, an independent t-test was carried out. In cases where the data of one or both groups violated the parametric test assumptions, a Mann-Whitney U test was carried out.
Figure 6.5 Sources used by PSSTs when searching for Science Education Research before and after the study.
Figure 6.6 Perceived barriers to accessing Science Education Research before and after the study.
The performance of both groups in the diagnostic instrument is visualised in Figure 6.7. The location of data is higher for the Blended Learning Group in PNM; the dispersion of the data is also much narrower than for the Conventional Group. In the case of chemical bonding, although the 2nd quartile and median scores are the same for both groups, the 3rd quartile of the Blended Learning Group is located higher than for the Conventional Group whose 3rd quartile achieved scores no higher than those achieved by the 2nd quartile. In the area of stoichiometry, the Conventional Group achieved a higher mean score ($M = 1.67$, $SD = 1.06$, $Mdn = 1.00$) than the Blended Learning Group ($M = 1.48$, $SD = 0.57$, $Mdn = 1.00$). In the area of equilibrium, the Blended Learning Group achieved a higher mean score ($M = 0.41$, $SD = 0.57$, $Mdn = 0.00$) than the Conventional Group ($M = 0.38$, $SD = 0.59$, $Mdn = 0.00$). The difference associated with each area was not significant and the associated effect sizes were negligible (see Table 6.5). This is not surprising given that neither stoichiometry nor equilibrium were addressed in the SuBATOMIC programme. Finally, PSSTs in the Blended Learning Group achieved higher mean and median total scores ($M = 7.24$, $SD = 2.68$, $Mdn = 7.00$) in the instrument than PSSTs in the Conventional Group ($M = 6.38$, $SD = 2.96$, $Mdn = 6.00$). This difference was not significant but the effect size associated with it was medium.
achieved a score of 0-2 marks compared with those in the Conventional Group (52.38%).
37.93% of PSSTs in the Blended Learning Group achieved a score of 3 marks compared to only 9.52% of those in the Conventional Group. The proportion of PSSTs achieving scores in the 4-7 mark range is slightly higher for the Blended Learning Group (41.38%) than the Conventional Group (38.1%). Overall, the higher performance of the Blended Learning Group may be said to be due to fewer scores in the 0-2 mark range and more scores of 3 marks. Therefore, the SuBATOMIC programme may have benefited those with a poorer conceptual understanding of PNM more than those with a better understanding of PNM.

![Figure 6.8 Performance of Conventional and Blended Learning Groups in PNM](image)

Each PNM item of the diagnostic instrument was further investigated using Pearson’s $\chi^2$ test\(^{150}\). A larger proportion of the Blended Learning Group selected the correct response options in six of eight PNM items on the instrument\(^{151}\). There were two questions associated with a significant difference between the Blended Learning and Conventional Groups. The Blended Learning Group were significantly more likely to provide the correct responses to Item 2, with small-medium effect size ($\chi^2(1) = 4.48$, $p < .05$, $V = .31$). This is a two-tier question assessing conceptual understanding of conservation of mass during phase change. The responses selected by PSSTs in both groups are provided in Figure 6.9.

\(^{150}\) Note that the variables investigated for each question were not the responses but whether the item was answered correctly or incorrectly. In the former case, the $\chi^2$ test assumptions were violated.

\(^{151}\) For Item 3c, none of the PSSTs in either group selected the correct response options and in Item 5 almost the same proportion of PSSTs in both groups selected the correct response option (the difference was 0.7%).

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A higher proportion of the Blended Learning Group (70.00%) selected the correct response options compared with the Conventional Group (40.91%). However, it is interesting to note that more of the Blended Learning Group indicated that a solid in a closed container would be lighter after it had been completely evaporated because gases are lighter than solids. It is also interesting to note that 13.65% of the Conventional PSSTs’ responses were inconsistent response options (i.e. the answer selected in the first and second tiers were inconsistent with each other) while none of the Blended Learning PSSTs selected inconsistent options. This may indicate that in some cases within the Conventional Group, PSSTs’ poor performance was the result of a lack of understanding rather than the result of alternative conceptions. PSSTs in the Blended Learning Group were also significantly more likely to answer Item 3b of the instrument correctly compared to the Conventional Group ($\chi^2(1) = 3.96, p < .05, V = .28$). Item 3b and PSSTs’ responses are shown in Figures 6.10 and 6.11, respectively.

Figure 6.10 Item 3b of the diagnostic instrument

152 Note that the title of this chart represents the theme of the question but was not the actual question asked. The same is true of all charts to which titles have been added in this section.
The main difference between the groups is that those in the Blended Learning Group were less likely to select the response option consistent with the alternative conception that a mixture of elements is a compound (i.e. identifying Diagram 4 as a compound or a mixture of both element and compound) than the Conventional Group. Similar proportions in both groups could identify a single element (Diagram 1), and a mixture of elements and compounds in solid form (Diagram 3). However, a larger proportion of the Blended Learning Group correctly identified a single compound (Diagram 2) and a mixture of elements and compounds in the gas phase (Diagram 5).

(d) Descriptive Investigation of the Conceptual Area Chemical Bonding
Figure 6.12 shows the performance of PSSTs in the area of chemical bonding. The proportion of PSSTs achieving a score in the 0-2 mark range was lower for the Blended Learning Group (65.52%) than the Conventional Group (80.95%). More PSSTs in the Blended Learning Group (34.48%) than the Conventional Group (19.05%) achieved scores in the 3-4 mark range. This suggests that SuBATOMIC may have benefited those PSSTs that participated in it, but not sufficiently to reach a medium-large effect size.
Figure 6.12 Performance of Conventional and Blended Learning Groups in chemical bonding

Each of the items in the area of chemical bonding was further analysed using Pearson’s $\chi^2$ test. The null hypothesis was not rejected for any item indicating that the Blended Learning and Conventional Groups were not significantly more likely to select either correct or incorrect responses. However, in the case of Item 12 ($\chi^2(1) = 2.64$, ns, $V = .24$), there was a small-medium effect size. The response options selected by PSSTs in the Blended Learning and Conventional Groups are shown in Figure 6.13.

Figure 6.13 Responses provided by PSSTs to Item 12 of the diagnostic instrument. (* refers to the correct answer, F and H are the fluorine and hydrogen in the hydrogen fluoride molecule)

Approximately twice the proportion of PSSTs in the Blended Learning Group, compared with the Conventional Group, selected the correct response options for Item 12. A lower proportion of the Blended Learning Group selected responses consistent with the alternative
conception that the electron pair is centrally located in all covalent bonds regardless of the polarity of the bond. However, a larger proportion of the Blended Learning Group selected responses suggesting that the electron pair is best represented as closer to fluorine given that this is a larger atom. As was the case with Item 2 in PNM, a higher proportion of the Conventional Group (22.73%) than the Blended Learning Group (6.67%) selected response options that were inconsistent between the first and second tiers. This again suggests that a lack of understanding, rather than the presence of alternative conceptions, may be a greater issue among the Conventional Group compared with the Blended Learning Group.

(c) Descriptive Investigation of the Total Scores in the Diagnostic Instrument

Figure 6.14 displays the total scores for PSSTs in the Blended Learning and Conventional Groups in the diagnostic instrument. Fewer of those in the Blended Learning Group (10.34%) than the Conventional Group (33.33%) achieved scores in the 1-4 mark range and more of the Blended Learning PSSTs (34.48%) than the Conventional PSSTs (19.05%) achieved a score in the 5-6 mark range. This suggests that the SuBATOMIC programme benefited those with the lowest conceptual understanding. Although more of those in the Conventional Group achieved scores in the 7-8 mark range than the Blended Learning Group, more of the Blended Learning Group (31.04%) achieved scores in the 9-14 marks range than the Conventional Group (19.04%). Overall, the Blended Learning Group has fewer PSSTs in the lowest range of conceptual understanding and more in the highest range.

Figure 6.14 Performance of Conventional and Blended Learning Groups for total score in the diagnostic instrument
SUMMARY OF MAIN FINDINGS

Although there was no statistical significance associated with mean and median scores in the diagnostic instrument, the results in the area of PNM display some promise with a medium effect size being associated with the Blended Learning Group’s higher scores compared with the Conventional Group. The same is true for the total scores on the diagnostic instrument. In almost all PNM items (six of eight), a higher proportion of those in the Blended Learning Group demonstrated evidence of sound conceptual understanding compared with the Conventional Group. However, the findings in relation to chemical bonding are disappointing, though there is some evidence that those in the Blended Learning Group benefited from the experience. The descriptive analysis of PNM, chemical bonding and total score on the diagnostic instrument suggests that the SuBATOMIC programme may have been mainly of benefit for those with the low conceptual understanding.
Chapter 7  Discussion

The data presented in the preceding two chapters were collected and analysed in order to address Research Questions C1 and M2, with Chapter 5 ‘Results of Phase 1’ relating to the former and Chapter 6 ‘Results of Phase 2’ relating to the latter:

C1. Does the model of STE (concurrent or consecutive) on which PSSTs are enrolled have an effect on the prevalence of alternative conceptions about fundamental chemistry concepts, taking into account other variables such as subject specialism, year of study (for those on the concurrent model), degree classification (for those on the consecutive model), and previous second-level school experiences?

M2. Does a blended learning programme improve PSSTs’ understanding of fundamental chemistry concepts?

This chapter will focus upon interpreting the results relating to each of these questions within the context of past research. The implications of the findings relating to both research questions will then be presented, which have relevance for chemistry education, science teacher education, and future research. Finally, the limitations of the quantitative strands of research in Phases 1 and 2 will be identified.

7.1  RESEARCH QUESTION C1

The results provided in Chapter 5 accounted for more variables than PSSTs’ model of STE in order to isolate, as much as possible, the impact of this variable-of-interest. The influence of PSSTs’ previous upper-second-level experiences and their third-level experiences (other than the model of STE) will first be discussed. These variables represent unexpected findings as a result of an investigation of PSSTs’ model of STE, however, they also lend insight into possible reasons for the differences associated with STE model. Therefore, the influence of PSSTs’ model of STE will be discussed after other variables have been considered.

(a) Influence of Previous Upper-second-level Education on Alternative Conceptions

This study found that previous upper-second-level experience of chemistry, and mathematics to a lesser extent, was overall, the most powerful predictor of PSSTs’ performance in the alternative conceptions diagnostic instrument. It should be noted that the instrument was developed based on the upper-second-level chemistry syllabus – with half the concepts being either included in the lower-second-level syllabus, or needed to create the solutions necessary for preparing experimental materials for the lower-second-level syllabus. However, one would expect that third-level educational experiences, for PSSTs following either model of STE, would supersede these prior educational experiences. However, even when variables
such as chemistry specialism, model of STE, and year of study for concurrent PSSTs, are held constant, previous upper-second-level educational experiences continue to have a significant impact on PSSTs’ understanding of fundamental chemistry concepts.

Those who studied higher-level mathematics at upper-second-level education can reasonably be assumed to be of higher mathematical ability than those who studied the subject at lower-level. Research into the mathematical ability of learners has correlated it with both cognitive ability and personal characteristics. Cognitive ability has been measured in general ways such as general intelligence (Levpušček et al. 2012), fluid intelligence (Kytrilä and Lehto 2008), and working memory capacity (Geary 2011). It has also been related to more specific cognitive abilities such as visuo-spatial ability (Battista 1990; Casey et al. 1997; Reuhkala 2001), problem-solving and reasoning skills (Yurt and Sünbül 2014), cognitive styles (e.g. field independence-dependence approaches) (Vaidya and Chansky 1980), and the interpretation of symbols (Arcavi 2003). Better outcomes in mathematics and mathematical ability have been correlated with each of these areas.

These cognitive abilities have intuitive relevance to developing understanding of chemistry and this has also been demonstrated in past research. The interpretation of symbols in chemistry has long been considered a challenge central to developing sound understanding in chemistry (Johnstone 2010). The ability to visualise and grasp the distinction between the meaning of symbols such as S, S₈, CH₄, NaCl, and so on, is central to developing an understanding in chemistry. Visuo-spatial ability has a small correlation with performance in general chemistry (Carter et al. 1987) and is particularly relevant to organic chemistry (Pribyl and Bodner 1987). Learners with cognitive styles characterised by field independence (i.e. an approach that overcomes the particular context of the problem and focuses only on salient features) have been found to outperform those with a field-dependent cognitive style (i.e. an approach which is determined by the embedded context of the problem) in chemistry and the other sciences (Tinajero and Páramo 1998). Problem-solving and reasoning ability has also been associated with chemistry achievement (Ertepinar 1995), and with the development of understanding in the areas included in the diagnostic instrument in the current study (Chandran et al. 1987; Abraham et al. 1994; Noh and Scharmann 1997).

Factors such as personality (Marsh et al. 2006), motivation and attitudes (Middleton and Spanias 1999), and, in particular, self-efficacy and confidence have been shown to impact upon mathematical ability (Fast et al. 2010; Levpušček et al. 2012; Stankov et al. 2014). Self-efficacy refers to a person’s beliefs about his/her abilities in achieving goals in a specific domain (Bandura 1997). Pajares and Kranzler (1995) found that self-efficacy had as much
predictive power, in terms of performance in mathematics, as measures of cognitive ability. Self-efficacy is also a positive predictor of achievement in chemistry (Kan and Akbas 2006; Uzuntiryaki-Kondakci and Senay 2015). However, given the domain-specific nature of self-efficacy, self-efficacy in mathematics is not necessarily an indication of self-efficacy in chemistry (Pajares 1996).

In the current research, the study of higher-level mathematics at upper-second-level education, as opposed to the study of lower-level mathematics, was a significant predictor of performance in the PNM area of the diagnostic instrument. It was also associated with a positive prediction of total performance, though this was non-significant. It seems unlikely that the influence of previous upper-second-level mathematics experience was due to the content that was studied at this level; it is a significant predictor of performance in PNM but not in stoichiometry, and it did not appear to have any influence in the area of equilibrium. Stoichiometry and equilibrium are associated with more mathematical content and skills than PNM. This suggests that the significance attributed to upper-second-level mathematics study is due to factors such as reasoning ability, visuo-spatial reasoning, motivation, and so on. Several studies have correlated understanding of fundamental PNM concepts with learners’ reasoning ability (Haidar and Abraham 1991; Abraham et al. 1994; Noh and Scharmann 1997) and this seems to be the most likely source of the significance attributed to PSSTs’ experiences with upper-second-level mathematics in the PNM regression model.

The study of upper-second-level chemistry, as opposed to not having studied the subject at this level, was a significant predictor of scores in PNM, stoichiometry, and total scores in the diagnostic instrument. In the area of equilibrium, upper-second-level chemistry and physics experiences were also associated with better performance. As mentioned previously, upper-second-level experiences of chemistry have been correlated with many of the cognitive and personal factors discussed in the context of mathematical ability. The value of the regression model is that variance is only accounted for by a single variable, i.e. the variance attributed to the level of study of mathematics at upper-second-level education is only attributed to that variable and to none other. Therefore, the variance accounted for by PSSTs’ experience of upper-second-level chemistry is due to factors above and beyond those associated with mathematics. Based on the literature mentioned previously, there are two main possibilities accounting for this variance: 1) the self-efficacy in chemistry associated with having studied the subject, and/or 2) the actual chemistry content studied in upper-second-level chemistry. A study by Seery (2009), which also took place within the Irish context, found that third-level students’ prior knowledge was a better predictor of performance in third-level introductory chemistry modules, than were their personal aptitudes. This suggests that the
actual content studied during upper-second-level chemistry was the primary source of the variance in the current study. However, self-efficacy developed during this phase of chemistry study may also contribute to the variance.

This finding is of particular interest considering the lack of any predictive power associated with specialising in chemistry in any of the regression models in this study. Upper-second-level chemistry experience continues to be a significant predictor of total performance in the instrument even when the year of study and degree classifications are held constant for the concurrent and consecutive cohorts, respectively. This suggests that the introductory chemistry modules in first-year science and chemistry degrees are not ‘levelling the playing field’ for students with varying second-level educational backgrounds. The foundation in chemistry that is being provided in upper-second-level chemistry is not being provided for in science and chemistry degrees, be they as part of concurrent or consecutive STE programmes; if they were, then upper-second-level chemistry would not continue be the most powerful predictor of performance.

This finding has implications for chemistry educators, regardless of whether they are preparing future teachers or chemists. The education in chemistry that is taking place in any year of study in science and chemistry degrees, is not building a foundation in basic chemistry concepts. This study demonstrates that a PSST who has not chosen to specialise in chemistry but who has studied the subject at upper-second-level will have fewer alternative conceptions about basic chemistry concepts than those who do choose to specialise in the subject but have not studied it in upper-second-level education. Furthermore, and as the next section will demonstrate, a PSST who has studied the subject at upper-second-level and chooses to specialise in the subject at third-level, will not develop more scientifically-acceptable conceptions about fundamental concepts during their degree programme.

(b) Influence of Third-Level Experiences on Alternative Conceptions

This section will address the findings of three further variables: PSSTs’ subject specialism, consecutive PSSTs’ degree classifications, and concurrent PSSTs’ year of study in their STE programme. The current study found that PSSTs’ subject specialism was a poor predictor of performance in any of the conceptual areas of the alternative conceptions diagnostic instrument. The same was true of the science degree classification (i.e. 1.1 degree, 2.1 degree, etc.) obtained by PSSTs following the consecutive model of STE. Among concurrent PSSTs, their year of study in the STE programme had a counter-intuitive impact upon their alternative conceptions about the fundamental chemistry concepts included in this study.
Previous research into the influence of PSSTs’ subject specialisation on their understanding of fundamental chemistry conceptions is not common within the body of research literature. However, those studies that have investigated this relationship have confirmed the intuitive relationship between PSSTs’ understanding of chemistry and their subject specialism: those with a specialism in chemistry outperform those who do not specialise in this subject on diagnostic instruments such as the one used in this study. This has been found to be the case among PSSTs on consecutive STE programmes (Kind and Kind 2011; Kind 2014), concurrent STE programmes (Chang 1999) and among newly qualified in-service teachers (Kruse and Roehrig 2005; Nixon et al. 2016). The current study found that the condition of having or not having a specialism in chemistry was not a significant predictor of scores in any of the regression models derived from the study cohorts. In most models, the chemistry specialism variable was one of the least powerful predictors of performance. This clearly contradicts the existing research literature in the area.

The advantage of the regression analysis is that it allows an investigation of the predictive power of each variable, when all other variables in the model are held constant. To illustrate the impact of this method, the comparison testing that was reported in Section 5.2 suggested a significant relationship between the scores achieved by PSSTs with and without a chemistry specialism in the areas of chemical bonding, stoichiometry, and total scores on the diagnostic instrument. The correlation analysis that was presented in Section 5.3(a) revealed a significant correlation between a PSST’s decision to specialise in chemistry and the likelihood that he/she had studied chemistry, and higher-level mathematics, at upper-second-level education (among other variables). Once these variables were held constant (i.e. in the multiple regression analysis), the earlier significance identified was revealed to be a false positive result; the variance associated with PSSTs’ subject specialism was, in fact, better explained by other variables. Given the importance of previous upper-second-level experience of chemistry, this is the most likely candidate accounting for the earlier false positive, i.e. the impact of study of upper-second-level chemistry was being attributed to PSSTs’ subject specialisation. Examining the past literature which reports on PSSTs’ subject specialism, reveals that these studies did not control for upper-second-level experiences of chemistry, as t-tests, ANOVAs or qualitative methods were used to investigate the relationship between subject specialism and scores on diagnostic instruments (Chang 1999; Kruse and Roehrig 2005; Kind and Kind 2011; Kind 2014; Nixon et al. 2016). Therefore, it is quite possible that these studies also attributed the impact of upper-second-level experiences to PSSTs’ subject specialism.
The results in relation to PSSTs’ subject specialism suggest that additional study of third-level chemistry does not improve understanding of fundamental chemistry concepts. Those on consecutive programmes who specialise in chemistry have completed degrees with significant amounts of chemistry content, and those on concurrent STE programmes continue to study chemistry content throughout all years of their programme. Yet their understanding of the concepts included in the diagnostic instrument is no better than their peers without a chemistry specialism and who, generally, have studied chemistry content only in the introductory portions of their degree programmes and/or at upper-second-level education. The finding in relation to previous experience of upper-second-level chemistry highlighted that STE programmes (and science degrees) are not providing an equalising experience for PSSTs who have not studied the subject at upper-second-level. The finding in relation to chemistry specialism confirms that additional study of third-level chemistry is not improving PSSTs’ understanding of the fundamental chemistry concepts which they will be required to teach in the future.

Consecutive PSSTs’ degree classification is often taken as a measure of their subject matter knowledge (SMK) (Ferguson and Womack 1993; Kind and Kind 2011). Previous studies have noted that, regardless, of degree classification, consecutive PSSTs and newly qualified teachers lack the necessary SMK to teach their future students (Gess-Newsome 1999b). The current study is in agreement with this past research. The degree classification obtained by consecutive PSSTs was not a significant predictor of performance in any area of the diagnostic instrument. Another interesting aspect to consider, is that previous experience of upper-second-level chemistry appeared to be even more influential for the performance of consecutive PSSTs than for the performance of concurrent PSSTs, regardless of their degree classification. For the consecutive cohort, upper-second-level chemistry experience was either the most important predictor or the only predictor of performance in the areas of PNM and chemical bonding, and for total scores in the instrument. In the regression model predicting total scores, it was associated with a difference in prediction of 2.50 marks – twice that of the prediction associated with the concurrent PSST cohort. This suggests that, although neither STE model is providing a truly equalising experience for PSSTs without past study of chemistry at upper-second-level, the concurrent model may be slightly more successful in the attempt than the consecutive model of STE.

The year of study for PSSTs following the concurrent model of STE presents an interesting finding. This was the most powerful predictor of performance for concurrent PSSTs in the area of chemical bonding and in overall performance in the instrument, with those in their first year of study predicted to outperform those in subsequent years of study. The same
trend was seen in the area of PNM, though this was non-significant. Past research on changes in PSSTs’ SMK in chemistry over the course of concurrent STE programmes is conflicting. Some studies indicate a general improvement between initial and final years of study (Taagepera et al. 2002) while others indicate no significant changes in PSSTs’ understanding of fundamental chemistry concepts (Nicoll 2001). In many cases, authors have come to the conclusion that some alternative conceptions reduce in prevalence while others increase in prevalence (Kahveci 2009; Cakmakci 2010; Kind and Kind 2011). No such conclusion can be made about specific alternative conceptions in the current study. Although the analysis presented in Section 5.4 provided some insight into alternative conceptions that differ based on the predictive variables in this study, this analysis cannot be used to conclude that some alternative conceptions increase in prevalence while others decrease in prevalence. This is because of the nature of any \( \chi^2 \) analysis, and also any simple comparison testing such as that described in Section 5.2, which cannot allow for the control of other variables. Therefore, any such analysis of specific alternative conceptions would likely lead to false conclusions. The same can be said of similar analyses, insightful though they may be, in the research literature (Taagepera et al. 2002; Cakmakci 2010; Kind and Kind 2011). The conclusion of the current study, with regard to PSSTs’ progress through the concurrent STE model, is that PSSTs’ alternative conceptions regarding fundamental PNM and chemical bonding concepts, tend to increase in later years compared with the first year of study. This trend is significant for chemical bonding and in overall scores in the diagnostic instrument – the latter appearing to result from the combination of this trend in PNM and chemical bonding.

It seems unlikely that the increase in alternative conceptions about fundamental chemistry concepts is being developed due to additional third-level study of chemistry – the additional study of third-level chemistry associated with having a specialism in chemistry does not lead to an increase in alternative conceptions. Arzi and White (2007), in a 17-year longitudinal study of changes in teachers’ SMK, found that content which remains unused fades from teachers’ memory. The addition of new content was also not associated with changes in their SMK. Rather, growth in understanding arose from the reorganisation of the structure of curriculum knowledge as they gained additional teaching experience. In light of Arzi and White’s findings, the results of the current study may be appropriately interpreted as follows: alternative conceptions are developing (or being re-asserted) as PSSTs’ memory of fundamental PNM and chemical bonding concepts fades over time. The last time the PSSTs in this study would have explicitly encountered these concepts would have been during: introductory chemistry modules, study of upper-second-level chemistry (if studied), Teaching Practices (if chemistry content was taught), or, science and/or chemistry
pedagogical methods modules. The increase in alternative conceptions with year of study suggests that these concepts are not being adequately addressed (or perhaps addressed at all) in the context of science and/or chemistry pedagogical methods modules. Although, PSSTs gain additional teaching experiences as they progress through their STE programme, this does not necessarily mean that they have gained experience of teaching chemistry. PSSTs specialising in chemistry would seem more likely to gain such experience, however, this was not investigated in the study. Therefore, the most likely reason for the decrease in understanding of, and increase in alternative conceptions about, PNM and chemical bonding concepts is the length of time since they have studied them within third-level introductory chemistry modules or upper-second-level chemistry. Therefore, it appears that fundamental concepts are not being adequately linked with more advanced SMK or PCK knowledge in either chemistry modules or in science/chemistry pedagogical methods modules.

(c) Influence of Model of Teacher Education
The model of STE which PSSTs were following was a significant predictor of performance in chemical bonding, and in total scores in the diagnostic instrument. A PSST on a concurrent programme was predicted to perform better in these areas than a PSST on a consecutive programme, all other variables being equal. There are a number of distinctions between the consecutive and concurrent models of STE. The quantity of chemistry and science studied by PSSTs within each model differs, with those following the consecutive model having more formal third-level study of these subjects. This is most relevant for PSSTs specialising in chemistry on either model. However, the difference associated with the models was found to favour the concurrent, rather than the consecutive, model and the previous examination of the impact of specialising in chemistry, which is also associated with more study of chemistry, has shown that additional study of chemistry does not have an impact on performance – for good or ill. Therefore, the subject matter exposure for PSSTs following either model of STE does not appear to be the source of the better performance of concurrent PSSTs. The length of time since PSSTs explicitly studied fundamental chemistry concepts (i.e. in introductory third-level chemistry modules and/or upper-second-level chemistry, if studied) also differs between the PSSTs following either model. Those in their fourth year of a concurrent STE programme have studied introductory third-level chemistry modules, generally, three years previously – when they were in their first year of study. This would be at least one year longer for those PSSTs following the consecutive model of STE, and may be more as PSSTs do not necessarily begin their postgraduate teacher training immediately upon completion of their third-level science degrees. Among the concurrent PSST cohort, it was observed that the length of time since they explicitly studied fundamental
chemistry concepts led to a lack of retention of these concepts in memory. This effect may be more significant among consecutive PSSTs, given that their study of these subjects took place further back in their education than for concurrent PSSTs.

The central distinctions between the concurrent and consecutive models of STE are: 1) the level of integration of the study of subject matter and the development of teaching knowledge, practice and skills, and, 2) the stage at which learners explicitly decide to become teachers. Consecutive PSSTs in Ireland study their subject matter for three to four years in a science or an applied science discipline. At the end of this study, they may declare their intention to join the teaching profession by applying to join the postgraduate teacher education certificate programme, wherein they develop their professional knowledge for teaching (other than SMK). However, concurrent PSSTs in Ireland declare their intention to become teachers at the beginning of their third-level education. They study subject matter and develop other areas of professional knowledge for teaching simultaneously during their degree programme. The concurrent model of TE is intended to provide integration between subject matter and professional teaching strands of education. However, this integration is notoriously lacking with the strands of education being treated separately, making this seem less likely to be the source of concurrent PSSTs’ better performance (Coolahan 2001).

PSSTs following concurrent STE programmes have made an explicit decision to enter the teaching profession (or at minimum to obtain a qualification to do so) at the outset of their third-level education. They study their subject matter having already made this decision about their future role. However, PSSTs on consecutive programmes only explicitly make this decision after they have completing their third-level study of subject matter, and possibly after additional work experience. Therefore, the two groups have different goals and mind-sets during their third-level subject matter study. PSSTs with different goals and perceptions of their future selves as teachers interact with course material in different ways (Lee et al. 2015). A positive perception of oneself in a future role leads to increased motivation to engage with course work that is perceived as relevant for that role, and increased effort in becoming proficient in the skills and knowledge required for this future role (Markus and Nurius 1986; Oyserman et al. 2002). Learners with long-term goals are more likely to perceive the content of their courses as having direct relevance to their future roles than those who hold only short-term goals, such as the desire to obtain a passing grade in a module (Creten et al. 2001). The perceived relevance of course content for a future role has been linked to increased motivation for learning the relevant content, increased self-efficacy, better self-regulation of learning, and better academic performance (Van Calster et al. 1987; Miller et al. 1999; Husman et al. 2004; Kover and Worrell 2010). Given the different motivations towards
goal-setting at the outset of third-level education associated with the consecutive and concurrent models of STE, PSSTs following the concurrent model of STE would seem more likely to view subject matter content that is close to the level at which they will be expected to teach as directly relevant for their future role of teaching. They would, therefore, experience higher motivation for learning this content with perceived-relevance.

Teachers’ and pre-service teachers’ long-term goal motivations are associated with differences in their motivations towards setting achievement goals for a task (Malmberg 2006). Learners’ achievement goals have been dichotomously classified into mastery-oriented goals and performance-oriented goals (Dweck 1986). Performance goals relate to a focus upon demonstrating one’s normative competence, i.e. demonstrating one’s competence in relation to one’s peers, while mastery goals relate to a focus upon developing one’s competence in a task (Dweck 1986). These achievement goals impact upon the manner in which a learner engages with a task and upon the learning outcomes (Elliot and McGregor 2001; Kaplan and Maehr 2007). Another dimension in which these goals can be classified is the approach-avoidance dimension. A learner with an approach intention to goal-setting directs their energy toward a task, while a learner with an avoidance intention directs their energy away from the task and toward extraneous distractions e.g. avoiding mistakes, avoiding alternative conceptions, etc. The mastery-oriented competence goal and the approach-intention to competence goals (i.e. either mastery-approach or performance-approach) have been linked with deeper approaches to learning (Ames and Archer 1988; Bernacki et al. 2012; Ranellucci et al. 2013). As a result, the approach-avoidance dimension has been postulated to impact upon conceptual change (Gregoire 2003).

Both the approach-avoidance dimension and the mastery-performance dimension have been associated with conceptual change in the literature. Those with approach intentions towards their competence goals for a task, experience more conceptual change than those with an avoidance intention toward their goals (Johnson and Sinatra 2014), and those with mastery goals experience more conceptual change, and remediate more alternative conceptions, than those with performance goals (Linnenbrink and Pintrich 2002; Ranellucci et al. 2013). These dimensions have also been linked with learners’ ability to retain information over longer periods of time. Those with mastery-approach goals have an interest-based focus on learning (Hulleman et al. 2008) which leads to a broader scope of learning attention and, therefore, a larger number of mental associations with the material being learned (Elliot et al. 2005). Performance goals (either approach- or avoidance-oriented), on the other hand, are associated with a narrower scope of attention and fewer mental associations with the material being learning (Elliot et al. 2005). This impacts upon learners’ ability to retain the material
being learned over longer periods of time. Those with a mastery-approach goal towards a task have better long-term recall of material acquired when deep approaches to learning were adopted, when compared with those with a performance-approach goal towards a task (Murayama and Elliot 2011). This long-term recall reflects a more consolidated set of concepts that is less susceptible to memory-loss (Murayama and Elliot 2011).

PSSTs who have identified their future roles as teachers at the outset of their subject matter studies will have a different perspective on which course material is directly relevant to their lives, when compared with those who have not identified such a future role. This impacts upon their motivation towards goal-setting for course material with a perceived-relevance and on their learning approaches to this material, as well as their ability to retain this material over longer periods of time. The concurrent PSSTs appeared to retain less of their memories of fundamental chemistry concepts as the time since they last explicitly studied this material increased. This effect is almost certainly present for consecutive PSSTs also. The differences associated with STE model may simply be the result of the additional year (or possibly more) since they last explicitly studied fundamental chemistry concepts, when compared with concurrent PSSTs in their final year of study. However, there is no evidence that this trend is entirely linear and it seems sensible to assume that there is some critical time period of memory-loss beyond which differences are minimal. However, the differences associated with explicitly identifying future roles and the resulting changes in motivation towards goal-setting for relevant course material are likely to impact upon concurrent PSSTs’ propensity towards conceptual change and their ability to retain that material. As a result, the memory-loss effect may have been partially mitigated for the concurrent PSSTs in comparison with the consecutive PSSTs. This indicates that PSSTs following the consecutive STE model may be at a disadvantage, given that any STE reforms cannot impact upon their past experiences of learning their subject matter. It seems vital, then, that sincere efforts be made to adequately review fundamental conceptions in chemistry in the context of science and/or pedagogical methods courses as part of consecutive STE programmes.

Throughout this strand of research, chemical bonding was observed to be somewhat distinct from other conceptual areas. This was the only area in which the regression models for the total cohort of PSSTs did not identify previous study of upper-second-level chemistry as a significant predictor of performance. Furthermore, the counter-intuitive impact of year of study was only a significant predictor in this conceptual area, and the model STE was also only a significant predictor of performance in this area. This makes chemical bonding a unique conceptual area in this study. These findings seem likely to be the result of the complex and abstract nature of chemical bonding. An understanding of PNM is essential for
understanding this area, and this may impact on how well these concepts are integrated in PSSTs’ cognitive structures. They may be associated with fewer conceptual connections making it more likely that PSSTs will experience greater memory-loss in this area since the time it was studied at upper-second-level and/or introductory third-level chemistry modules.

7.2 RESEARCH QUESTION M2
Research Question M2 relates to the effectiveness of the SuBATOMIC blended learning programme in improving the conceptual understanding of PSSTs. The SuBATOMIC programme involved the blending of an online and face-to-face component over the course of seven weeks, and the continuation of the online component of the programme during PSSTs’ Teaching Practice (TP). The face-to-face sessions took the form of small-group learning and the online component involved the gradual development of a website (based, in part, on the small-group work carried out during face-to-face session) and communication via a Facebook group. The SuBATOMIC programme approached PSSTs in an authentic way, by engaging with them as future teachers rather than attempting to teach them SMK as learners. As such, it was hoped that PSSTs’ SMK would develop along with their PCK. Face-to-face sessions involved creating resources for future use in particular chemistry topics or creating resources that could aid their peers in revising their understanding prior to teaching a lesson. The website was also intended to be a space for PSSTs to prepare their lessons by giving them access to:

- teaching resources which had been developed in face-to-face sessions,
- in-depth explanations of the chemistry content which they may wish to revise prior to teaching a topic,
- advice on practical teaching issues,
- information about common alternative conceptions among their students,
- useful teaching and learning ideas from Science Education Research (SER), etc.

A more complete description of the SuBATOMIC blended learning programme was provided in Section 3.10.

(a) Influence of SuBATOMIC on Conceptual Understanding
The analysis of the quantitative data collected before and after the implementation of the SuBATOMIC programme was presented in Chapter 6. The analysis suggested that, although not reaching statistical significance, the Blended Learning Group outperformed the Conventional Group in PNM and in total scores in the diagnostic instrument, as previously shown in Table 6.5 and Figure 6.7. The Blended Learning Group also had a marginally better performance in chemical bonding. The differences in performance appeared to arise as a result of the SuBATOMIC programme primarily benefiting PSSTs with the lowest
conceptual understanding, when compared with the Conventional Group. The face-to-face component of the programme arranged PSSTs into small-groups, which were set various tasks requiring the creation of resources for the SuBATOMIC website. In the final session, they modelled a teaching and learning strategy rather than creating a resource. Sessions 2 and 3 involved creating concept cartoons or diagnostics questions in order to elicit their future students’ alternative conceptions about PNM concepts. In Sessions 4 and 5, the PSSTs used a cooperative learning approach to develop revision materials for their peers on the topic of chemical bonding, and, in Session 6, they experienced concept mapping on the topic of chemical bonding. In tandem with the face-to-face component, sections of the SuBATOMIC website were added as they became relevant. For example, common alternative conceptions and revision webpages that were relevant to the PNM conceptual area were added during the weeks of face-to-face Sessions 2 and 3, as were webpages with practical advice on creating concept cartoons and diagnostic questions. Online communication on Facebook often involved PSSTs reflecting on their face-to-face experiences and evaluating the usefulness of that week’s teaching and learning strategy for various hypothetical teaching circumstances.

The blended learning experiences surrounding preparation for teaching PNM appear to have been more successful in aiding PSSTs to develop their SMK than those surrounding chemical bonding. The PNM face-to-face sessions were far more focused upon PSSTs’ PCK than the chemical bonding sessions. In the PNM sessions, the SuBATOMIC group were primarily focused upon creating resources to elicit and/or remediate their future students’ alternative conceptions. PSSTs had the freedom to select any area within a topic on which to base their concept cartoons and diagnostic questions. The SuBATOMIC website was used by PSSTs in the sessions to inform themselves of common alternative conceptions which they may wish to represent in their resources. This more PCK-focused strategy appears to have been more helpful to them than the more SMK-focused strategy of developing revision materials for their peers in the area of chemical bonding153 or modelling a teaching strategy which could be used with their future students154. The publication of webpages on the SuBATOMIC website was also more timely and relevant during the weeks in which PNM was the focus of the face-to-face sessions and PSSTs saw their face-to-face resource ideas being made available, in a more polished form, on the website. Much of the work on the chemical bonding section of the website was only completed after the final face-to-face

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153 In Sessions 4 and 5, they were asked to create a ‘Check Your Understanding’ webpage for the SuBATOMIC website in the area of chemical bonding.
154 In Session 6, they modelled concept mapping by creating group concept maps on the topic of chemical bonding.
session. Therefore, the main differences between the PNM and chemical bonding aspects of the blended learning programme were the:

- differences in the topics of PNM and chemical bonding,
- timeliness of the addition of relevant material to the SuBATOMIC website, and
- SMK- or PCK-focus of the face-to-face sessions.

As previously noted in Section 2.3(b), the conceptual area of chemical bonding is widely acknowledged as one of the most difficult in which to gain conceptual understanding (Taagepera et al. 2002; Unal et al. 2006). Past research has confirmed this to also be the case among PSSTs (Kind and Kind 2011). Both PNM and chemical bonding are abstract topics, however, interactions between the abstract concepts of atoms and molecules are central to all chemical bonding concepts, which adds an additional layer of complexity (Unal et al. 2006).

Coll and Treagust (2003) note the ease with which alternative conceptions develop in the area of chemical bonding due to this complexity. Furthermore, chemical bonding is founded upon PNM concepts (Taber 2002), a point which was demonstrated in the analysis of the Phase 1 results of the current study. Lingering alternative conceptions and misunderstandings in the area of PNM will compound errors in the area of chemical bonding (Harrison and Treagust 2000; Taber 2002; Levy-Nahum et al. 2010). Therefore, chemical bonding is a more complex area in which to induce conceptual change when compared with PNM (Kind and Kind 2011).

The integration of face-to-face and online learning components is central to the effectiveness of blended learning (Garrison and Vaughan 2008). Such an integration was provided in the consistency between face-to-face sessions focusing on PNM and the publication of webpages that supported and extended PSSTs’ efforts in these face-to-face sessions. However, the face-to-face and online learning components gradually became more divorced over time owing to the time-intensive nature of developing the web-based learning resources and the time-constraints associated with the learning programme. This also resulted in PNM web-based learning resources which made better use of the multimedia capabilities of web technology and provided learner feedback, when compared with chemical bonding web-based learning resources. For example, PNM sections of the website contained a ‘Diagnostic Questions’ section wherein learners could respond to some of the questions created by their peers (and

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155 Recalling that scores in PNM were predictors of performance in all regression models for chemical bonding.
156 This typically required the creation of molecular (and other) images using Adobe Illustrator™, multimedia resources using Adobe Animate™ (formerly Adobe Flash Professional™), in addition to the creation of text-based sections and consideration of issues such as layout, hypertext links, etc.
the researcher). They received feedback on their alternative conceptions, depending on their specific response, and hypertext links to relevant materials to review their understanding. The chemical bonding portion of the website did not provide this facility. The use of the multimedia capabilities of web technologies and the provision of web-based feedback has been found to be central to the development of learners’ understanding of science, and the remediation of alternative conceptions, in web-based learning environments (She and Liao 2010; Ferguson and Chapmen 1993; Powell et al. 2003; Tsai and Chou 2002). Therefore, it seems likely that the separation of the online component from the face-to-face component during the chemical bonding-focused weeks, and the failure to make the best use of the capabilities of web-based technologies during these weeks contributed to the disappointing results in relation to this conceptual area when compared with the area of PNM.

Throughout the blended learning programme, PSSTs were engaged with in their authentic role as student teachers of science who were preparing to embark on their first TP. However, the PNM portion of SuBATOMIC took a more PCK-focused approach than the chemical bonding portion, which took a more SMK-focused approach. The PNM face-to-face sessions involved the PSSTs creating specific teaching resources in the conceptual area, and the online component supported this approach. Although many research studies take an orientation to their studies in which SMK is transformed into PCK in a one-way process (Magnusson et al. 1999), this is recognised by others as two-way process in which developments in PCK lead to developments in SMK, and vice versa (Sperandeo-Mineo et al. 2006; Nilsson 2008; Rollnick et al. 2013). This approach to the topic of PNM in the blended learning programme, may have better aided PSSTs in developing their PCK which in turn also improved their SMK and supports other such studies with similar outcomes (Yakmaci-Guzel 2013). This approach may also have been more authentic for PSSTs, thus, increasing the cohesiveness of the PSSTs as a learning community and increasing their motivation to engage with the topic (Bielaczyc and Collins 1999).

It is difficult to say which of these factors led to the difference in impact of the blended learning programme on improvement of conceptual understanding. It is likely that all these factors impacted upon the PSSTs’ ability to engage with the material in some way. However, the SuBATOMIC learning programme does demonstrate the potential for a blended learning approach to developing PSSTs’ SMK on STE programmes, given that a topic-specific PCK-focused strategy was linked to improvement in SMK. Such an approach is plausible within the context of the chemistry/science pedagogical methods modules that take place on consecutive and concurrent STE programmes.
(b) Influence of SuBATOMIC Programme on the Research-to-Practice Gap

The analysis presented in Chapter 6 revealed interesting exploratory findings as regards PSSTs’ exposure to and attitudes towards SER. At the outset of the study, the Conventional Group and Blended Learning Group revealed similar levels of exposure to SER, with approximately 77-80% of both groups reading SER ‘seldom or never’ and 17-23% reading it ‘sometimes’. However, at the end of the study, the Conventional Group maintained about the same level of exposure to SER, while the Blended Learning Group increased their exposure to SER, with 10% reading it ‘frequently or often’, 40% reading it ‘sometimes’, and 50% reading it ‘seldom or never’. Overall, the Blended Learning Group also perceived fewer barriers to accessing SER with approximately 20% stating that they experienced no barriers to accessing it (compared with approximately 5% prior to the study). This largely appears to be the result of a decrease in PSSTs’ perception of time constraints as a barrier to accessing SER. The findings in relation to PSSTs’ perceptions of the importance of SER for teaching were also interesting. Prior to the study, approximately 90% of both groups perceived it as ‘very or extremely important’, with the remainder identifying it as ‘moderately important’ – none believed it to be only ‘slightly or not at all important’. At the end of the study, all PSSTs had experienced their first TP and the other components of their STE programme, including a science pedagogical methods module. The Conventional Group’s perceptions of the importance of SER decreased, with 75% of PSSTs identifying it as ‘very or extremely important’, 20% believing it to be ‘moderately important’, and 5% believing it to be ‘slightly or not at all important’. However, the Blended Learning Group maintained similar perceptions of SER for the duration of the study. This suggests that the exposure to SER as part of the SuBATOMIC programme may have had a positive impact on PSSTs’ exposure to SER and attitudes towards SER, in comparison to the Conventional Group.

The gap between SER and teachers’ practices is widely acknowledged (Kennedy 1997; De Jong 2004; Broekkamp and van Hout-Wolters 2007; Childs 2009; Vanderline and van Braak 2010). Perceptions of the importance of SER are important in predicting the use of the outcomes of SER in the practice of teaching (Lysenko et al. 2014). Past research has shown that teachers do not benefit from the outcomes of SER, as they are not aware of the research and/or have difficulty in converting it into practice (Ilhan et al. 2015). In the SuBATOMIC programme, PSSTs actively created resources based on SER and experienced other teaching and learning activities that research has shown to be useful in improving learners’ understanding. Furthermore, during their TP, SER articles were added to a section of the SuBATOMIC website created for this purpose. The selected articles engaged with conceptual areas which PSSTs were teaching on TP (including areas within physics and
and presented practical strategies and advice which teachers could use in the classroom. PSSTs were informed on Facebook of any new SER additions to the website and, using the Facebook tagging facility\textsuperscript{157}, articles were directed towards particular PSSTs. The ability to direct PSSTs towards potentially useful SER while on TP was entirely due to the online component of the blended learning programme. It permitted PSSTs to quickly access SER likely to be relevant to them while carrying out their TP. This combination of the creation of resources based on SER and directing useful research articles to PSSTs is likely to have impacted upon the reduction in their perceived barriers to access, and the maintenance of their perceptions of the importance of SER. Some researchers have argued that in order for SER to become relevant to teachers, it must engage with them from the bottom-up by involving teachers in the design of research studies (Englert et al. 1993; Kaestle 1993; Vanderline and van Braak 2010). However, this study demonstrates that PCK-focused blended learning experiences do have the potential to easily and quickly direct PSSTs to SER which is relevant to them, thus allowing the wealth of past research to inform practice, in addition to new studies which may involve teachers from the bottom-up. Many researchers have noted the inability of researchers to disseminate their findings to teachers and the lack of appropriate mechanisms for research dissemination (Kaestle 1993; Chafouleas and Riley-Tillman 2005). Hallinan (1996) recommended that formal ‘research dissemination’ positions be created as way to bridge the gap between research and practice and the current study also suggests that such an idea may have merit on STE programmes.

\section*{7.3 IMPLICATIONS FOR SCIENCE TEACHER EDUCATION}

The results of the quantitative research strands raise a number of points for consideration in the context of chemistry education and science teacher education. The quantitative findings of Phase 2 suggested that a PCK-focused blended-learning approach has some merit for improving the understanding of fundamental PNM concepts among PSSTs with lower conceptual understanding, and that it can serve as a bridge between research and informing PSSTs of the outcomes of that research.

\textsuperscript{157} ‘Tagging’ involves mentioning a Facebook user in a post or update such that they are notified on their personal Facebook profile that they have been mentioned in a post.

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The findings in relation to each of the variables involved in Phase 1 were as follows;

Previous experience of upper-second-level chemistry is the most important predictor of performance: this finding revealed that third-level science/chemistry education, be it as part of the education of future teachers or scientists, is not providing an equalising experience for PSSTs who have not studied chemistry at upper-second-level.

Chemistry specialism is one of the weakest predictors of performance: this finding confirms that additional study of third-level chemistry is not improving PSSTs’ understanding of the fundamental chemistry concepts which they will be required to teach in the future.

Being in the first year of study in a concurrent STE programme results in a better prediction of performance than being in any subsequent year of study: this finding suggests that alternative conceptions are developing as PSSTs’ memory of fundamental PNM and chemical bonding concepts fades with increasing time since the concepts were last studied explicitly. It also implies that explicit links with fundamental concepts are not being adequately expressed as part of chemistry courses or as part of science and/or chemistry pedagogical methods courses.

Following the concurrent model results in a higher prediction of performance than the consecutive model: this finding suggests that the memory-loss effect is partially mitigated for concurrent PSSTs due to the motivations resulting from having made a firm decision to join the teaching profession prior to their third-level subject matter study. This also suggests that science and chemistry pedagogical methods courses in consecutive STE programmes are not adequately linking fundamental chemistry concepts to topic-specific teaching methods or teaching considerations.

(a) Chemistry Education
These findings have implications for chemistry educators in STE programmes and throughout third-level education. Third-level lectures with more of a focus on transmission of knowledge encourage students to adopt surface approaches (i.e. an orientation towards memorisation and reproduction) to learning that subject, while those with lecturers that adopt more student-oriented teaching approaches, encourage their students to adopt a deeper approach (i.e. an orientation towards understanding) to learning the subject (Trigwell et al. 1999). This effect has also been found at the departmental level, where university departments oriented towards transmission/teacher-focused approaches discouraged students’ deep approaches to learning (Kember and Gow 1994). Unfortunately, lecturers in ‘hard’ disciplines like chemistry are more inclined to transmission approaches than those in ‘soft’ disciplines such as education (Neumann et al. 2002; Lindblom-Ylänne et al. 2006). In disciplines like chemistry, knowledge acquisition is emphasised, and students more often
experience large group lectures involving overhead presentations and handouts (Neumann et al. 2002). In fact, third-level lecturers in chemistry have been found to be more likely than those in either biology or physics to have teacher-focused views on teaching and to experience contextual factors (e.g. departmental-norms to teaching approaches, promotion pressures, classroom layout, availability of teaching assistants, and pressures of content coverage) that hinder them from implementing student-oriented teaching approaches (Lund and Stains 2015).

Teacher-centred learning approaches have, generally, been shown to be poorer than any other alternative strategy in reducing learners’ alternative conceptions about, and improving their understanding of, fundamental chemistry concepts (Kogut 1997; Atasoy et al. 2009; Dalacosta et al. 2009; Antonoglou et al. 2011; Beerenwinkel et al. 2011). Furthermore, as previously mentioned, less teacher-centred approaches are associated with students adopting deeper approaches to learning. Therefore, this issue is one which needs to be addressed in third-level chemistry modules in order to, at minimum, level the playing field between PSSTs who have and have not previously studied chemistry at upper-second-level education, and in order to improve the understanding of all students in fundamental areas of chemistry. The first year of study would appear to be the most obvious place to provide an equalising experience to learners with different upper-second-level educational experiences. This study also demonstrates the need for more advanced chemistry modules to contain explicit links to the fundamental chemistry concepts encountered during introductory chemistry modules, in order to mitigate the memory-loss effect that was found to be detrimental to PSSTs’ understanding in this study.

(b) Science Teacher Education

PSSTs with a specialism in chemistry study more chemistry pedagogical methods modules than those who don’t specialise in the subject, and those further on in their STE programmes have studied more science pedagogical methods modules than those embarking upon their STE programmes. However, these do not appear to improve or impact upon PSSTs’ understanding of fundamental chemistry concepts. Furthermore, the only opportunity to aid PSSTs on consecutive STE programmes is through such modules. The purpose of pedagogical methods modules is not to teach/learn subject matter knowledge (SMK). However, these courses and other experiences in which PCK is the focus, such as teaching experiences, do have the potential to meet the needs of PSSTs with regard to their understanding of fundamental concepts. Although many studies seek to investigate the impact of SMK on PCK, taking a research orientation that investigates a one-way knowledge transformation from SMK to PCK (Magnusson et al. 1999), there is evidence that this is a
reciprocal relationship (Sperandeo-Mineo et al. 2006; Nilsson 2008). Rollnick et al. (2013) found that teachers learning new physics content, regularly took a PCK orientation to this learning; in developing their own understanding of the topic, they considered how it should be presented to students. Nilsson (2008) found a complex and dynamic relationship between PCK and SMK in her in-depth study with pre-service physics teachers; as the PSSTs developed their PCK, they reflected upon and developed their SMK. The findings of the current study also suggest that a PCK-focused approach has the potential to improve PSSTs’ SMK in fundamental areas of chemistry. However, STE programmes and pedagogical methods modules are already attempting to fulfil the needs of PSSTs in multiple areas already identified in the literature. With limited contact hours, there is a practical time constraint which must be addressed. A blended learning approach to such modules could allow for explicit connections to be made between topic-specific teaching methods, and the fundamental concepts to which such methods relate, without radically reducing the contact hours relating to other important issues. This study has demonstrated that this is a viable strategy for use with PSSTs.

(c) Future Science Education Research
This study also has implication for future SER. It is very significant for future research that the majority of variance in the data in Phase 1 was not accounted for by the regression models presented in Section 5.3. Depending on the regression model, it accounted for between 11% and 26% of the variance. This suggests that personal factors such as achievement goals, motivation, self-regulation strategies, and so on, need to be accounted for in future research of a similar nature. The predictive primacy of previous upper-second-level chemistry experiences also needs to be accounted for in any future research that intends to investigate any connection between PSSTs’ subject specialism and their understanding of fundamental concepts in chemistry. Studies with quasi-experimental control group designs that attempt to improve PSSTs’ understanding of chemistry should also control for this variable either through their analysis methods or by ensuring that groups are comparable. As a consequence of the results of Phase 1, the research carried out in Phase 2 of this study took these measures by ensuring that groups were comparable in terms of educational background, motivation, learning strategies, and self-regulated learning. Phase 2 of the study demonstrates that blended learning approaches to pedagogical methods courses have merit for increasing exposure to SER, maintaining positive attitudes towards SER, and improving conceptual understanding of PSSTs by taking a PCK focus. However, this merit requires further investigation with blended learning programmes that make consistent use of the integration of online and face-to-face components and utilise web-based technologies to their fullest.
7.4 LIMITATIONS OF THE RESEARCH

The first phase of the research focused upon the educational variables that may impact upon PSSTs’ conceptual understanding when considering the impact of the model of STE on PSSTs’ understanding. However, past research has found that factors such as visuo-spatial ability (Carter et al. 1987), the field-dependence of learners’ cognitive styles (Tinajero and Páramo 1998), problem-solving ability and reasoning ability (Abraham et al. 1994; Noh and Scharmann 1997) impact on learners’ conceptual understanding of chemistry. In this research study, it is likely that past experience of upper-second-level mathematics served as indirect and imperfect measure of these factors. Had these factors been directly measured and used in the regression analysis, the resulting models would account for greater variance in the data. Past experience of upper-second-level chemistry is also likely to be correlated with greater self-efficacy in chemistry. Self-efficacy has also been correlated with achievement in chemistry (Uzuntiryaki-Kondakci and Senay 2015) and had a direct measure of self-efficacy been used this would also likely result in the regression models accounting for greater variance in the data.

A potentially confounding variable in this study was the inclusion of PSSTs from two different educational systems – the Northern Ireland (NI) and Republic of Ireland (ROI) systems – and the exclusion of this variable from the regression models. Although the concepts in the alternative conceptions diagnostic instrument are included in both systems of education, chemistry at upper-second-level (where studied) is given a greater depth of treatment in NI than in ROI (Qualifax 2017). This seems likely to have had some impact on the study, given the long-lasting effect of previous upper-second-level study of chemistry. It seems reasonable to conclude that the greater depth of treatment of chemistry in the NI upper-second-level system would result in greater integration of the concepts and, therefore, better retention of these concepts in memory. This is avenue for future research.

The results have been interpreted in terms of PSSTs’ differing perceptions of their future roles, learning approaches, and memory retention. Memory retention was highlighted as a potential issue due to the concepts not being used by PSSTs over the course of their STE programme. However, PSSTs may have taught these fundamental chemistry concepts on TP during their STE programme. The concepts taught by PSSTs and the quality of their TP experience then is also a factor potentially impacting on the study. These factors were not measured in this study and this study’s interpretation should be treated lightly at this stage. Future research could include measures of these factors to assess whether they account for greater variance in the data and refute or confirm the interpretation presented in this study.
The SuBATOMIC blended learning programme was very time-intensive to create and as the online component was developed in response to face-to-face sessions, it was developed over the course of the programme itself. This lead to the gradual divorce of the face-to-face and online components, which undermined the learning efforts of the PSSTs. The analysis of the quantitative strand of research in the second phase of this study is highly limited by the small sample size. It would only have been possible for the analysis to attribute statistical significance to large effects but not medium or small effect sizes. There are several such non-significant effects that cannot be confirmed as a result of the limited statistical power associated with the sample size. A pre-test/post-test control group comparison design may have been more statistically appropriate (rather than merely a post-test control group comparison design) under these circumstances. However, the decision was made early on that administering the alternative conceptions diagnostic instrument at the outset of the SuBATOMIC programme would undermine attempts to build a trusting, open and cohesive learning environment. This will be further demonstrated in the next chapter which focuses on an analysis of the qualitative data collected during semi-structured interviews with PSSTs as they reviewed their responses to the instrument.
Part III
Qualitative Strands
Chapter 8  Findings of Phase 1

The qualitative findings of Phase 1 of the study refer to the interviews with PSSTs in the M1 Sample. These findings will be discussed in relation to pre-existing literature with a view to answering Research Question M1. This minor research question is as follows:

How do PSSTs approach conceptual questions in a quantitative alternative conceptions diagnostic instrument?

Details of the sample group will be provided in this chapter along with the qualitative data analysis methods used in this phase. Therefore, this section constitutes the methodology, analysis and discussion of the findings. In answering the research question, the focus was on PSSTs’ strategies for responding to diagnostic items. This was central to addressing the research question and the interview protocol was directed towards investigating this. However, over the course of the interviews, it became clear that there were issues surrounding alternative conceptions that were not cognitive issues. There appeared to be affective factors that impacted upon PSSTs’ experience of responding to the alternative conceptions diagnostic items. Therefore, this chapter will also present and discuss these unexpected findings. The affective findings were of central importance to the direction of the qualitative research which followed in Phase 2. Qualitative research involves a level of researcher interpretation. This chapter, and the next, will use the first person tense in order to reflect the active role of the researcher in the interpretation of the findings.

8.1 CONTEXT AND METHODS

The tool used in this portion of the research study was the semi-structured interview. I will present the reasons for selecting this tool and an outline of the interview process. The location in which the interviews were carried out, as well as the intended tone and style of the interviews will be discussed in order to provide a sense of the context of the interviews. Details of the sample group (the M1 Sample) have been provided in Section 3.9(c). However, I provide a more descriptive profile in this section, in order to give the reader an appreciation for the people behind the data.
(a) Selection and Structure of Interviews
There was a dual purpose to the interviews: 1) to validate the alternative conceptions diagnostic instrument, and 2) to answer Research Question M1. This chapter focuses on the data only as it relates to Research Question M1. I considered semi-structured interviews to be the appropriate methodological tool for the following reasons:

- investigating PSSTs’ approach to diagnostic items required open-ended questions and the ability to ask probing questions in order to clarify PSSTs’ thinking,
- Research Question M1 lends to an investigation which focuses on gaining insight and understanding, rather than collecting generalisable data, and
- I considered the depth of PSSTs’ reasoning to be more important than the comparability of their responses with others.

An interview permits a greater depth of questioning, probing of understanding and focus on gaining insight when compared with other qualitative methods such as open-ended questionnaires or other written artefacts (Gillham 2000, pp. 9-18). I designed the interview to be semi-structured, utilising the diagnostic instrument as the core of the interview protocol. In order to gain insight into PSSTs’ approaches to diagnostic items, I required the flexibility to clarify understanding and adapt the discussion based on the PSST’s particular reasoning. All interviews were audio-recorded and later transcribed into NVivo 10 – a software programme for increasing the efficiency of qualitative data analysis.

The interview comprised four main parts as advised by Gillham (2000, pp. 37-43): introduction or pre-interview phase, opening development, central core, and closure. The pre-interview phase involved communicating with PSSTs by email to inform them of the location and purpose of the interview. It also included my initial meeting with them on the day of the interview, at which time I again sought permission to record the interview and PSSTs signed a consent form. The opening development involved a number of general questions about their experience of responding to the instrument. This included questions about conceptual areas which they perceived themselves as being more or less confident to teach and had more or less confidence in the accuracy of their understanding. I also asked the participants whether they had a preference for a particular style of item: language-based or pictorial-based. The diagnostic instrument acted as the protocol for the central core of the interview. I asked PSSTs whether they understood what the item was asking of them, how they would respond to the item and why they would respond in that way. I also gave them time to read over each item prior to any questioning. All PSSTs were not asked about all items of the instrument. This was to reduce the length of the interview and prevent exhaustion (Gillham 2000, p. 54). I successively pruned items from interview-to-interview in order to focus on those that were
more problematic or that evoked interesting reasoning from PSSTs. Finally, the closure of the interview involved asking PSSTs about whether they had, prior to involvement in the study, been aware of the issue of alternative conceptions. I also asked them whether they had any other reflections on their experience of responding to the diagnostic instrument.

(b) Data Analysis

I used NVivo 10 to organise the transcribed interviews, and, code and model the interview data. I conducted an inductive thematic analysis according to the method described by Braun and Clarke (2006). Braun and Clarke’s analysis involves six steps that were applied to the data set as follows:

Step 1. *Familiarising yourself with your data*: this step involved listening, transcribing and re-reading the interviews, and writing down initial thoughts about the data.

Step 2. *Generating initial codes*: this involved developing codes for the data. I decided to code events in order to keep the bigger picture in mind about the approach that PSSTs were using. As such a PSST’s entire response to an item was coded to reflect the main steps he/she was taking in order to respond to the item. The entire dataset was coded during this step.

Step 3. *Searching for themes*: I collated codes developed during Step 2 into possible themes.

Step 4. *Reviewing themes*: the extracts coded to each potential theme were re-read to assess how well they fit into the theme. At this stage, I again reviewed the entire dataset to ensure that all data had been collated into a theme. I discarded some potential themes and combined others. I created a thematic map of the analysis, the final version of which is shown in Figure 8.1, in order to visualise the relationships between themes and further refine the analysis.

Step 5. *Defining and naming themes*: this involved refining the theme names and definitions and ensuring that themes were sufficiently distinct.

Step 6. *Producing the report*: this chapter is the written report of the preceding analysis. It was built up from individual reports about each item of the diagnostic instrument\(^\text{158}\). It involves not only presenting the themes and their inter-relationships but also selecting quotes that demonstrate the meaning of each

\(^{158}\) A report was produced for each item of the instrument in order to validate and inform revision of the instrument and to address Research Question M1. A number of sample reports, for the PNM items, have been provided in Appendix I.
theme. My approach to quote-selection is to include sufficient quotes to demonstrate the breadth of responses under each theme.

(c) Setting and Sample
I decided that the interview should be informal and as comfortable an experience as possible. The PSSTs and I were relatively close in age and the interview was to feel akin to discussing ideas with a peer. Therefore, the interviews took place in a quiet coffee-shop on the campus of the university and I sat on the adjacent side of the table from the PSST. I focused largely on the instrument in front of us. This seating position and the sparing use of eye contact, save for to convey interest, can reduce the domination of the interviewer and make the interviewee feel more at ease (Gillham 2000, p. 31). The convenience sampling method for selecting the M1 Sample has previously been discussed in Section 3.9 and a short description of the composition of the group was provided. There were seven PSSTs involved in this portion of the study: two male and five female. The questions at the opening development of the interview allow for a more qualitative description or profile of each PSST to be built up. This profile is provided below.

BRENDAN
Brendan was a fourth year PSST specialising in physics and chemistry. He had been aware of alternative conceptions as an issue interfering with learners’ understanding of chemistry prior to any involvement with this study. His awareness of this issue was based on his personal study of alternative conceptions in physics – a topic which he had chosen as part of a project carried out during his STE programme. Brendan expressed a preference for language-based items on the diagnostic instrument as he found that there was an additional level of interpretation required for pictorial-based diagnostic items. He identified stoichiometry as the area he felt most confident about, due its mathematical nature. He identified particular topics within PNM, notably ionisation energy, as areas he was lacking in confidence. While responding to diagnostic items, Brendan usually expressed his ideas with confidence, although there were also occasions where he was uncertain of his understanding. In discussing his approach to the diagnostic items, Brendan relied upon scientifically-acceptable conceptions about as often as he relied upon alternative conceptions.

EAMON
Eamon was also a fourth year PSST specialising in physics and chemistry. He had been aware of the issue of alternative conceptions in chemistry prior to involvement in the study and stated that he had observed this as a problem amongst his peers. Eamon’s preference was for pictorial-based diagnostic items, due to their ability to immediately convey the meaning
of an item. Eamon was very confident of his understanding of all conceptual areas in chemistry at the outset of the interview, although he later identified stoichiometry as an area of weakness. Despite Eamon’s initial confidence, his responses to diagnostic items were categorised as expressed with confidence and lack of confidence in approximately equal amounts. Eamon also introduced scientifically-acceptable conceptions about as often as alternative conceptions when responding to diagnostic items.

**Eileen**

Eileen was a fourth year PSST specialising in biology and chemistry. She stated that she was completely unaware of the issue of alternative conceptions prior to her engagement with this research study. She expressed a preference for more traditional language-based diagnostic items based on the fact that the use of images to convey meaning at the particulate level was not something she had ever experienced in her previous education. Eileen identified PNM as an area in which she was confident of her understanding, while she expressed a lack of confidence in her understanding of stoichiometry. Throughout the interview, Eileen’s responses were categorised as confident as often as they were categorised as being expressed with a lack of confidence. She was far more likely to introduce alternative conceptions in her responses than she was to introduce scientifically-acceptable conceptions.

**Patricia**

Patricia was a fourth year PSST specialising in biology and chemistry. She had been aware of alternative conceptions as an issue which can interfere with learning prior to her involvement in the study. Patricia did not express a preference for either language- or pictorial-based diagnostic items, feeling that one style or the other can be suitable depending on the concepts being addressed in the item. She did not identify a particular area in which she felt most confident but did identify stoichiometry as an area of weakness. Throughout the course of the interview, Patricia’s responses were categorised as expressed with confidence slightly more often than they were categorised as lacking in confidence. Patricia’s responses were also categorised as relying upon alternative conceptions more often than they were categorised as relying upon scientifically-acceptable conceptions.

**Nora**

Nora was in her fourth year of study and was specialising in biology and chemistry. She had been aware of the issue of alternative conceptions prior to this study having learned about alternative conceptions as part of science and chemistry pedagogical methods modules in her STE programme. Nora preferred pictorial-based items to language-based items because she found it difficult to visualise a concept from text alone. Nora identified concepts within PNM
as those in which she was confident (pure substances and mixtures, for example) and in which she was lacking in confidence (ionisation energy). Nora’s prior knowledge was typically categorised as being expressed with certainty although in some cases it was categorised as uncertain. Nora’s discussion of her approach to the diagnostic items was as likely to be coded as composed of concepts that were scientifically- and alternatively-conceived.

DEIRDRE
Deirdre was a second year PSST specialising in biology and chemistry. She stated that she was unaware of alternative conceptions as an issue interfering with understanding prior to her involvement in the study. Like Patricia, Deirdre did not express a preference for either language- or pictorial-based diagnostic items feeling that some concepts were more suited to one or the other style. Deirdre did not identify any conceptual area as one in which she felt confident of her understanding and stated that she lacked confidence in all conceptual areas in chemistry. Over the course of the interview, Deirdre’s responses were categorised as being expressed with confidence and lack of confidence about equally. Deirdre’s responses to items of the diagnostic instrument were the most commonly coded as including alternative conceptions of all the PSSTs involved in the M1 Sample. She relied upon scientifically-acceptable conceptions in only a single item.

ANNE
Anne was in her third year of study and specialising in biology and chemistry. She was aware of the issue of alternative conceptions from science and chemistry pedagogical modules in her STE programme. Anne preferred the more traditional language-based diagnostic items over the pictorial-based items because the use of images to convey submicroscopic meaning was not something which she was familiar with from her previous second-level education. She identified PNM as an area in which she lacked confidence. Anne responded to items with and without confidence about equally. She was somewhat more likely to rely upon alternative conceptions than scientifically-acceptable conceptions in her responses.
8.2 THEMATIC MAP

Step 4 of the Braun and Clarke (2006) thematic analysis involved modelling the data through the creation of a thematic map. Due to the relationship between the themes, I created a thematic diagram as shown in Figure 8.1. There are five main themes included in the figure and these have been separated into Upper Themes and Lower Themes. The Upper Themes are those which directly answer Research Question M1. The Lower Themes are those which constitute the unexpected affective findings.

Upper Themes

1. **Approaches**: five main approaches to responding to alternative conceptions diagnostic items were identified\(^\text{159}\). PSSTs using any approach could rely upon conceptions that were either scientifically- or alternatively-conceived. However, some were slightly more or less associated with alternative conceptions than others.

2. **Conceptions**: this theme is depicted as a continuum with the approaches above it placed in order of how often alternative or scientific conceptions were associated with the approach. For example, the *Balancing of Factors* approach was most often associated with scientifically-acceptable conceptions while the approach *Concept Consideration and Algorithm* was most commonly associated with alternative conceptions\(^\text{160}\).

3. **Confidence in Conceptions**: this theme is also depicted as a continuum that is mapped to the Conceptions continuum. This reflects the fact that PSSTs usually expressed their conceptions with certainty when those conceptions were scientifically-conceived and usually expressed their conceptions in an uncertain manner when those conceptions were alternatively-conceived. However, there were exceptions to this.

\(^{159}\) In a number of cases, PSSTs used what could be called a non-approach (i.e. a non-rational approach) and this will be described in Section 8.3(f).

\(^{160}\) This is not to suggest that these approaches would be associated with scientific or alternative conceptions in the general population in the same manner. This structure merely models the data for this group of PSSTs answering these particular diagnostic items.
Lower Themes

1. Negative Affective Background: Throughout the interviews PSSTs made comments or engaged in mannerisms (e.g. nervous laughter) that were indicative of negative affective experiences of the interview process. Therefore, all of the discussions took place against a negative affective background. For this reason, I have designed the thematic diagram to reflect this, by depicting the Upper Themes as placed upon this Negative Affective Background.

2. Reflection on Previous Educational Experiences: PSSTs also reflected on previous educational experiences at various points during the interview. These reflections were on upper-second-level education, third-level education, or on their TP experiences. The reflections could be either negative or positive. These reflections may be the result of attempting to lay blame (and in a few cases credit) on something external to the PSST. Therefore, this theme may be related to the Negative Affective Background. I have chosen to depict this theme as a step off the Negative Affective Background in the thematic diagram; I did not think it appropriate to place this theme directly underneath the Upper Themes because these reflections were not a consistent background to the discussion, but were introduced more sporadically and largely took place at the interview closure.

A definition was developed for each theme that could describe all extracts coded to the theme. The definitions of each theme, including the five difference approaches, will be provided along with quotes from the PSSTs to illustrate the themes and allow the reader to hear from the participants of the study.
Figure 8.1 Thematic diagram of the analysis of the qualitative data in Phase 1 of the study
8.3 UPPER THEMES

The Upper Themes are those that primarily address Research Question M1. The theme of **Conceptions** identifies responses which relied upon scientifically-conceived ideas or responses which included alternatively-conceived ideas. In some cases, I could not code an excerpt as either scientifically or alternatively-conceived as the PSST did not or could not elaborate upon his/her ideas. The excerpts I coded as scientifically-conceived are those in which PSSTs relied upon scientifically-acceptable conceptions to develop their response. Those I coded as alternatively-conceived are those in which at least one alternative conception that the item could diagnose was relied upon. For example, a PSST might discuss an alternative conception in the midst of a discussion that was largely scientifically-conceived: if the alternative conception was one which the item being discussed was designed to diagnose, then I coded the excerpt as alternatively-conceived; if the alternative conception was one which the item was not designed to diagnose, then I coded the excerpt as scientifically-conceived. In these few latter cases, the alternative conception was introduced outside of the context of responding to the item and did not appear to interfere with their response selection. In other cases, a PSST introduced an alternative conception that could be diagnosed by the item but swiftly refuted this conception. Given that he/she did not rely upon this conception in selecting the response and that it was displaced with a scientifically-acceptable conception, I coded the excerpt as scientifically-conceived.

The theme **Confidence in Conceptions** refers to PSSTs’ confidence in expressing the reasons for their response. I coded the excerpts as certain or uncertain. The excerpts I coded as uncertain were those in which PSSTs presented their ideas in a doubtful manner as conveyed, not just by tone of voice, but by changing their minds about the selected response, changing their minds about the meaning of the concepts being discussed, or otherwise expressing confusion. Excerpts coded as certain were those in which PSSTs gave confident accounts of their understanding with little self-doubt apparent. Indications of the certainty with which they expressed their understanding were: a confident tone of voice, continuing to use the same rationale and concepts throughout their response, and/or continuing to use the same reasoning after I asked probing questions. In some cases, a PSST stated that he/she did not feel confident in a general way, but over the course of the discussion did not waver in his/her adherence to a particular set of ideas; in these cases, I coded the excerpt as certain given that the conceptions were expressed in a certain and confident manner.

Each of the PSSTs’ approaches to answering diagnostic items will be discussed by providing a detailed description of the theme and a number of excerpts that illustrate these approaches. The excerpts will also demonstrate the themes Conceptions, and Confidence in Conceptions.
and I will discuss how the excerpts fit into these themes. The approaches will be discussed in the order with which each was associated mostly with scientifically-conceived ideas to alternatively-conceived ideas as shown in Figure 8.1. Although some themes were associated more with one type of conception than the other, the excerpts I have selected demonstrate both scientifically-conceived and alternatively-conceived ideas rather than focusing on only the typical type of conception associated with the theme. Thus, the reader should get a sense of the range of the themes rather than the typicality of the PSSTs’ responses.

(a) Balancing of Factors
This approach involved the PSST introducing a number of concepts or factors which he/she considered relevant. He/she then balances the factors against each other to decide upon a response to the item. I identified this approach in relation to Item 2a only, where it was used by all PSSTs who were asked to respond to this item. Item 2a required PSSTs to identify the state of matter of five different particulate diagrams and was one of the easier items on the α-instrument161. This is likely the reason why this approach is associated with mostly scientifically-acceptable conceptions. In responding to Item 2a, PSSTs introduced the concepts of: regularity of particle arrangement, proximity of particles to one another, and freedom of particles to move. Figure 8.2 shows the diagrams associated with this item.

![Diagrams associated with Item 2 of the α-alternative conceptions diagnostic instrument](image)

I have provided three excerpts to illustrate this approach. I asked six PSSTs to respond to this item and Deirdre’s excerpt is very typical of the responses from two of the other PSSTs (Eileen and Brendan), in which each of the three factors were balanced with each other. I also coded Deirdre’s excerpt as scientifically-conceived under the theme of Conceptions and as certain under the theme of Confidence in Conceptions.

*I*: So why did you choose A and C as solids?

*Deirdre*: They look kind of in block format and they look, d'you know, tidy enough, packed together and... they seem kind of really rigid and stuff.

*I*: Okay.

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161 See Appendix E for the statistic P-chart for the α-instrument.
162 I have used ‘*I*’ to refer to myself as the interviewer throughout this chapter.
Deirdre: While D looks kind of flowy and they're not in straight lines and then E and... B are kind of just all over the place, like, dispersed like a gas.

Anne’s response was the only response within this approach which I categorised as uncertain under the theme Confidence in Conceptions. In the excerpt below, Anne focuses primarily on the proximity of particles in categorising her responses. However, prior to this excerpt, she also discusses the arrangement of particles by focusing on the packing of particles in diagrams. I took Anne’s wavering over her categorisation of Diagram D to be an indication that she was uncertain about her conceptions.

Anne: So I said A and C, they were solids because I said they were more tightly packed together.
I: Mmmmm.
Anne: And... E and D... well that looks like am... looks, could, could be a C-O-two [CO₂]... a gas... or it could be water as well, H-two-O [H₂O].
I: Mmmmm.
Anne: But am... oh I said it was a liquid there actually sorry. In D. Yeah I said that looked more like a liquid... ‘cause it was further apart, but then... I dunno why I guessed... D a liquid... it's tightly packed together as a solid.
I: Okay. So would you still go with D as a liquid?
Anne: Am... I dunno what I’d go with. It could... I, I don't know what D is to be honest.
[...]
I: But you're torn between liquid and solid is it... for D? You're not sure?
Anne: Yeah. But I probably would, like I would probably stick with the liquid because it's more separate than...

Nora used the same approach but appears to adhere to a conception of solids in which there is no space between particles when she states that Diagram C could be a gas based on the fact that it shows regular gaps in the particle arrangement as shown in Figure 8.2. I also coded Nora’s response as certain under the theme Confidence in Conceptions because she does not express any doubt about her response or ideas. She does use the phrase ‘I dunno’ but

163 This convention is used to indicate that a portion of the interview has not been shown. Where the excluded portion is not relevant to the discussion, I have removed it to shorten the length. In this case, Anne’s discussion of her categorisation of gases has been removed as the purpose of the excerpt is to demonstrate her uncertain categorisation of Diagram D.
164 Her response also contains the alternative conception that the space between particles is filled with air but as the item could not diagnose this conception, it isn’t the reason I coded it as alternatively-conceived.
this was a common phrase used by PSSTs and I felt it was more akin to a colloquial connecting phrase (similar to the usage of the word ‘like’) rather than an actual expression of doubt about one’s understanding.

I: And, ah, why did you just am, let’s say, C and D you chose as liquids. So could you explain what it is about those diagrams that –

Nora: Am, they're just not as, say, uniform....I guess that would be the word I'm looking for. They're kind of close together but they're not packed tight together. So that would kind of remind me of the, am, atoms in a liquid. They're still close together. They're all in the one area but it looks like they'd slide over each other.

I: Okay. So you chose A as a solid then because...

Nora: Because it, it looks to be very, am... kind of placed uniformly and it looks set and it can't move kind of.

I: Okay. And C then?

Nora: C is very like it but, I dunno, I think it's probably closer to a gas… I woulda thought that, am, it would slide over like a gas but, on the other hand, that could just be a little air pocket.

I: Okay. And, am, you chose B and E as gases then because...

Nora: Because they're so dispersed over the, the box.

(b) Pure Algorithm

I defined this approach as the application of an algorithm with either no ability to discuss or no attempt to discuss the underlying concepts. PSSTs used this approach when responding to items for which some form of calculation could be used to develop a response to the item, but PSSTs did not discuss or could not discuss the concepts related to the algorithm. This approach was used a total of six times throughout the interviews by six PSSTs. Eamon used the Pure Algorithm approach on an item requiring the use of a mole ratio (Item 10) but did not explain the concepts associated with the algorithm. I coded Eamon’s excerpt as scientifically-conceived because his algorithm was scientifically-acceptable. I also coded it as certain under the Confidence of Conceptions theme. Eamon did appear to struggle as he applied his algorithm. However, I interpreted this as having more to do with applying an algorithm without writing it down than to do with any form of doubt about the algorithm itself. Also, once a simplified mole ratio was presented to Eamon, he clearly mentally applies the same algorithm.

Eamon: What I would do is I’d… it’s a ratio kind of business so… at the moment you have, ah… you’ve two moles of B… is needed… yeah, so, yeah you need…
if you want to react three moles of A, you need two moles of B. It’s a ratio kind of business so, ah… am… so I find out what I multiply… what I need to multiply three by to give me five… and I multiply that by two… and that should give me the answer of how many moles of B I need.

I: Okay. Supposing I had instead said ‘how many moles of B would you need to react completely with six moles of A?’. Supposing I had said that it was six moles of A, what would you do?

Eamon: Okay six moles of A… how many of B, so… you would need four moles of B.

Nora used the pure algorithm approach on an item related to the equilibrium constant (Item 18). Although Eamon did not discuss the concepts associated with algorithm, Nora could not discuss this. I coded Nora’s excerpt as scientifically-conceived, because her algorithm was scientifically-acceptable, and her conceptions as uncertain. She makes many statements indicating her lack of confidence and even her application of the algorithm is uncertain as she says ‘I’m just clutching at straws here’. Nora’s tone of voice was also very uncertain.

I: So would you be able to… would you be able to pick an answer now?

Nora: Am… [reading question]… I don’t think I would now to be honest.

I: Okay. Because you’re…

Nora: Just because I’m struggling to remember equilibrium.

I: Okay. So do you remember anything about the equilibrium constant?

Nora: I remember how to get a formula for it.

I: Okay.

Nora: The concentrations of the right hand side over the left hand side. So… I’d say maybe C.

I: Okay. C [reading response] ‘less than 1’ [< 1], and why?

Nora: I’m just kind of clutching at straws here now, like, but, am, you could write down… I’m saying it’s less than one because if it’s, if it’s two molecules of A to make B…

I: Okay. You’re plugging into your formula are you?

Nora: Yeah.

An excerpt from Patricia demonstrates how the pure algorithm approach could also be associated with alternative conceptions. Patricia is discussing her response to Item 10 and her response demonstrates a confident conception that the mole ratio is applied by dividing one part of the ratio by the other. Even when I probed her pure algorithmic approach by
giving her an easier mole ratio to manipulate, Patricia uses the same approach. Therefore, her excerpt is coded as alternatively-conceived and certain. I also noted that Patricia used the phrase ‘I dunno’ in a colloquial way.

*I*: Am. Okay. So your Question 10 here. So you had your chemical reaction?

*Patricia*: Yeah.

*I*: And [reading question aloud] ‘how many moles of B would you need to react completely with five moles of A?’.

*Patricia*: Am… [reading question]… I dunno… one point five [1.5] because it’s three divided by two. Am…

*I*: So three divided by two because it’s three-A [3A] plus two-B [2B]?

*Patricia*: Yeah. Am… no… if I have…

*I*: If I change the question a little bit. If I changed it to say ‘how many moles of B would you need to react with six moles of A’?

*Patricia*:… am, how many…

*I*: How many moles of B, if you had six moles of A?

*Patricia*: Yeah. Then it’s just… three.

*I*: Okay… because it’s six divided by two?

*Patricia*: Yeah.

(c) Concept Consideration and Immediate Consistent Response
This approach involved PSSTs discussing their concepts and then almost immediately selecting a response that was consistent with these concepts. There is no use of an algorithm, any form of elimination, or the balancing of all relevant factors to develop a response. This approach was the most common approach to answering diagnostic items and was used on many occasions by all PSSTs. I have selected excerpts from Anne and Brendan that demonstrate the application of this approach with scientifically-acceptable conceptions.

Anne is responding to Item 5 of the instrument. This was a two-tier item which required the respondent to select a particulate picture that was representative of the product and reactants for a balanced chemical equation describing a hydrogen peroxide decomposition reaction. After her initial response to Tier 1 of the item, I asked a number of probing questions to gain deeper insight into her understanding and this has been included in the excerpt. Anne’s scientifically-acceptable reasoning is clear in the excerpt. Although Anne initially appeared to lose confidence when I asked her a probing question, she then continues to use the same reasoning and does not alter her response. Therefore, I coded her excerpt as being certain.
I: Question 5 there... if you want to have another look?
Anne: [reading] I probably would still go with that one [Tier 1 Response B].
I: Mmhmm
Anne: 'cause you've the two oxygen's and you've the two hydrogen's and there's...
multiply by two, d'you know, there's two of them.
I: Okay. And are there any other one's that you'd be tempted by there?
Anne: Am... maybe that one [points at Tier 1 Response D]
I: Maybe D?
Anne: Yeah... maybe.
I: And why would you choose B over D?
Anne: Am, because there's two in the front [referring to the coefficient]. If there wasn't two in the front I'd go for that one [points at Tier 1 Response D].
I: Okay. I'm just wondering about A there. That didn't...
Anne: Oh I didn't really look at that. Oh. Am... I dunno... I just imagine that there would be two separate hydrogen peroxide, rather than a whole chain.
I: Okay. If that [Tier 1 Response A] were written out how would it be written?
Anne: I'd probably say H four O four [H₄O₄]... d'you know.
I: Okay for your second one there... [pointing at Tier 2]
Anne: [reading question] okay so I'm looking for water and oxygen. I'd probably still stick with this one [Tier 2 Response A].
I: Okay.
Anne: Because you've the... two water and the oxygen.

Brendan is responding to Item 20 of the instrument which required the respondent to select the appropriate representation of hydrazine: one representation showed a triple bond between the two nitrogen atoms and a total of five bonds for each nitrogen atom (which was labelled Y), while the other showed a single bond between the nitrogen atoms and a total of three bonds for each nitrogen atom (which was labelled X). I coded Brendan’s response as scientifically-acceptable although further elaboration of the concepts would be preferable. I also interpreted his response as being expressed with a lack of confidence as evidenced by his tone of voice, repeated apologies and his nervous laughter mid-response in addition to other short phrases such as ‘I think’.

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165 Emphasis has been added using italics to demonstrate how Brendan placed emphasis on this word to convey a lack of confidence.
Brendan: X, am yeah, definitely as being, am… the correct one.
I: Yeah.
Brendan: Because… there’s… if you look at Structure Y there, there’s five bonds in each nitrogen atom and… it can’t, like, the maximum it can have is whatever… three I think.
I: Okay
Brendan: Am… well, no, sorry, four.
I: Why can you only have three or four?
Brendan: Because… I think it’s four because, am, you’ve only got… ah, you’ve only got like enough electrons in the outer shell to form four bonds.
I: Okay
Brendan: I think now. Sorry… [laughs] off the top of my head. And… yeah here like the hydrogens are fine because they’ve only got one bond which… yeah I don’t think nitrogen can take five bonds so I would have said that would be wrong.

This approach was also associated with alternative conceptions, as demonstrated by excerpts from Eileen and Deirdre. Eileen, like Brendan, is responding to Item 20 of the diagnostic instrument. Eileen introduces the alternative conception that nitrogen always forms a triple bond. In some of her statements, Eileen appears to lack confidence. However, she also uses phrases such as ‘I always just know’ and ‘I always remember’. She also does not waver from her idea that nitrogen always forms triple bonds nor does she consider any other response option as a possibility. For these reasons, I coded her except as certain under the theme of Confidence of Conceptions.

Eileen: Yeah I would’ve said Y. I’d still say Y is correct.
I: Okay… and why would Y be correct and X incorrect?
Eileen: I always just know… I always remember nitrogen forming a triple bond. I remember seeing it and there’s always, you know, N-H-three [NH₃]. There’s always three. So I would’ve just said… I don’t remember ever seeing nitrogen formed like that [pointing at nitrogen atoms with lone pairs].
I: With the two lone pairs?
Eileen: With the lone pairs and the single bond. I always… remember it, anytime I remember… seeing nitrogen it’s in a triple bond so… I just remember triple bond, nitrogen. I just associate it with that. So that’s why I picked…
I: Okay. Oh and that’s why you chose [reading Response Option B] “Nitrogen forms triple bonds if possible”?
Eileen: Yeah. Do you know when you just associate... in questionnaires like this you just, you know, I just know nitrogen, triple bonds, and then I saw a question that kind of, or an answer that... you know was similar to it...

Deirdre is responding to Item 1 of the diagnostic instrument. This item required PSSTs to select from a list of properties of a macroscopic sample of sulfur, those that are also properties of a single atom of sulfur. Deirdre selected Response Option D which stated that all properties would be the same (including physical properties such as melting point, etc.). She did not consider any other response options. Although she did not initially state her reasoning, when asked to explain the meaning of the item she provided the reasoning upon which her response was based and, therefore, I coded this excerpt as Concept Consideration and Immediate Response Selection. Deirdre’s reasoning is based on the alternative conception that a single atom of a substance has all the properties of a macroscopic sample of the substance. She may have a granular view of matter as evidenced by her statement that “one atom still has, still has everything that’s kind of... built up to a whole thing”. I, therefore, coded her excerpt as alternatively-conceived. I also coded the excerpt as certain under the Confidence of Conceptions theme; she does not communicate any doubts about her reasoning during the discussion.

Deirdre: … yeah I’d still go for this one [pointing at Response Option D]

I: Okay. You’d still go for D. So if you were just to explain what this question was asking you?

Deirdre: They’re asking you to say how the properties of sulfur... you know what’s in it, what kind of... it’s more kind of just facts about it, it’s kind of... true or false for them [the item-stem list]

I: Okay and –

Deirdre: And for this bit [the response options] it’s kind testing your understanding that, we’ll say, that one atom still has, still has everything that’s kind of... built up to a whole thing, like d’you know... the atoms still has all the, the elements of the stuff, like.

(d) Elimination

This approach involved PSSTs focusing primarily on the responses from the outset. PSSTs using this approach considered multiple response options in an attempt to discern which were false and which was true. PSSTs didn’t necessarily consider all responses but might focus on two or three. I have selected an excerpt from Eamon that demonstrates this approach combined with scientifically-acceptable conceptions. His use of elimination is a
carefully considered approach, rather than a less considered form of elimination in which the
approach is used because the respondent has poor prior knowledge. He is responding to
Item 6 of the diagnostic instrument in which respondents were asked to select a picture that
best represented the sulfur trioxide that would be created from limited amounts of sulfur
atoms and oxygen molecules in a closed system. I coded his conceptions as certain. Eamon
does not doubt the visual appearance of sulfur trioxide nor the conservation of atoms.

_Eamon:_ I would have gone to the diagram. I would have compared this diagram
[the stem diagram] to each of these [the response diagrams]. Am… and that one
[Diagram E] clearly doesn’t work. I think that [Diagram C] probably has too
many oxygens. I’m not sure but that probably wouldn’t work. That [Diagram B]
doesn’t work. It’s really between A and D.

_I:_ Why is A an option whereas it wasn’t before when you were looking at the
equation?

_Eamon:_ Oh well A is only an option now because I’m not finished looking at it.

_I:_ Okay.

_Eamon:_ Am… [counting atoms]… it’s because there’s twelve oxygens [in the stem
diagram] and there’s only nine here [Diagram A]… A doesn’t work either because
it’s got two, am, it’s got two sulfurs [in the compound depicted]. That’s why I
disregarded it. It’s possibly this one so then [Diagram D]. I was thinking about it
for a bit longer because it has S-O-three [SO₃]. I dunno, there was probably too
many oxygens in that one [Diagram C].

[…] 

_Eamon:_ For the most part it’s a diagram… it just requires to stop, think, compare
this [the response diagrams] with this [the stem diagram]. The first thing is to
compare the reaction. You’re going to get S-O-three [SO₃] and compare that with
each [response diagram] and look and how many of them have three oxygen and
sulphur bonded to it and that will eliminate three straight away. And then
compare your starting amount to your finishing amount and it’ll sort itself out.

Patricia, Eileen and Anne provide examples of an elimination approach being used with
alternative conceptions. Patricia responds to Item 16 of the instrument, in which respondents
were asked to select a response that best explained the difference in boiling points between
sodium hydroxide and water. Patricia selects either B or E as a response to Item 16 with E
representing a belief that ionic bonding is always stronger than covalent bonding. I coded
her conceptions as uncertain because of her inability to choose a final response option and
her uncertain tone of voice which was not characteristic of her speaking manner.
I: Am… Question 16 there?

Patricia: [reading question]… am… that’s not true [pointing at Response A] because that’s ionic [pointing at sodium hydroxide] and that’s [pointing at water] hydrogen bonding. Ah…

I: So that’s… A isn’t right?

Patricia: Yeah. [Reading Response Option B aloud] ‘This is due to the difference in the strengths of the bonds in sodium hydroxide and in the force of attraction between… the molecules in water’. Yeah… well… that is true I suppose. There is a difference in strength… in the bonds of sodium hydroxide and in the force of attraction between molecules of water. [Reading Response Option C aloud] ‘The boiling point in sodium hydroxide is higher because it is a solid and water is a liquid’. That shouldn’t really have anything to do with it. [Reading Response Option D aloud] ‘sodium hydroxide is made up of a metallic element and this causes an increase in the boiling point’. [Reading Response Option E aloud] ‘ionic bonding is always stronger than covalent bonding’. I dunno. B is right. I still think E is right too.

Eileen responds to the first tier of Item 5, in which an image was to be selected to represent the reactant for the decomposition reaction of hydrogen peroxide as represented by the balanced chemical equation (i.e. $2\text{H}_2\text{O}_2$). I categorised this response as elimination because Eileen focuses on each response option and eliminates based on the state of matter and the coefficient of hydrogen peroxide. I also categorised the response as alternatively-conceived because Eileen introduces the conception that $2\text{H}_2\text{O}_2$ is represented as a single molecule because she believes hydrogen peroxide to be a solid. I coded this response as expressed with certainty because she is confident in her belief that either Response Option A or D is correct and then gives a considered rationale for finally selecting Response Option A.

I: Okay. Why would you choose A?

Eileen: Because like, that’s a single one [Tier 1 Response D] and, like… I suppose it’s… I wouldn’t have picked any of them because… there’s two [Tier 1 Response B]… and there’s many of them [Tier 1 Response C], and, two, so I would take them as liquids [Tier 1 Response C, B and E] like so they’re…

I: So you’d take B, C and E as being liquids?

Eileen: Yeah. Maybe C as a gas. But I would take them [Tier 1 Response B and E] because they’re free flowing, or even gases, and… yeah they could be gases, yeah they’re free flowing yeah.

I: But hydrogen peroxide is a solid?
Eileen: Yeah, Is it?

I: Okay. And going back to this one [Tier 1 Response B]. Why does it matter that there’s two there? Is it just because it’s a solid?

Eileen: Yeah. I’d say it’s a solid so I would have picked A or D. I suppose at the time I just picked A but I… no I would have picked one of them [Tier 1 Response A or D] again.

I: And would you have looked up here at the formula for hydrogen peroxide?

Eileen: Yeah because if it’s two like… do you know I would have thought that [Tier 1 Response D] would be one and that would be two [Tier 1 Response A].

Anne responds to Item 17. This item involved selecting a graph that best represented the concentration of a reactant of an equilibrium reaction on approach to and during equilibrium from five possible options. Anne selects multiple response options and, therefore, I coded her excerpt as uncertain. I also coded her excerpt as alternatively-conceived as she expresses a belief that the concentration of a reactant undulates on approach to equilibrium.

Anne: In a way you could say… that one [Response Option A], you know, because it’s going up and down… but it’s not…

I: Okay. Maybe A?

Anne: But it hasn’t come to equilibrium there [Response Option A]

I: Okay.

Anne: That would be equilibrium there wouldn’t it [pointing at Option E]

I: So E? Okay.

Anne: Maybe it could be something like that [pointing at Response Option C] because it’s going up and then it could go down to concentration at equilibrium.

(e) Concept Consideration and Algorithm

This approach involved the consideration of relevant concepts and the application of an algorithm. The algorithm may either be developed based on the concepts, or the concepts underlying the algorithm may be discussed by PSSTs after the algorithm has been applied. This approach was used three times over the course of the interviews and by two PSSTs (Brendan and Nora). An excerpt from Nora is provided in which she responds to Item 9 of the instrument. Nora develops an algorithm based on scientifically-acceptable concepts. Her reasoning is also presented with confidence and has been coded as certain.

I: Could you explain how you went about doing Question 9 there?

Nora: [Reading question] If I was doing it again, the way I’d go… I’d, am like, one atom of carbon has six electrons so I think what I’ve done there is because
I want six-by-ten-to-the-twenty-three \[6 \times 10^{23}\] or whatever. What I did was I divided six into twelve to give me two, 'cause for every one atom of carbon there is gonna be six electrons. So that’s how I came up with two grams.

I: And how did you know that twelve… so why six into twelve? Why did you choose twelve to divide six into?

None: I probably… twelve grams or carbon… because in twelve grams of carbon you had one mole and so six grams, I mean six moles of electrons.

Brendan also used the Concept Consideration and Algorithm approach when responding to Item 11. I have provided an excerpt in which he presents his algorithm. This is followed by two brief portions of his discussion of the concepts. Brendan initially presents his algorithm with confidence. However, throughout his explanation of the concepts related to the algorithm, I took his tone of voice, nervous laughter and numerous apologies to belie a lack of confidence. He also gets confused on a number of occasions throughout his explanation. Therefore, I coded this excerpt as uncertain. As can be seen from the initial portion of Brendan’s response shown below, he also relies upon an alternatively-conceived algorithm in which he considers finding the number of molecules in one gram to be the same as finding the number of atoms in one gram. He also discusses other alternative conceptions throughout his response, such as the notion that two molecules with the same empirical formula but a different number of atoms (in this case vinegar and sugar) must have a different number of atoms in the same mass of the respective substances.

Brendan: I would’ve figured out… [reading question and laughs] I suppose I would have gotten the MR\(^{166}\) of vinegar and sugar.

I: Mmm

Brendan: Figured out how many… moles one gram of vinegar and one gram of sugar are, kind of, respectively.

I: Okay

Brendan: And then multiplied that by Avogadro’s number to work out the number of atoms. I would have had.

[…]

Brendan: Yeah. Well I… I suppose I would’ve looked at it straight away and said that… am… d’you know, you’ve got two carbon atoms here and four hydrogen atoms and two oxygen atoms for vinegar… then six, twelve and six for the

\(^{166}\) Throughout Brendan’s interview he uses the phrase ‘MR’ to refer to molecular weight.
sugar… am… and because you’ve different numbers of atoms of each element in both of the substances then they couldn’t have the same number of… am… atoms, like, per mole say… Sorry in one gram is what I mean there.

[...]

Brendan: Am… [laughs] yeah… because it’s got a bigger like… molecular weight let’s say. So if I’ve a gram of each of them then to find the number of… atoms then I’d have to find the number of moles. So because that has a bigger MR there’d be ah… less moles of that I suppose. Sorry of the sugar… and because of that then there’d have to be less atoms of sugar in the…

Brendan demonstrates the use of an algorithm and a discussion of the underlying conceptions. His algorithm appears to be a set of memorised steps. However, he connects each of the steps to his own conceptual understanding.

(f) Non-Approaches

A number of excerpts were considered to be non-approaches. The excerpts that I placed in this category were those for which the PSSTs had no rationale, save for feeling drawn to a particular response because ‘it looks right’ or ‘it sounds right’. I also categorised guesses as non-approaches and occasions when a PSST could not discuss any concepts or select any response. In a few cases, PSSTs reported their response selection but could not even attempt to discuss the response when I followed up with them, or else I failed to follow up with them167, thus not permitting any insight into the approach. There were a total of eleven responses that were considered non-approaches. I have provided a few excerpts to give a flavour of the nature of these responses. An example of an ‘it sounds right’ non-approach comes from Nora in her response to Item 11 about ionisation energy.

Nora: I’m just looking at it now and I’m going towards E or D or something.
I: Okay and why E or D now instead of A?
Nora: ‘cause… it just sounds like it could be more right.
I: Yeah.
Nora: D’y you know what I mean? Am…

167 This occurred four times over the course of all seven interviews.
Eamon’s response to Item 18 of the instrument demonstrates the non-approach of guessing.

I: Okay. Am… for your Question 18?

Eamon: [reading question]… I don’t even know what ‘K’ means.

I: Okay so if I had said which of the following must be the equilibrium constant for this? So K is the equilibrium constant. Would that have helped?

Eamon: Am no honestly. I don’t know what it means when it’s greater than one or less than one. I just guessed it.

I: Okay so… if I were to give you a reaction and ask you to find the equilibrium constant, would you remember or know…?

Eamon: No I don’t think so. Am… equilibrium constant… wait a minute… it’s to do with the logs and stuff no? I can’t remember being honest.

I: Yeah okay, so that was really just a guess?

Eamon: That was definitely a guess.

I also categorised Deirdre’s response to Item 9 as a non-approach. Her approach is not a rational approach as she selects a response based on its similarity to a piece of information in the stem.

I: I just wanted to ask you as well about Question 9 there.

Deirdre: [Reading question]… am… I’d probably say six.

I: You’d go for six now is it… instead of twelve?

Deirdre: Yeah.

I: And, ah, why would you go for six?

Deirdre: Am… just ‘cause it contains six electrons.

8.4 RELATIONSHIPS BETWEEN UPPER THEMES AND CONCEPTUAL AREAS

I utilised the matrix coding query function within the NVivo software package to determine the relationship between the Upper Themes and the conceptual areas of PNM, chemical bonding, stoichiometry and equilibrium\(^{168}\). These matrix coding queries investigating the relationships between themes informed the structure of the thematic diagram shown in Figure 8.1. In this section, I will provide further information about the findings of these queries. Although it would be possible to present numerical data, I have decided against this

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\(^{168}\) Two questions had been included in the α-instrument that did not fit into these conceptual areas. These are not included in this discussion as the decision was made to remove these items and focus solely on these four conceptual areas in the β-instrument.
as there is a temptation with numerical data to consider the findings to be generalisable. The previous section focused on the range of responses, while this section does provide a more general overview of trends within the findings; however, in keeping with the purpose of this chapter (i.e. answering the associated research question with a focus on depth and insight), I have not provided numerical data and have instead used a system of ‘X’s to depict relative frequencies. These relative frequencies were produced by the NVivo software.

The Upper Themes are Conceptions, Confidence of Conceptions, and Approaches. The relationship between the various approaches and the conceptions which PSSTs relied upon in responding to diagnostic items are shown in Table 8.1. This table provides a visualisation of how often PSSTs’ responses were coded as alternatively-conceived or scientifically-conceived within each of the approaches to answering diagnostic items. The relative numbers of ‘X’s in Table 8.1, and in all tables in this section, is based on the proportion of each column coded as either alternatively- or scientifically-conceived.

| Table 8.1 Frequency with which scientific or alternative conceptions were associated with approaches |
|--------------------------------------------------|---------------------------------|---------------------------------|-------------------------------|-----------------|-----------------|
|                                                  | Balancing of Factors           | Pure Algorithm                 | Concept Consideration & Immediate Response | Elimination | Concept Consideration & Algorithm |
| Scientifically-conceived                         | XXXX                           | XXX                            | XX                              | X              | X               |
| Alternatively-conceived                          | X                               | XX                             | XXX                             | XXXXXXX       | XXXXXXX         |

Frequency indicated by ‘X’ with ‘XXXXX’ indicating highest frequency and ‘X’ indicating the lowest.

The approaches are already presented in order, from left to right, of most associated with scientifically-conceived ideas to least associated with scientifically-conceived ideas (with the opposite being the case for alternatively-conceived ideas). The approaches Balancing of Factors and Pure Algorithm were more often associated with scientifically-conceived conceptions than alternatively-conceived ideas while the remaining approaches were more often associated with alternative conceptions than with scientifically-conceived conceptions. This relationship is the reason for the ordering of these approaches along a Conceptions continuum in Figure 8.1. However, to gain further insight into this relationship, the occasions when PSSTs used each of these approaches must be examined. Table 8.2 visualises the frequency with which each approach was used by the PSSTs in each conceptual area.
The Balancing of Factors approach was only used in the area of PNM and was applied exclusively to Item 2a of the instrument. This was one of the easier items on the α-instrument, based on the quantitative item difficulty analysis. Therefore, this is the likely reason for its comparatively higher association with scientifically-acceptable conceptions. It is also interesting, from Table 8.1, that the two algorithmic approaches are almost at opposite ends of the scale. Both of these approaches were used equally as often in the area of stoichiometry. Pure Algorithm, but not Concept Consideration and Algorithm, was used in the area of equilibrium. The difference in the association of these approaches with alternative conceptions may be because if one discusses concepts then one is more likely to introduce an alternative conception, whereas simply remembering and applying an algorithm is much more likely to result in a correct response but does not necessarily indicate any understanding. The use of Pure Algorithm in the area of equilibrium but not Concept Consideration and Algorithm may also be reflective of the fact that PSSTs were unable to discuss equilibrium concepts due to a lack of knowledge.

Elimination was used as much as Concept Consideration and Immediate Consistent Response in the area of chemical bonding. These two approaches were the only two used in this conceptual area. An algorithmic approach would have been unsuitable for PNM and chemical bonding diagnostic items. However, the greater use of elimination in chemical bonding compared with the use of this approach in PNM may be indicative of a lack of confidence in responding to chemical bonding items.

Table 8.3 visualises the frequency of alternative and scientific conceptions within each conceptual area. In the area of chemical bonding and stoichiometry, PSSTs expressed alternative conceptions much more often than scientific conceptions. In the area of PNM, PSSTs expressed alternative conceptions only slightly more often than scientific conceptions. Equilibrium is an interesting case because, although Table 8.3 shows that conceptions were
more often scientific than alternatively-conceived, a large portion of equilibrium responses could not be categorised because either they were incorrect but PSSTs could not discuss their ideas (therefore, the response could be not be categorised), or PSSTs did not respond to the item at all, stating that they would only be guessing. PSSTs were unable to discuss their ideas due to a lack of understanding. Therefore, it may be said that alternative conceptions were not the main barrier to understanding equilibrium concepts; a lack of any kind of understanding was the main barrier to understanding these concepts.

Finally, the relationship between Conceptions and Confidence of Conceptions is shown in Table 8.4. This visualisation demonstrates that, where PSSTs relied upon scientifically-conceived ideas, they usually also presented their conceptions with confidence and certainty. However, where alternatively-conceived ideas were relied upon, PSSTs expressed their conceptions with uncertainty about as often as with certainty. This suggests a possible relationship between the type of conceptions and the confidence with which the conception is expressed. PSSTs may be more inclined to be less confident of conceptions that are alternatively-conceived. Conceptions which are adhered to with less confidence may be those that are not as ‘deeply held’ and may be more effectively targeted than those that are adhered to with confidence. This relationship was the rationale behind depicting Confidence of Conceptions as a continuum mapping to the Conceptions continuum in Figure 8.1.
8.5 FRAMING OF APPROACHES WITHIN THE RESEARCH LITERATURE

The Upper Themes just discussed relate directly to Research Question M1: How do PSSTs approach conceptual questions in a quantitative alternative conceptions diagnostic instrument? I identified five rational approaches among the PSSTs that participated in the interviews: Balancing of Factors, Pure Algorithm, Concept Consideration and Immediate Consistent Response, Elimination, and Concept Consideration and Algorithm. Non-approaches were also identified which encompassed intuitive guessing (‘it sounds right’) and random guessing. In the previous section, the manner in which excerpts were coded as alternatively- or scientifically-conceived was demonstrated, as was PSSTs’ confidence in their conceptions. The various approaches and PSSTs’ confidence in their conceptions, whether scientific or alternative, will be discussed in relation to the relevant research literature. However, the specific alternative conceptions of PSSTs will not be discussed given that this does not contribute to answering the research question and a comprehensive presentation of PSSTs’ conceptions has been presented in Chapter 5.

(a) PSSTs’ Approaches to Diagnostic Items

We argue that the design of such questions [diagnostic items] shifts the nature of student responses from one of attempting to make sense of particulate ideas to picking a choice from a given list, shifting student’s frame of thinking from sense-making to choice-making.

(Nyachwaya et al. 2011)

The analysis of the qualitative data related to answering Research Question M1, demonstrates that Nyachwaya et al.’s view may be somewhat bleaker than the reality. The approach that I have labelled Elimination is certainly an approach focused on ‘choice-making’. Yet it would be incorrect to categorise all uses of this approach as lacking in sense. For example, Eamon’s use of elimination\(^\text{169}\) in which he took one piece of stem information, interpreted it with his prior knowledge, and then eliminated a number of options before repeating the process with another piece of stem information was a considered approach in which he clearly engaged in a lot of ‘sense-making’ in addition to ‘choice-making’. However, other applications of Elimination were less considered and could be thought of as ‘choice-making’. The Pure Algorithm approach could also be said to be an approach devoid of sense-making as PSSTs only applied an algorithm and did not, or could not, consider any relevant concepts: the algorithm was sufficient for them to make a choice. However, the rest of the approaches could not be said to be lacking in sense. Concept Consideration and Immediate Consistent

\(^{169}\) Eamon’s excerpt was provided in Section 8.3(d).
Response was by far the most common approach used by these PSSTs and it involved drawing a conclusion based on their own ideas and then selecting a response that was consistent with that conclusion. Therefore, Nyachwaya et al.’s (2011) assertion is too narrow and pessimistic to encompass the full range of PSSTs’ approaches.

Many studies within the alternative conceptions literature have carried out interviews with learners using a multiple-choice diagnostic instrument as the protocol for the interview. The purpose of these interviews is to validate an instrument that was developed as part of these studies. However, previous studies have not used such interviews for the dual purpose of validation of the instrument and investigation of learners’ approaches to diagnostic multiple-choice items. Therefore, studies typically do not provide sufficient interview details with which to compare the current findings. However, a few studies have provided detail about these interviews. Tan et al. (2005) focused on upper-second-level students’ understanding of ionisation energy. Tan et al. carried out interviews with students using the Ionisation Energy Diagnostic Instrument\textsuperscript{170} as the interview protocol. The authors note that students answering satisfactorily used an approach that I have labelled within the current study as ‘Balancing of Factors’. Sanger (2000) also carried out interviews focusing on third-level chemistry students’ rationale for responding to a diagnostic item\textsuperscript{171}. Sanger categorised the approaches by focusing specifically on the item, rather than a general focus on approaches used over a number of items. However, the author includes excerpts from interviews which I categorise as ‘Concept Consideration and Immediate Consistent Response’. One of the student excerpts provided by Sanger is provided below; the student considers his/her own conceptions in order to select a response that is consistent with this conception.

If a mixture is not homogeneous, then you can take one sample from one area and it wouldn’t be the same as a sample from another, different area. [For a homogeneous mixture], if you take a sample in one area, it would be the same as a sample in another area.

(Sanger 2000)

A number of studies have shown that learners’ often use a process of elimination when responding to multiple-choice items in science or other subjects (Hamilton et al. 1997; Kitsantas 2002; Harlow and Jones 2004). Learners’ use of a process of elimination as an approach to responding to multiple-choice questions is usually seen in a negative light. Kitsantas (2002) and Harlow and Jones (2004) found that such an approach could lead to a
correct response without any understanding of the concepts which the multiple-choice item addresses. Harlow and Jones (2004), who investigated learners’ approaches to answer TIMSS items, described this approach as follows:

The process of elimination can occur when the student recognises the meanings of three of the four choices available as answers to an item. None of these fits what the student perceives to be a possible choice for the item; so the fourth option, which may be unfamiliar or misunderstood but happens to be the correct answer, is chosen. (Harlow and Jones 2004)

Nakhleh and Mitchell (1993) also report on the use of a process of elimination, referring to it as a test-taking strategy associated with a lack of understanding of the concepts. However, Hamilton et al. (1997) found that an elimination approach could involve a reasoned and careful evaluation of all response options. Therefore, it may take the form of an in-depth and considered approach to responding to multiple-choice items. They describe this approach as follows: “many students used a strategy of reading each option and seeking logical flaws in it until they had eliminated all but one”. The process of elimination used by Eamon was closer to that found in Hamilton et al.’s study than that described by Nakhleh and Mitchell (1993) or Harlow and Jones (2004). Eamon’s use of this approach was certainly careful and considered and he demonstrated sound understanding of the concepts which the item was designed to assess. Eileen, although answering incorrectly, also demonstrated consideration of the concepts which the item was assessing. Her incorrect response was the result of her alternative conceptions rather than being the result of a lack of knowledge. On the other hand, Anne and Patricia’s application of an elimination approach is closer to that described by Harlow and Jones (2004) above. Therefore, the analysis I undertook in this study, agrees with Hamilton et al. (1997): an elimination approach can be either carefully considered, or it can be an approach based on educated guessing.

Algorithmic approaches are typically viewed negatively in the research literature and are associated with a lack of understanding of the relevant concepts (Nurrenbern and Pickering 1987; Nakhleh and Mitchell 1993). I have used the term algorithm in this study to mean a step-by-step procedure for solving a mathematical problem. Within the research literature, an algorithmic approach is usually defined as the use of a memorised set of procedures to solve a problem (Zoller et al. 1995; Huddle and Pillay 1996). This latter definition applies to the Pure Algorithm approach in this study and, by definition, this approach is not associated with an ability to discuss associated concepts. Previous studies have noted that the use of

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172 Both Eamon and Eileen’s excerpts may be found in Section 8.3(d).
rote-learned algorithms is not typically associated with conceptual understanding (Huddle and Pillay 1996; Tyson et al. 1999; Quílez 2004). The approach Concept Consideration and Algorithm goes beyond this rote-learned view. In Section 8.3(e), Nora’s excerpt demonstrates a very clear and logical thinking pattern in which the algorithm and conceptual understanding went hand-in-hand. In the same section, an excerpt from Brendan shows the use of an algorithm and a discussion of the underlying conceptions. Although both the understanding and the algorithm were not scientifically-acceptable, this is not a blind application with no consideration of the underlying concepts. Previous studies have noted an algorithmic approach in the conceptual areas of stoichiometry and equilibrium (Huddle and Pillay 1996; Tyson et al. 1999). The PSSTs involved in the interviews in this study used only the Pure Algorithm approach in the area of equilibrium and both Pure Algorithm and Concept Consideration and Algorithm in the area of stoichiometry.

Non-approaches were rarely used and encompassed intuitive guessing and random guessing. Learners’ selection of responses based on intuitive guessing (e.g. ‘it looks right’) has been previously demonstrated in the research literature (Hamilton et al. 1997; Wiediger and Hutchinson 2002). It has been suggested that this may be due to a learner recognising a response that is similar to an answer he/she has seen before (Wiediger and Hutchinson 2002). Many studies have pointed out the potential for random guessing in multiple-choice items and take this into account in their analysis (Peterson et al. 1989; Tamir 1991; Tan et al. 2002). The non-approaches were not often used by the PSSTs interviewed. However, that doesn’t necessarily translate to an instrument administration context. An interview is personal and I sensed that the PSSTs wanted to be able to answer my questions and were ashamed when they could not. If they were responding to the instrument in isolation, then these non-approaches may have been more commonly utilised.

(b) PSSTs’ Confidence in their Conceptions

PSSTs’ confidence in their conceptions is an interesting theme in this study. A few previous studies have utilised confidence ratings to determine whether an alternative conception is genuine or spurious (Hasan et al. 1999; Caleon and Subramanium 2010; McClary and Bretz 2012). Diagnostic instruments have been administered that include a confidence rating scale, often from 0 to 5, with 0 indicating no knowledge and a total guess, and 5 indicating complete confidence in the conceptions used to respond (Hasan et al. 1999). Alternative conceptions with low confidence ratings are spurious and those with high confidence ratings are genuine because it is taken as indication of the extent to which the alternative conception is deeply held (Caleon and Subramanium 2010). From the point of view of this previous research, the
majority of alternative conceptions discussed by these PSSTs are spurious because many conceptions were coded as being expressed with uncertainty.

Would a rating scale present an accurate reflection of our PSSTs’ ideas? I determined PSSTs’ level of confidence, not based on their self-report, but based on whether they had solid reasoning for their ideas and whether they continued to adhere to the conception throughout the discussion. In some cases, PSSTs self-reported a lack of confidence or conveyed lack of confidence in their tone of voice and mannerisms, but were coded as expressing their conceptions with certainty because they did not waver from their reasoning. It is difficult to convey the lack of confidence that PSSTs expressed during interviews through their demeanour and tone in a textual format. I provide an example from Patricia that might demonstrate something of this demeanour based on a brief interaction I had with her in which I openly address the stress I sense from her. I have included part of our discussion of the item (Item 11) to demonstrate that, despite this, she does not doubt her conception by considering any alternative. The final sentence of the excerpt was also expressed without doubt and as though it should be obvious that this is the case. In the extended exchange, I continued to ask probing questions and yet she never considered any alternative response.

_I_: Okay so Question 11. Have a quick read.

_Patricia_: Am… [reading question]… Am… one gram. I think I’ll stick with my same answer there. Because [reading her response on the instrument aloud] ‘it was a gram. If you had one mole, you’d just have the same number of atoms but because it’s a gram you’d have a different number of atoms.’

_I_: Okay. So if I had said that you have one mole of vinegar and one of sugar, would you have the same number of atoms in each?

_Patricia_: Atoms… no I’d still have a different number, because these are compounds.

_I_: Okay. [laughs] I’m starting to feel like giving you a hug. Stop stressing out so much! [laughs]

_Patricia_: [laughs] oh God!

_I_: Okay. So for our one gram of vinegar and one gram of sugar.

_Patricia_: Yeah.

_I_: Can you explain to me why you say ‘no they don’t have the same number of atoms’?

_Patricia_: ‘cause they’re… they’ve different… ah… They’re different so they’re going to have a different number of atoms!
If Patricia had a confidence rating scale, she might not have rated her confidence in a way that was consistent with her adherence to her conception. Her attitude certainly conveyed stress, panic and lack of confidence. Yet in the excerpt and extended exchange she did not waver from her conception. This underlying attitude was present throughout much of the interviews with the PSSTs. Eamon was an exception as his attitude was generally quite self-assured. However, I coded the conceptions as being expressed with certainty at least half the time for each PSST because they did not give serious consideration to alternatives when I questioned them, even when that questioning led them to a cognitive conflict. Take another example from Brendan below. I asked Brendan about Item 2 which was a three part item consisting of Items 2a, 2b and 2c. Brendan initially states that he lacked confidence about Items 2b and 2c but not 2a.

Brendan: Am… then again I remember actually answering this question when you gave it to me. And… I really kind of tried to do the first one [Item 2a]. Then I kind of realised that I wasn’t sure… for the other two [Items 2b and 2c] I was just kind of like ‘ugh’.

I: You mean you weren’t sure which diagram was…

Brendan: Which diagram was… well the first one [Item 2a] was grand because I kind of got that straight off.

I then questioned him about Item 2b. Brendan identified pure elements [Diagram C] as pure substances, pure molecules [Diagram E] as homogeneous mixtures, and all mixtures [Diagrams A, B and D] as heterogeneous mixtures. In the excerpt below, I ask a number of probing questions with the ultimate goal of bringing Brendan to a cognitive conflict about his definitions. Brendan does appear to engage in two conflicts. In the first conflict, he considers whether pure substances could also be molecules, but it is unclear whether he is referring to elemental or compound molecules. In the second conflict, he questions whether his definition of homogeneous mixtures is actually a mixture at all. However, he almost immediately dismisses these ideas and maintains his original conceptions. He never considers altering his choices and does not give mental space to the conflict. Therefore, his conceptions are expressed with certainty, despite the fact that he said in the excerpt above that he wasn’t sure. He was even more certain of his conceptions in Item 2c but I have chosen to include this excerpt because it demonstrates that even upon probing his conceptions and a conflict arising, he continues to maintain to the same conceptions.
I: So if you were to define a heterogeneous mixture –

Brendan: Yeah.

I: How would you define it?

Brendan: It would be… a mixture containing… two or more things that are different.

I: Okay. And if you were to define… a pure substance how would you define that?

Brendan: Am… something that contains all of the same atoms… [mutters] or is it molecules maybe?

I: [pause] Yeah. And… your homogeneous mixture?

Brendan: Homogeneous mixture then I would have said… ah… containing the same types of molecules? Mixture? Well I suppose then it’s not really a mixture then is it? Am…

I: [pause] So if you go back to your pure substance there. You’re saying that it’s the same type of atom… or the same type of molecules?

Brendan: Oh okay.

I: Is that what you’re saying?

Brendan: No. I would have said that a pure substance is just type, same type of atom… so it’s… a block of gold of something like that. Whereas a homogeneous mixture then would be like… say, water. D’you know where two atoms of oxygen combine to a hydrogen. Sorry, I mean two hydrogen’s and an oxygen… and then… you’d have two types of atoms but they’d be the same type of molecules.

We can see that the self-reported confidence is lower than the confidence suggested by his adherence to the same conceptions. An interview is, of course, different from administering a diagnostic instrument. Perhaps the self-reported confidence, the sense of confidence, matches better when a person responds in isolation from others. However, these PSSTs in the interview situation can be said to demonstrate a difference between self-reported confidence and the deeply-held nature of their alternative conceptions. This suggests that self-reported confidence might not be the best measure of whether or not an alternative conception is genuine.

**SUMMARY OF MAIN FINDINGS**

I observed five approaches to responding to diagnostic items among PSSTs. Some of these approaches involve little evaluation of conceptual understanding of any kind; for example, Pure Algorithm and some of the applications of Elimination. I identified a few occasions in which PSSTs engaged in guessing. However, other approaches can be categorised as careful
and considered approaches. Although, some of the previous research literature has painted a bleak view of the manner in which learners approach diagnostic items, the analysis I carried out in this study demonstrates that there is more nuance to PSSTs’ approaches than a dichotomy between ‘choice-making’ and ‘sense-making’. Whether PSSTs would apply the same approaches in the same manner outside of an interview is not a question that can be answered by an interview method. I undoubtedly impacted upon the degree of consideration in which PSSTs engaged. However, we can say that PSSTs can approach diagnostic items in a manner that is a careful evaluation and that they can (and in this study they usually did) select responses based on their own conceptions, on their own sense, rather than selecting a response largely based upon the available responses. However, the latter does occur also.

Although some of the approaches I identified were more associated with alternative conceptions or scientifically-acceptable conceptions, that is not to suggest that this would be typical of the use of the approaches by the general PSST population. This is simply the trend among this group of PSSTs and is influenced by the items, to which PSSTs tended to apply different approaches. Another interesting finding is the link between PSSTs’ conceptions and the confidence associated with the manner in which they express these conceptions. There is a trend among these PSSTs in which alternative conceptions are less likely to be expressed with certainty than scientifically-acceptable conceptions. According to previous research using confidence rating scales, this indicates that most of the alternative conceptions discussed are spurious. Perhaps this is the case and, if so, there is much hope for these PSSTs improving their understanding in the right learning environment. However, the interview findings also raise some questions about the validity of confidence rating scales in categorising alternative conceptions as genuine and spurious. As was shown in the previous section, PSSTs’ personal confidence can be at odds with the extent to which they maintain their alternative conceptions, even in the face of cognitive conflicts. As such, the use of confidence rating scales may place genuine alternative conceptions in the spurious category.

8.6 **LOWER THEMES**
The two themes, Negative Affective Background and Reflection on Previous Educational Experiences, represent unexpected findings associated with investigating Research Question M1. These themes impacted greatly upon the direction of the research carried out in Phase 2. Based on the interviews, the importance of PSSTs’ lived experiences became something of central importance. I will first outline the themes of Negative Affective Background and Reflection on Previous Educational Experience and then discuss how these findings came to inform Phase 2 of the research study.
(a) Negative Affective Background

Throughout the interviews, PSSTs engaged in mannerisms and statements that were indicative of a negative experience such as nervous laughter, repeatedly apologising\textsuperscript{173}, admitting that they lacked understanding, and making other negative statements about their attitudes or emotional states. At all times, I tried to make the interviewee feel more at ease and shared with them my own lack of knowledge and difficulties in understanding, but this did not stem the flow of negative statements and/or mannerisms. There are numerous examples of negative statements throughout all of the interviews carried out. A selection is provided to give a sense of the range of statements that have been coded in this way.

\textit{Brendan}: And… I really kind of tried to do the first one. Then I kind of realised that I wasn’t sure… so for the other two I was just kind of like ‘ugh’.

\textit{Eileen}: Like if I was given a, like, we were even saying this not so long ago – me and my friends. Like, if we were given a, a basic reaction to balance… we would still struggle at it and probably wouldn’t get it right. Like, we’re going to be qualified in a few months like.

\textit{Patricia}: I know myself that my, am, basic chemistry is diabolical and … like, I usually get ‘A’s in college chemistry and stuff, but it's just that it's not...

\textit{I}: Are there any general comments you want to make about the test or the topic?
\textit{Nora}: I think I just want to go to bed! [laughs]

\textit{Anne}: I was mortified after I handed it up.
\textit{I}: [laughs]

\textit{Anne}: I didn’t even want to see the results.
\textit{I}: Yeah?

\textit{Anne}: Except, d’you know, to get feedback on it. D’you know, I was saying after, ‘I shouldn’t even be teaching,’ like, d’you know. It was just so many small things.

There were also numerous examples of PSSTs admitting they lacked knowledge or understanding when discussing the items. Again I have provided a selection from a number of PSSTs. These excerpts are also very typical of the rest of the interviews. Within some of

\textsuperscript{173} Note that in some cases PSSTs used the word ‘sorry’ as a connecting word that is not necessarily indicative of a sincere apology. However, I felt that too much interpretation would be required on my part to differentiate between the two and so I coded all instances of the word ‘sorry’ as apology. Therefore, this particular code is a mixture of both types of usage of this term.
these, and the previous, excerpts there are also examples of mannerisms such as apologising and engaging in nervous laughter.

_Brendan_: Then… you have a half-filled subshell that’s less stable…
_I_: Yeah
_Brendan_: So… yeah if I’d read it properly, I would’ve…
_I_: Is it compared to aluminium there that you would have done… is it?
_Brendan_: Oh wait I’m wrong. Sorry, sorry.

_Anne_: Am… I dunno what I'd go with. It could... I, I don't know what D is to be honest.

_I_: If I brought your attention here to this phrase 'in a closed container', what would that mean to you?
_Deirdre_: Not much.
_I_: Okay. So that wouldn't really make any difference would it?
_Deirdre_: It probably should but... my chemistry is very bad like.

_Nora_: Am… there is. It’s, like, am… it’s, like, whatever, a mole… sorry now.
_I_: What are you trying to think of?
_Nora_: D’you know, like a table, the Periodic Table, like am… one mole of, am… is… chlorine is 35 grams and it’s the same number… I’m trying to think now, is it the number of protons or something like that, like, am… I don't know. Sorry.

_Patricia_: Am… [reading question aloud] ‘what mass of carbon contains a mole of electrons’… a mole of electrons. Am… twelve is the molecular weight of carbon… twelve grams is the molecular weight of carbon and… ah… [laughs] I did say this was my weak spot didn't I? Am… oh God! I don't know. I just think it is.

There were no instances that could be coded as positive affective and clearly the interview and diagnostic instrument experience was a trying one for the PSSTs. Although these negative incidences were more common where alternative conceptions were discussed (as visualised in Table 8.5), they were also present in some cases where scientifically-acceptable conceptions were expressed.
Table 8.5 Frequency of with negative affective mannerisms/statements with conceptions

<table>
<thead>
<tr>
<th>Scientifically-conceived</th>
<th>Negative Affective</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XX</td>
</tr>
<tr>
<td>Alternative Conceptions</td>
<td>XXX</td>
</tr>
</tbody>
</table>

Frequency indicated by ‘X’ with ‘XXXXX’ indicating highest frequency and ‘X’ indicating the lowest.

The constancy of negative mannerisms and statements throughout all interviews and from the opening development to the closure of interviews, was my rationale for depicting these as a Negative Affective Background in Figure 8.1, upon which the Upper Themes rest. The final theme shown in Figure 8.1 is Reflection on Previous Educational Experiences.

(b) Reflection on Previous Educational Experiences

During the interviews, PSSTs spontaneously introduced reflections upon previous educational experiences. These reflections usually had a negative connotation in which the previous experience was being suggested as, or implied to be, the cause of the PSST’s poor understanding. However, in a few cases the reflection was a positive one. Only Brendan, Eamon and Anne engaged in positive reflections on previous educational experiences. All three engaged in a positive reflection on the experience of TP (Brendan engaged in two such reflections) and its impact on their understanding.

_Eamon:_ I’d say I probably taught that in Teaching Practice and that does enormous things for, for ah… not only learning, reminding me of how all the simple things work but am… also really it makes, I remember it an awful lot better then, like. So there’s… I think there might be a correlation there between something I might have taught on Teaching Practice and the stuff that I didn’t teach on Teaching Practice and what, how I’d do on the test.

_Brendan:_ I was grand with that yeah… ‘cause I would have… even on second year TP I would have taught that. So I would have used diagrams like that.

_Anne:_ Yeah I would. I’ve taught matter and all this kind of thing here [pointing at questions on the instrument].

_I:_ Meaning of chemical formulae?

_Anne:_ Yeah. Am… well… yeah some of those diagrams and here as well. You know the… solid, liquid gases for Junior Cert.

_I:_ Yeah.

_Anne:_ I did that last semester when I was on Teaching Practice. And, am… the more I taught it, the more I understood it myself.
Anne and Eamon also engaged in one positive reflection each on their upper-second-level experience of chemistry.

*Anne:* I did chemistry as well yeah, yeah. But I got on better in biology. That’s probably because I liked it more. I had two very good teachers though for each subject.

*Eamon:* We had a very good teacher for Leaving Cert. and a lot of the concepts, I understand them quite well. Am… it only takes a certain amount of am… it only takes a certain amount of revision just to get a hold of them again like.

Negative reflections were far more common with a total of nineteen negative reflections from six PSSTs. Brendan was the only PSST who did not engage in any negative reflections. These reflections were about second-level education and third-level lectures. Deirdre was the only PSST to engage in a negative critique of TP experience, described in the excerpt below. The comment is not directly negative about the impact of TP but it is implied that TP does nothing to improve understanding of chemistry but only of educational practices.

*I:* About none of them or are there some concepts that you would maybe be confident about and others definitely not?

*Deirdre:* Am… well… some of them are a lot easier than others but, like, you’d need to be doing it constantly to, ah, work up any bit of confidence. Sure we’ve no, even, chemistry module this semester… we’ve got Teaching Practice so it’s more education.

There were about twice as many negative reflections on upper-second-level education as there were on third-level education. The tenor of these reflections was deemed to be negative because the comments introduced an educational experience as having had a negative impact on their ability to answer diagnostic items. I have included a few excerpts from Anne, Eileen and Deirdre to demonstrate the type of comments made about third-level education. Anne’s comment mentions the tendency to learn for the exam. A very similar comment was made by Eileen and Patricia.

*Anne:* But you know when you’re kind of… I don’t know, when you’re in college and you only kind of study for the exam and then you just… you know it’s really hard to go beyond and do the reading and all that.

*Eileen:* If I was being honest it would be my own, my own ability at it. Like I don’t, I don’t know would I be… even though we’ve done so many chemistry modules in college, there’s still a lot of basics that I am still struggling with so…
Deirdre: I’m not sure if that was the lecturer or just the module itself but that was hard.

PSSTs’ third-level reflections included comments about PSSTs’ own tendency to study for the exam, identified certain chemistry modules as difficult, or simply comprised a confession that PSSTs still did not fully understand certain concepts after having studied third-level chemistry modules. However, many of the second-level education reflections had a higher degree of blame attached to them. Nora, Patricia and Eileen reflected on the idea that their alternative conceptions began in upper-second-level education and went unaddressed there. Excerpts from Nora and Patricia demonstrate this.

Nora: I just remember doing the test [the diagnostic instrument] and the lot of us were, like, putting down different answers. So, like, even at our level you’d see some or a lot of misconceptions which I’d say, kind of, began in Leaving Cert.

I: Do you feel confident to find out what students actually think… what their conceptions are? And then trying to address them?

Patricia: After that [pointing at instrument] I don’t know [laughs]. I don’t know what my misconceptions are so, yeah, you definitely should try and address them. Am… clearly something that was never done for me [laughs].

Other reflections were negative about educational methods and/or failure to focus on basic concepts within upper-second-level education. Several of Eileen’s comments focused on this and I have included two excerpts from her interview and an excerpt from Eamon’s interview.

Eileen: D’you know if I was given that, like, in school, like, our teacher could’ve gone back over the basic things with us like d’you know. I just like, because there’s a lot of the basics, that’s what it is [the basics], like.

Eileen: In school we were never… you know they said that… they suggest for us to teach, you know, using … you know, like, if you were doing the atoms using the building blocks or whatever… but we, in school… we never, you know they didn’t even draw it on the board, like, so you could kind of visualise it. It was just all written in the book and you kind of have to figure it out yourself.

Eamon: You’re looking for more detail than I was used to doing when I last covered this in detail for Leaving Cert.

The majority of all reflections on previous educational experiences occurred during the opening development and closure. Only in a few cases, did PSSTs spontaneously introduce
a previous educational experience into the discussion while responding to a diagnostic item. Therefore, this theme could not be considered to underlie all of the discussion (as was the case with the Negative Affective Background) and, yet, the theme also could not be considered to be one of direct relevance to their approach to diagnostic items. This theme appears to have some connection with the Negative Affective Background, given the, generally, negative connotations and the fact that PSSTs appeared to be apportioning an element of blame to factors external to themselves; this could be because of feelings of guilt and/or embarrassment. For these reasons, I interpreted this theme as having a connection to the Negative Affective Background theme and that it also belonged in the Lower Themes of the Thematic Diagram in Figure 8.1. Therefore, this theme is depicted as step off of the Negative Affective Background.

These reflections also appear to lend more weight to the interpretations of the quantitative results in relation to the upper-second-level experiences of chemistry and third-level educational experiences in Chapter 7 of this thesis. Although many of the reflections painted upper-second-level chemistry experiences in a negative light, it is nonetheless quite telling that the PSSTs reflected on these experiences more than any other experiences, including those within their concurrent STE programme. This reinforces the findings of the regression analysis presented in Chapter 5: that upper-second-level experiences of chemistry continue to have a more powerful impact on PSSTs’ understanding of fundamental concepts than their third-level educational experiences. The results of the quantitative strand of Phase 1 in relation to concurrent PSSTs’ year of study were interpreted as PSSTs experiencing memory-loss as the time increased since they last explicitly studied fundamental chemistry concepts. A review of the excerpts in this chapter also lends some weight to this interpretation. Eamon mentions needing to revise concepts, and identifies TP as having helped him to remember what he had previously learned at upper-second-level education. Eileen refers to memory throughout her interview (e.g. “I remember learning that in school,” “I kind of forget it [third-level chemistry]… because that’s the whole thing, that you just forget it, like.”). Nora also refers to memory-loss about equilibrium, “I’m struggling to remember equilibrium.” Anne also refers to her memory in terms of aiding her as she remembers second-level education experiences, or memory-loss of introductory chemistry as hindering her, “I kind of forget a lot it.”
Etherington (2004, pp. 31-32) describes reflexivity in research as “the capacity of the researcher to acknowledge how their own experiences and contexts inform the process and outcomes of inquiry.” It was at this stage in the research study, that I seriously began to reflect on PSSTs’ experiences, and on my own experiences engaging with them. I was also forced to acknowledge that much of my understanding of PSSTs' experience of answering the diagnostic instrument and taking part in the interview were based on my interaction with them; I was empathising with them and so much of my understanding of their experience was based on these acts of empathy. How could I, within a largely postpositivist paradigm, quantify this knowledge? How could I, within a constructivist paradigm, avoid the pitfalls of solipsism and relativism? I needed a new paradigm within which to work and to critically reflect on my beliefs about the world and the nature of knowledge, rather than simply accept the typical constructs used within the research area I had chosen. In this section, I will discuss the impact of the interviews (particularly the Lower Themes) on the direction of the research.

Prior to these interviews, the design of the research study had a focus that was weighted on quantitative research strands. In developing and administering the diagnostic instrument, I treated the problem of alternative conceptions as a purely cognitive one. At the point at which the interviews were analysed for Research Question M1, I had not made a final decision about an instructional method that could be used with PSSTs to improve their understanding. I had difficulty in committing to an instructional method and I recognise, on reflection, that this was primarily because I was not entirely comfortable in the research space I had created. I was not comfortable with treating human beings like they were brains in a body and little more. My experience of the interview process was one of empathy with PSSTs. I felt their angst and shame upon attempting to answer my questions and finding themselves coming up short. They made comments that reflected negatively upon themselves, which possibly led to the tendency to apportion blame upon previous educational experiences, and all of this impacted upon the openness of the conversation.

At this point I began to ask myself several questions such as:

- How can one improve understanding, in the absence of openness about misunderstandings?
- If one cannot improve understanding without openness, then how can openness be created?
- What is it about PSSTs’ experience of alternative conceptions that creates a barrier to openness?
These questions shifted the focus away from ‘what are their problems and how can they be fixed?’ and towards ‘how do they experience this issue and how does this experience impact on their freedom and ability to learn?’ These questions became of central importance in my decisions about Phase 2 of the research. I began to question whether postpositivism and constructivism were the appropriate philosophical tools to address these issues and began to investigate alternatives. This ultimately led me to phenomenology and the works of Edith Stein which I discussed in Chapter 3. Her focus on the role of empathy and community in human experience could allow for a deeper investigation of the issues that had been raised. I was also drawn to her work because of my reflections on how my empathy with PSSTs had such a major impact on my perception of the issues surrounding alternative conceptions. My investigations into Edith Stein’s philosophy also influenced my final choice of an instructional method. I desired an instructional method that placed empathy and community at its core, and in which I would be a facilitator of learning. This led me towards a community-oriented, blended learning approach and a focus that was less about improving understanding (although this was, of course, still a goal) and more about investigating PSSTs’ experience of uncovering and discussing their alternative conceptions. The question of whether openness, i.e. empathy, was necessary to address alternative conceptions among learners also impacted on my decisions. Originally, I had intended this research to be a dispassionate investigation of PSSTs’ alternative conceptions and the development and evaluation of an instructional programme to address these conceptions. Indeed, this original intention can still be seen in places within this thesis. Now, I saw the direction of the research as treating alternative conceptions as a phenomenon to be investigated with regard to PSSTs’ lived experiences of this phenomenon. Blended learning was a vehicle to allow this goal to be achieved rather than the end goal in itself. This led to the development of Research Question C2: How do PSSTs experience the issue of alternative conceptions in chemistry in a community-oriented, blended learning environment?
Chapter 9  Findings of Phase 2

This chapter is a report on the qualitative findings associated with data collected during the SuBATOMIC learning programme. Similar to Chapter 8, this chapter comprises the methods, findings and the discussion of those findings. The techniques and strategies used to analyse the qualitative data developed over time with increasing exposure to the data and literature. The analysis was carried out with the aim of addressing Research Question C1:

How do PSSTs experience the issue of alternative conceptions in chemistry in a community-oriented, blended learning environment?

Audio-visual data, reflective journal data, and social media data were the forms of data collected to provide insight into this research question. However, the PSSTs participating in the SuBATOMIC programme rarely discussed their conceptual understanding when writing in their reflective journals or engaging with one another on social media. As a result, these data sources are less helpful in addressing the research question. Audio-visual data, therefore, constitutes the primary data source, with the reflective journal and social media data lending additional insight to observations drawn from the audio-visual data, where relevant. The data has been divided into four case studies. Each case study comprises audio-visual data of three-four PSSTs participating in a SuBATOMIC face-to-face session and any secondary data arising from these PSSTs which relates to that particular face-to-face session.

The audio-visual data was analysed according to two perspectives:

1) I analysed the data in order to obtain a general overview of PSSTs in each case study working together as a community-oriented group. This comprised a thematic analysis in which the data was examined according to the Level of Community present at any one time, and the Community Goal or focus at any one time. This categorisation of experience at each point in time allowed me to observe patterns in the manner in which each group of PSSTs worked with one another. In order to maintain a connection with the PSSTs’ lived experiences, I created narrative stories depicting their experience of discussing chemistry concepts throughout the SuBATOMIC session and connected these to the general overview.

2) The previous step of the analysis suggested the presence of dialectical tensions and, therefore, the next step in the analysis was to apply Relational Dialectics Theory (RDT) to the narratives, to ascertain the dialectical tensions experienced by the group as they discussed these chemistry concepts. Furthermore, RDT was applied to the micro-talk surrounding conceptual discussion. That is, the discourses surrounding a concept, and the interplay between these discourses were identified.
This chapter presents the findings and discussion for two of the case studies according to these two stages of analysis. I will present the experience of each community-oriented group in terms of the patterns within the flow of experience (i.e. the first step of the analysis). I am using the term flow of experience as a way to describe the tendency of one experience to flow into the next, and the next, and so on. I will then present the findings in relation to the dialectical tensions experienced by each case study group. Excerpts will be provided from the narratives and the full set of narratives for each case study has been made available in the Appendices. In each case, I will examine how the flow of experience and the dialectical tensions may have influenced the interplay between the conceptual discourses in the group.

The findings suggest that the interplay between dialectical tensions was central to how groups engaged with conceptual discourses. A number of supra-dialectics were observed in the experience of the groups. Not all case study groups experienced all of these tensions, but where a supra-dialectic was observed in multiple case studies, it presented in an idiosyncratic way in each group. The supra-dialectics were as follows:

Denial – Acceptance; this was a tension surrounding PSSTs’ awareness of barriers to conceptual discussions. There was a tension between the acceptance of these barriers and the denial of these barriers.

Expression – Non-Expression; this was a tension with regard to the extent to which PSSTs desire to share their personal thoughts, understanding, etc. and their desire to withhold this kind of information.

Learner – Teacher; this tension related to the differing perspectives adopting by groups: they sometimes saw themselves as learners of chemistry, and at other times saw themselves as teachers of chemistry.

Integration – Separation; this was a tension surrounding the extent to which PSSTs were integrated into the group or separated from the group. However, this tension was not overtly observed in the two selected case studies and will, therefore, not be discussed further.

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174 This decision has been made as it simply isn’t possible, within the confines of a single chapter and also within the confines of this thesis which already contains three chapters of results/findings, to include all four case studies. The analysis produced a large volume of written reports and even a summary of these reports is too large to include all four case studies.

175 This includes the two case studies not included in this chapter. These can be found in Appendix J.
The interplay in which tensions were constituted appeared to play a significant role in the experience of conceptual discussions. An interplay may be described as the manner in which tensions are constituted in the group, e.g. marginalising or delegitimising one aspect of a tension, while allowing another aspect to dominate, is an interplay of disqualification (Baxter 2011, p.134). The interplay between the tensions noted above influenced the group behaviours and the interplay between conceptual discourses. The analysis lends insight into experiences which may impact upon the anatomy of conceptual discussions in group settings, such as those experienced in the SuBATOMIC learning programme.

The problem of alternative conceptions is being reframed in this chapter as a problem of persons relating to one another, rather than a problem in the realm of cognition.

9.1 **METHOD OF ANALYSIS**

The two steps of the analysis method will be presented in this section. Both steps of the analysis involved the application of Braun and Clarke’s (2006) method of inductive thematic analysis. This method was previously applied as part of the analysis reported upon in Chapter 8 and a description of it has been provided in Section 8.1(b). Both steps of the analysis focused upon the audio-visual data as the primary data.

(a) **Obtaining an Overview of the Experience of the Community-Oriented Groups**

Audio-visual data is a very rich data source. It captures not only verbal communication but also captures gestures, atmosphere, etc. (Heath et al. 2010, p. 59). This made it easy to get ‘lost in the data’ and made it difficult to break down the data to address the research question. At this stage of the analysis, the goal was to obtain an overarching view of how each case study community-oriented group experienced the SuBATOMIC face-to-face session which was the context for the case study. The composition of the two case study groups which are the focus of this chapter, the SuBATOMIC session which formed the context for each case study, and the available secondary data sources, are provided in Table 9.1.

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Group composition</th>
<th>SuBATOMIC session</th>
<th>Other data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Study A</td>
<td>Mairéad (F) Ciara (F) Maeve (F)</td>
<td>Concept Cartoons: group created a concept cartoon to assess understanding of element, compound and mixture.</td>
<td>Social media entry for each group member Reflective journal entry from Mairéad</td>
</tr>
<tr>
<td>Case Study B</td>
<td>Michael (M) Aoife (F) Una (F) Bríd (F)</td>
<td>Cooperative Learning Part 1: group wrote a revision sheet on covalent bonding for their peers.</td>
<td>Social media entry for each group member Reflective journal entry from Michael</td>
</tr>
</tbody>
</table>

176 All names used are pseudonyms.
Stein’s philosophy on empathy and community were the primary guiding ideas at this stage of the analysis. This led to the development of a coding strategy which could account for the extent to which the case study group experienced ‘community’ at any one time. A community is characterised by solidarity (Stein 1989). It is evidenced by mutual interdependence among group members, interactivity between members, and shared goals (Rovai 2002). A strong sense of community arises when members (Rovai 2002):

- empathise with one another;
- engage in communicative behaviours that reduce psychological distance;
- share common interests, attitudes and values;
- trust and help one another;
- engage in two-way communication, and
- pursue common learning objectives.

Therefore, the analytical strategy was designed to achieve two objectives: to examine the common objective, focus or goal of the group at any one time, i.e. the Community Goals, and 2) to determine the extent to which the group members connected with one another at any one time, i.e. the Levels of Community. These two components of the coding strategy allowed each moment to be considered in terms of the extent to which the community-oriented group engaged in the behaviours associated with a strong sense of community as listed above.

**COMPONENTS OF THE CODING STRATEGY**

The coding strategy comprised two components: Community Goals and Levels of Community. The development of this coding strategy was an ongoing process. I coded the audio-visual data for one case study. Over time, I built up larger categories of codes as more audio-visual data was added from the other case studies and I reviewed the literature to shed light on the experiences I was observing. This led to the creation of a code book that described each of these larger code categories which I then applied to the full dataset. I decided to directly code the audio-visual data rather than coding a transcription of the data. This decision was also influenced by Stein’s philosophy of empathy, wherein the perceiving of another subject and their experience is founded upon the perception of the whole human person, including the foreign living body, the ‘energy’ which saturates their expressions and words, etc. (Stein 1989 p. 38-63). A transcription method could have been employed which accounted for physical gestures, movements, expressions and so on (Heath et al. 2010, p. 150-153). However, on attempting this, I found that much of the sense of the data was lost and, therefore, I decided that the best way to proceed was to focus on the audio-visual data in all its richness. This ensured that I was continually met with the richness of PSSTs’
experience and, thus, could better represent and interpret this experience. The Community
Goal codes and a general description of these codes is shown in Table 9.2.

<table>
<thead>
<tr>
<th>Code Name</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sharing Metacognitive Judgements and Monitoring (SMJM)</strong></td>
<td>This code refers to instances in which one or more members <em>share the outcome</em> of their metacognitive judgements and monitoring (MJM) with other group members about anything related to chemistry/science learning/teaching. This is the ongoing awareness of: ease of learning, learning and comprehension, feeling of knowing, and confidence judgements.</td>
</tr>
<tr>
<td><strong>Practical and Pragmatic Matters (PPM)</strong></td>
<td>Contains instances of group members focusing on practical activities, statements, or decisions, or pragmatic statements or decisions.</td>
</tr>
<tr>
<td><strong>Developing Understanding (DU)</strong></td>
<td>This code refers to activities, statements, discussions, etc. that focus on the development of concepts related to chemistry or teaching. It could be said to loosely correspond to knowledge, comprehension and analysis of Bloom's taxonomy.</td>
</tr>
<tr>
<td><strong>Application of Understanding (AU)</strong></td>
<td>This code refers to activities, statements, discussions, etc. that focus on applying understanding of a concept to an exemplar, task, or another concrete situation. It could be said to loosely correspond to application, synthesis and evaluation of Bloom's taxonomy.</td>
</tr>
<tr>
<td><strong>Multiple (Mult)</strong></td>
<td>This code refers to instances of group members being on-task but no two members have a common focus.</td>
</tr>
<tr>
<td><strong>Off-Task (OT)</strong></td>
<td>This code refers to instances of group members having a conversation unrelated to the task or issues surrounding the task.</td>
</tr>
</tbody>
</table>

A code book was created and each code was described in terms of a general description (shown for each code in Table 9.2), inclusion criteria, exclusion criteria, typical examples, atypical examples, and examples that were close to the description but which did not belong within that code category. A portion of the code book showing this for the SMJM category is provided in Table 9.3.

The Levels of Community component of the coding strategy also arose from the data itself and the literature. The literature was examined to get a sense of some key characteristics of ‘community.’ As previously noted, Rovai (2002) noted that strong learning communities empathise with one another, attempt to reduce the psychological distance between one another, and help one another. The data was viewed with these characteristics in mind and gradually various ‘levels’ of community were identified in the data based on the presence of these characteristics. The number of levels arose from the data itself as I engaged in a process of re-examining each of the experiences grouped under each level to ensure that they were similar in relation to the group characteristics that were present. Where some experiences were qualitatively different from others in terms of the sense of community, I added a new level of community. After a number of iterations, six levels of community were identified based on the presence and extent of the characteristics identified in the literature. The final version of this portion of the code book, became a decision tree, shown in Figure 9.1, rather than a discrete set of descriptions such as that in Tables 9.2 and 9.3.
Table 9.3 Portion of code book describing Sharing Metacognitive Judgements and Monitoring

<table>
<thead>
<tr>
<th>Code</th>
<th>Sharing Metacognitive Judgements and Monitoring (SMJM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>This code refers to instances in which one or more members share the outcome of their metacognitive judgements and monitoring (MJM) with other group members about anything related to chemistry/science learning/teaching. This is the ongoing awareness of: ease of learning, learning and comprehension, feeling of knowing, and confidence judgements.</td>
</tr>
<tr>
<td><strong>Inclusion Criteria</strong></td>
<td>Considering task/learning difficulty, sharing judgements of personal or group understanding/task progress, a feeling of knowing something but being unable to recall it, or their confidence in statements made.</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td>Discussing the actual meaning of concepts.</td>
</tr>
<tr>
<td><strong>Typical Examples</strong></td>
<td>Identifying concepts that one or more of the group doesn’t understand; implying that the learning/task is difficult through gestures; appraising the value of a task product or idea; admitting confusion about a concept; comparing the difficulty/ease of tasks/learning experiences; stating one’s confidence in a concept/topic/statement, etc.</td>
</tr>
<tr>
<td><strong>Atypical Examples</strong></td>
<td>Being sarcastic or humorous about one’s own or the group’s understanding/task progress; facilitator sharing her judgements of the group’s learning.</td>
</tr>
<tr>
<td><strong>Close but no</strong></td>
<td>Asking a conceptual question, e.g. “Why do atoms form bonds?” This implies a lack of understanding/confidence but the focus is upon developing understanding and not sharing a judgement or the outcome of monitoring. An example of an SMJM comment on similar lines would be “I don’t understand why atoms form bonds.”</td>
</tr>
</tbody>
</table>

Each of the terms used within the decision tree shown in Figure 9.1 for the Levels of Community, e.g. public domain, private domain, etc., were explained within the code book. The full version of the code book, including the additional information about both the Community Goals and the Levels of Community, may be found in Appendix F.

**INTER-RATER RELIABILITY**

The inter-rater reliability in applying the Community Goals and Levels of Community was assessed by providing a science education researcher, Coder 2, with approximately 15% of the audio-visual data to which she was to apply the codes as described in the code book. Cohen’s Kappa and the percentage of agreement between my coding and that of Coder 2 were used as a measure of reliability. Cohen’s Kappa may be between -1 and +1, with +1 indicating complete agreement: Cohen suggested that 0.61 – 0.80 indicates substantial agreement, while a value of 0.81 – 1.00 indicates almost perfect agreement (McHugh 2012).

In this study, all codes were found to be sufficiently reliable and either in the substantial agreement or almost perfect agreement categories, as shown in Table 9.4. Where there was disagreement, this was usually the result of imprecise coding (i.e. beginning to code a moment before or after the applicable experience began on the audio-visual data) and, as a result, the agreement between myself and Coder 2 was actually higher in many cases than shown by the values in Table 9.4: we agreed that an experience should be coded the same way but the imprecision associated with directly coding audio-visual data led to ‘disagreement’.
Figure 9.1 Decision tree for the Levels of Community
### Table 9.4 Inter-rater reliability for Community Goals and Levels of Community

<table>
<thead>
<tr>
<th>Component of Coding Strategy</th>
<th>Code</th>
<th>Cohen’s Kappa</th>
<th>% Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community Goals</td>
<td>Application of Understanding (AU)</td>
<td>0.84</td>
<td>92.93</td>
</tr>
<tr>
<td></td>
<td>Developing Understanding (DU)</td>
<td>0.77</td>
<td>89.22</td>
</tr>
<tr>
<td></td>
<td>Practical and Pragmatic Matters (PPM)</td>
<td>0.76</td>
<td>94.13</td>
</tr>
<tr>
<td></td>
<td>Sharing Metacognitive Judgements and Monitoring (SMJM)</td>
<td>0.76</td>
<td>93.93</td>
</tr>
<tr>
<td>Levels of Community</td>
<td>Level 0</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Level 1</td>
<td>0.89</td>
<td>95.52</td>
</tr>
<tr>
<td></td>
<td>Level 2</td>
<td>0.76</td>
<td>97.58</td>
</tr>
<tr>
<td></td>
<td>Level 3</td>
<td>0.86</td>
<td>97.33</td>
</tr>
<tr>
<td></td>
<td>Level 4</td>
<td>0.87</td>
<td>96.81</td>
</tr>
<tr>
<td></td>
<td>Level 5</td>
<td>0.91</td>
<td>95.59</td>
</tr>
</tbody>
</table>

### Linking Codes to PSSTs’ Experiences

The coding strategy described above allowed me to create a visual representation of the flow of experience for each case study group. This provided an overview of the experiences of the PSSTs and provided a semi-quantitative way to support or refute my impressions of the group. However, the advantage of the overarching view was also its downfall – the richness of the experience was lost in its generalisation. I needed a way to imbue this overarching view with the experiences of the community-oriented groups. Therefore, I created a set of narratives for each group that depicted them engaging with the task which they had been assigned in the SuBATOMIC session. These narratives were preferable to simple transcription because they allowed me to more accurately depict the meaning imbuing gestures, tone of voice, etc. Consider the following two ways of representing a situation:

— “But what’s an atom? [Laugh]”
— “But what’s an atom?” asks Catriona, with a nervous laugh.

Although the first way depicts the language and behaviour of the moment, it lacks the meaning which imbues this behaviour. There is a qualitative difference between a nervous laugh, and a laugh arising from humour. This difference is easily accessible to human beings when faced with one another (through empathy), but it is difficult to represent what is easily accessible to a human being in the form of a transcription. I coded each of the narratives according to the Community Goals and Levels of Community, connecting them to the associated visual representation of the flow of experience. In this way, the overarching view of the community-oriented group experience was connected with the meaning and sense of the experience. I examined the experiences in the narratives with a focus on the flow of experience, i.e. how one experience flowed into the next. For example, an SMJM experience
in which a group member admits a lack of understanding of some concept, might lead to a PPM experience, as another group member decides that they should look up this concept online. Alternatively, it might lead to DU experience as another group member attempts to explain the concept. This led me to observe patterns in how and why the group moved from one experience to the next, which I also visually represented. This method of analysis, resulted in a sizeable report for each case study and in presenting the findings of this step of the analysis, I will be presenting a summary of two of these reports.

**(b) Applying Relational Dialectics Theory**

In examining the flow of experience for a group, it became clear that in some cases there existed certain tensions between opposing ‘forces.’ For example, the tension between expression and non-expression which was apparent in Case Studies A and B. These tensions seemed to be integral to the experience of the community-oriented groups. This led to a further review of the literature and to RDT. The distinction between RDT and what I had already observed, was that my focus had been largely behavioural whereas RDT focuses rather upon the meaning which makes sense of such behaviours (Baxter 2011). For example, the non-expression behaviours might make sense in the context of discourses surrounding privacy, i.e. one’s right to one’s own information, or self-protection, i.e. one’s desire to protect oneself from negative attitudes about sensitive information. I decided to apply RDT to the narratives that depicted the experiences of the group using contrapuntal analysis as described by Baxter (2011). This can be thought of as “a specific kind of discourse analysis” (Baxter 2011, p. 151). It focuses upon the interplay of contrasting or opposing discourses in a text. In this case, the selected texts were the narratives which I had created in the previous step of the analysis. Discourses can be present at the socio-cultural level or the interpersonal level and my focus was upon those at the interpersonal level. Baxter recommends the application of Braun and Clarke’s method of inductive thematic analysis in order to identify the discourses within the text and this was the method selected. Braun and Clarke (2000) identify a distinction between manifest themes and latent themes, and Baxter (2011) notes that, within contrapuntal analysis, these themes are discourses. The manifest themes are those explicitly stated within the talk of the participants, while latent themes “rest below the surface, functioning as the underlying meaning that often sits implicit in the words.” Both types of themes were considered in my analysis. The contrapuntal analysis was carried out on two levels: 1) the discourses within the more general group experience, and 2) the discourses about specific concepts. Essentially, the former represent the latent themes in the data, while the latter represent the manifest themes. This step of the analysis also involved the creation of a report which will be summarised in this chapter for Case Studies A and B.
Past research that has applied RDT has largely relied upon self-report data in which one participant involved in some relationship discussed the issues which she/he believes are present in that relationship. This self-report data arises from semi-structured interviews. As a result, Baxter (2011) has noted the need for data which represents all parties in the form of observational data of relationship parties actually interacting. This type of data remains uncommon within the body of RDT research literature (Halliwell 2015), making the data in this study suitable to glean new insights. Furthermore, RDT has almost exclusively focused upon dyadic relationships (Halliwell 2015). Very few studies have examined non-dyadic relationships (Kramer 2004, Prentice and Kramer 2006). RDT has not, to the best of my knowledge, been applied in the research literature on alternative conceptions.

(c) Presenting the Findings

The findings for the two case studies will be presented according to the following format:

*Flow of Experience*: this section will present the findings of the first step of the analysis starting with the visual representations I created for each study. I will also present all the excerpts from the narratives upon which I will be relying as I discuss the findings of the case study. These excerpts will be titled and given line numbers in order to use them to provide evidence and exemplars throughout the discussion. The full set of narratives for each case study is also provided in the Appendices. I will then discuss the patterns in the flow of experience for each case study and the apparent impact of various types of experiences upon the groups.

*Relational Dialectics and Community-Oriented Group Experience*: this section will describe and discuss the latent themes identified during the contrapuntal analysis. The discourses which these themes represent are under the surface of the talk and behaviour, and lend meaning and *sense* to the behaviours noted in the Flow of Experience. The interplay between opposing discourses will be discussed.

*Relational Dialectics and Conceptual Discussion*: this section will describe and discuss the manifest themes identified during the contrapuntal analysis. These discourses relate to the conceptual meanings which the group attributes to concepts. The interplay between these conceptual discourses will be examined with reference to the behaviours of the group, and the relational dialectics discussed in the preceding section.

A summary will also be provided at the end of each case study, in order to highlight the important observations made for each case study group.
9.2 CASE STUDY A
This group was made up of three female PSSTs: Mairéad, Ciara and Maeve. The setting was one in which Mairéad and Maeve sat at one side of a table with their personal notepads and a laptop between them. Ciara sat on the other side of the table and also had a laptop and a personal notepad. Throughout this session, the laptops were used as learning resources rather than recording devices. Personal notepads were used to record their notes and individual copies of their concept cartoon. The context for this case study is the Concept Cartoons session of the SuBATOMIC learning programme. The group was set the task of writing a concept cartoon in the conceptual area of ‘Elements, Compounds and Mixtures’. This concept cartoon is provided for context in Figure 9.2.

My general observations of this group were that it worked well as a learning community. The community-oriented group began the session with an upfront admission of their uncertainty about the concepts and agreed to first spend time researching the meaning of these concepts. Mairéad appeared to have a leadership role and all group members appeared to have positive attitudes towards addressing their conceptual difficulties. The body of the session was spent addressing the meaning of concepts and the focus shifted solely to drawing their concept cartoon at the end of the session. This group regularly engaged in experiences with SMJM as the Community Goal, and their conceptual discussions tended to involve alternating between DU and AU experiences at the high-levels of community and appeared to be regularly punctuated with SMJM experiences.

(a) Flow of Experience
A breakdown of the percentage of primary data categorised at each Community Goals code and Levels of Community code is provided in Table 9.5. Low-levels of community refers to Levels 0 and 1, middle-levels refers to Levels 2 and 3, and high-levels refers to Levels 4 and 5. This group spent almost 50% of the session engaging at the high-levels of community. They also engaged with virtually no time off-task. These two factors indicate that they were quite committed to participating in the session. It is also notable that when engaging with AU and DU goals, they experienced high-levels of community approximately half of the time. They also engaged with AU goals far more than was the case in other case studies. However, this appears to be largely due to the context of the case study (i.e. the creation of a concept cartoon). A notable point about this group was the proportion of time they engaged with the SMJM goal, mostly at high-levels of community, and the frequency of these types of experiences – 11% of the data related to SMJM experiences and these were spread over more than 30 separate experiences, as shown in Figures 9.3 and 9.4.
Table 9.5 Breakdown of coding for Case Study A as a percentage of duration

<table>
<thead>
<tr>
<th></th>
<th>% at Low-Levels of Community</th>
<th>% at Mid-Levels of Community</th>
<th>% at High Levels of Community</th>
<th>Goal as % of Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application of Understanding (AU)</td>
<td>32.45%</td>
<td>17.58%</td>
<td>49.97%</td>
<td>44.82%</td>
</tr>
<tr>
<td>Developing Understanding (DU)</td>
<td>43.59%</td>
<td>9.18%</td>
<td>47.23%</td>
<td>28.56%</td>
</tr>
<tr>
<td>Off-Task (OT)</td>
<td>0.00%</td>
<td>0.00%</td>
<td>100.00%</td>
<td>0.65%</td>
</tr>
<tr>
<td>Practical and Pragmatic Matters (PPM)</td>
<td>26.98%</td>
<td>36.48%</td>
<td>36.54%</td>
<td>14.91%</td>
</tr>
<tr>
<td>Sharing Metacognitive Judgements and Monitoring (SMJM)</td>
<td>22.06%</td>
<td>20.86%</td>
<td>57.08%</td>
<td>11.07%</td>
</tr>
<tr>
<td><strong>Total Duration</strong></td>
<td><strong>33.46%</strong></td>
<td><strong>18.25%</strong></td>
<td><strong>48.30%</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figures 9.3 and 9.4 show the visual representation of the flow of experience for this group\(^{177}\). Figure 9.5 is a representation of the patterns in the flow of experience for the group. As shown in the latter, the group tended to flow between two ‘cycles of experience’ which I have labelled the Expressive and Non-Expressive Cycles of Experience. This pattern was identified based on the narratives, excerpts of which will now be provided, and the visual representation of the flow of experience shown in Figures 9.3 and 9.4.

\(^{177}\) The line graph suggests that this data is continuous. That is not the case and it is only represented with a line graph in order to make it easier to see. Each dot in the figure represents approximately five seconds of audio-visual data (labelled on the X axis), the colour coding indicates the Community Goals code, and the Y axis indicates the Levels of Community.
Figure 9.3 Flow of Experience for Case Study A (Part 1)

Figure 9.4 Flow of Experience for Case Study A (Part 2)

Legend for Flow of Experience Diagrams

- ○ Community Only
- △ Community-Facilitator
- Blue: Developing Understanding (DU)
- Red: Practical and Pragmatic Matters (PPM)
- Purple: Application of Understanding (AU)
- Yellow: Sharing Metacognitive Judgements and Monitoring (SMJM)
- Blue: Off-Target (OT)
Figure 9.5 Pattern of the Flow of Experience for Case Study A
EXCERPTS FROM THE NARRATIVES

The following excerpts are presented in chronological order and the time stamps corresponding to Figures 9.3 and 9.4 are provided at the outset of each excerpt. The full set of narratives may be found in Appendix J.

Excerpt I

This excerpt depicts time stamp 11:25 – 12:50 of Figure 9.3.

“Does molecules come into this?” asks Ciara. Mairéad and Maeve look at her and she continues, “Because I’m after finding this thing that ‘All compounds are molecules, but not all molecules are compounds.’”

Mairéad hangs her head slightly, “What does that even mean?” she exclaims, and Maeve has a brief conspiratorial laugh. Mairéad points to the screen of the laptop that she and Maeve have been using as she says, “I see molecules here actually.”

Ciara provides her own understanding of the statement as Maeve and Mairéad give their attention to her.

“Yeah so, like, a molecule… can be… H-two. That’s a molecule of hydrogen, or a molecule of oxygen is O-two, but then—“

“So does that mean—” interrupts Mairéad.

“So compound is a mixture, of like—“ continues Ciara.

“—of any of them,” finishes Mairéad before she asks a clarifying question, “So does a molecule have to be the same elements coming together? Like two oxygens come together. A hydrogen and an oxygen can’t come together,” says Mairéad.

Maeve, looking down at her notepad, begins to speak in a quiet voice and Mairéad and Ciara glance over at her.

“Yeah, it says…” starts Maeve, before Mairéad and Ciara begin to talk over her.

“No, then that’s a compound,” says Ciara, answering Mairéad’s previous question.

“Then that’s a compound,” confirms Mairéad.

Maeve continues to read aloud quietly from her notepad, “—two or more different elements.” Maeve raises her head to look at Ciara as she surmises her own understanding.

“So a molecule is just one element.”

“It’s just one of them,” agrees Mairéad as she turns over a sheet of her notepad in preparation for writing.

“Consists of one element,” says Maeve.

Ciara reads aloud from a web page, “It’s the smallest bit of each…” before her voice trails off into silence.

“Okay. Hang on,” says Mairéad, “I’m going to look up the definition of a molecule.”

“Yeah,” agrees Maeve. Mairéad begins to type on the keypad.

Ciara reads out the definition that she has already found for a molecule, “I have that ‘A molecule is formed when two or more atoms join chemically together.’”

Mairéad stops typing a raises a hand to her face in frustration as Maeve and Ciara look at her.

“Every single… what does it mean?” she says, shaking her head, and she begins to type again.

“But what’s an atom though?” says Ciara with a little nervous laugh, “This is where I get confused.”

“An atom?” says Mairéad, looking up from the screen of her laptop.
“Like, what’s the definition of an atom?” says Ciara.

At this exact moment, I pass close by the group’s table and am within earshot, although I am not listening but merely returning to the top of the room to retrieve something for another group. When Mairéad sees me walk close by, she puts one hand up to shield her face in embarrassment.

“Oh Jesus Christ!” she says with embarrassed laughter before continuing, “This is so confusing.”

“I’m gonna click that link,” says Ciara murmurs.

Mairéad waits for me to walk by the table again on my return journey to a different group, before she returns to the task at hand.

“Oh,” she says and then reads aloud from a web page, “A molecule is an electrically neutral group of two or more atoms held together by chemical bonds.”

“Are you on Jefferson lab?” asks Ciara.

“No. I’m on Wikipedia.”

Maeve, who has been looking at the web page that Mairéad found, says, “An atom is supposed to be like, a hydrogen atom, an oxygen atom.”

“Yeah,” agree both Maeve and Mairéad.

Mairéad raises her two hands to simulate two atoms and says “And then they come together,” as she brings her two hands to meet each other. She follows up with a joke, “We need, like physical means to do this because I’m getting so confused.”

“It’s an actual balls like,” agrees Ciara.

Maeve returns to their conceptual issues.

“An element then would be like hydrogen and oxygen,” she says.

“It makes sense,” says Ciara.

Mairéad begins to summarise what they have learned thus far as the group intermittently writes in their notepads.

“Okay. So… a molecule is two hydrogen’s coming together… to make H-two”

“Yeah,” agree Maeve and Ciara.

“Okay,” says Mairéad, “And now we have to think, what’s an atom?”

Excerpt II

This excerpt depicts time stamp 14:15 – 14:20 of Figure 9.3.

Mairéad proposes a direction for the questions that they could create to accompany their concept cartoon in a teaching context. She looks between Maeve and Ciara as she does this.

“Say if we stay with our original idea, right, and in the questions underneath we say, how is H-two formed, or, like, like, the answer would be a molecule but, like, you have to phrase the question in such a way –“

“That they get to molecules,” contributes Ciara as she looks between Mairéad and the screen of her laptop.

“Yeah,” agrees Maeve.
“But wait now hang on. I’m confused,” says Mairéad, “I thought an element is the same thing as an atom.”

Both Maeve and Ciara look down at their notes and laptop screen for a moment.

“No an element is only just one,” explains Maeve as Ciara looks first in her direction and then looks over to me as I am leaving another group and making my way towards this group. Mairéad turns to Maeve to confirm that she understands Maeve’s explanation, “Just one, so that’s H… on its own.”

“Yeah. And then a molecule, then is two Hs,” continues Maeve.

At this stage, I have now come adjacent to the table and all the group members are aware of my presence.

“But then how is an atom not the same as an element… because one H is an atom,” says Mairéad before she glances over at me and abruptly finishes, “I don’t know.”

Mairead laughs a little while Maeve rests her head in her hand with a sigh.

“I’ll come back to ye,” I say as Mairéad laughs, “Ye’re in the middle of a discussion and I’m going to ruin it so I’ll go over there. I’ll come back to ye in a minute.”

Mairéad returns to the previous conversation and, looking over at Ciara, says, “D’you know what I mean?”

Ciara then contributes a definition that she has found online to the discussion.

“An element is a substance that is made entirely from one type of atom.”

“Well that is H,” says Mairéad. Maeve begins to carry out her own search for information using the internet while Ciara and Mairéad continue the conversation.

“So if we put loads of Hs together—“ says Ciara.

“—then that’s an element—“ adds Mairéad.

“For example, ‘An element hydrogen is made up of atoms containing a single proton and a single electron. If you change the number of protons on the atoms you change the type of element it is.’”

Maeve then contributes the definition she has just found for the concept of an atom.

“Oh, an atom is a basic unit of matter that consists of a dense central nucleus surrounded by a cloud of negatively charged electrons,” she says.

After a moment Ciara adds, “Sure that is, like, a kind of an atom.”

“It’s an element though,” says Maeve.

“So atoms and elements—“ starts Ciara, before being interrupted by Maeve.

“—So an atom is an element… No?” she says as she looks to Mairéad.

“I think an element is made up of atoms,” says Mairéad, “I have no, see this, this is where this gets me. I have no idea. That’s being so honest with you.”

Maeve drops her pen with a sigh and leans back her seat. Ciara returns to looking at the web page she has open.

“I’m confused now,” admits Maeve.

Mairéad then begins to summarise what they have decided upon so far and after each statement looks to the others for confirmation. They jot down notes throughout the summary.

Okay, so, hang on,” she says, “A compound is water.”

“Yeah,” they agree.
“An element is… hydrogen.”
“Yeah.”
“A mixture is sand and water.”
“Yeah.”
“A molecule is… H plus H making H-two.”
“H-two,” agrees Ciara. The three group members write this down.
“Okay. And then, we dunno what the difference between an atom and an element is. I assume an element is made up of the atoms,” says Mairéad.
“Yeah. This says an element hydrogen is made from atoms so… atoms are used to make an element,” adds Ciara.
“Okay,” says Mairéad as she adds this to her notepad.

Excerpt IV
This excerpt depicts time stamp 17:45 – 19:00 of Figures 9.3 and 9.4.

Maeve sits slightly forward in her chair with her chin resting lightly on her hand and says, “We don’t know the difference between atom and element.” I ask what they think an element is and Ciara looks down at her laptop and Mairéad at her notes. Maeve answers for them, occasionally looking down at her own notes. “Well, we know an element is like hydrogen or oxygen. It’s made up of atoms, like, just one atom, like.”
Mairéad looks away from her notes and gives her full attention to the conversation. She adds, “But then it’s a pure substance.” I move to bring the conversation back to an earlier point to ensure I have understood the meaning they attribute to the concept element. “Yeah. Okay so hang on now. Say that again… an element is just made up of one atom?”
Maeve looks at me while Mairéad and Ciara initially look down at their notes. “Yeah,” she says. “Like, hydrogen is an element.”
Ciara and Mairéad now return their full attention to the conversation. Mairéad adds that an element is “one type of atom.”
“One type of atom,” I repeat as Ciara turns to face me. Mairéad confirms that this is their understanding. I present them with an example to further clarify their understanding. “So… if I had loads and loads of H-twos, so hydrogen in the air is two hydrogens bonded together. So if I had loads of those, would that be an element?”
“No,” says Maeve, “That’s a molecule… loads of H-twos.”
Mairéad seeks to clarify the situation. “Yeah, see, we were saying that hydrogen would be an element.”
“One hydrogen atom is it?” I ask, holding up one finger.
“Yeah,” says Mairéad.
“So lots of single hydrogen atoms would be an element?” I ask.
“Yeah,” she says.
“But what if they were bonded together?” I ask.
“If they were bonded together that’s a molecule,” she explains.
“So… you’re saying that an element is different from a molecule,” I surmise.
“This is why we’re confused,” says Mairéad and she laughs along with Ciara and me, Maeve then jumps in to say, “No an element is different from a molecule.”
“Yeah,” agrees Ciara.
“Yeah they’re different!” confirms Mairéad.
“But then an element is an atom,” adds Maeve.
I then summarise my perspective on the main source of confusion, “Okay so really the crux of the problem is, for you, element and atom pretty much mean the same thing”
“Yeah,” they agree and nod their heads.

Excerpt V
This excerpt depicts time stamp 21:05 – 21:10 of Figure 9.4.

I then try to summarise the overall thinking in the group about atom, molecule, element and compound but inadvertently misdescribe it, “So, I’d say, maybe the crux of the problem is the element-atom thing and then you’ve a, let’s say, all molecules are compounds? Would that be a fair description of what you think at the moment?”
The group moves to correct me. “But not all molecules are compounds,” says Maeve.
“But no it’s that all compounds are molecules—“ adds Ciara.
I ask a follow up question. “But then what else can molecules be other than compounds?”
Ciara repeats a phrase that she read earlier on the internet. “Is it not that all compounds are molecules, but not all molecules are compounds?”
“Yeah. That’s true,” I say, though in fact the phrase is incorrect.
“I don’t know why. I just read it there a minute ago,” says Ciara.

Excerpt VI
This excerpt depicts time stamp 21:30 – 22:45 of Figure 9.4.

“An element is made up of one type of atom,” I say and pause for a moment. Mairéad and Maeve nod. I go on then to develop this point. “But they can be bonded together. They can be bonded covalently together. Okay, so you can have molecules that are elements. The point is that it’s only one type of atom.”
I then go on give three examples; the element hydrogen as being made up of H₂ molecules, the element carbon in the form of buckminsterfullerene (C₆₀), and the element sulfur in the form of S₈. Throughout these examples, the group members nod or jot down the occasional note.
At the end of this review of the meaning of element, Maeve says, “Oh right! I think I know the difference now.”
I once more reiterate the main point about elements, “Okay. So it’s just that it’s one type of atom. It doesn’t matter that they’re bonded together and actually, in reality, they will be bonded together.” The group members nod their agreement.

Excerpt VII
This excerpt depicts time stamp 25:50 – 28:05 of Figure 9.4.

I have just left the group and they consider what has been said. “So we weren’t clear,” says Mairéad of their understanding prior to my joining the group. Maeve agrees. Mairéad then begins to summarise their understanding. “Okay. So we’re still right,” she says as Maeve and Ciara give her their attention. She looks between the two of them as she says, “Water is a compound. Loads of different hydrogens are an element. It doesn’t have to be just one of them. A mixture is air… because, like she said, nothing is broken and nothing is gained.”
“Yeah,” agrees Ciara.

Mairéad continues, “Okay. Then a molecule is water.” She pauses, thinking. “Okay. So a molecule and a compound are kind of the same, except like, like—“

“No,” says Ciara. “It’s that ‘All compounds are molecules, but not all molecules are compounds,’” she says while looking at the screen of laptop.

There is a long pause before Mairéad sighs and covers her face with her hands. “Oh my God,” she says quietly.

Ciara laughs and then tries to explain further, “So, like, the compound H-two-O—“

“But then some elements can be molecules too,” points out Maeve.

“But she said salt is a compound but not a molecule,” Mairéad remembers. “So that’s wrong,” she says with conviction as she points to Ciara’s laptop. “Read that again.”

“All compounds are molecules, but not all molecules are compounds.”

“But she said salt is a compound but not a molecule.”

“That makes sense. Compounds… all…” says Maeve gesturing towards Ciara’s laptop.

“All compounds are molecules, but not all molecules are compounds,” repeats Ciara. “That’s right,” she says with certainty.

“Okay,” says Mairéad uncertainly.

Ciara begins to explain further, “Because, say, a molecule, the H-two… that’s a molecule but it’s not a compound because it’s not a mixture of two different atoms. But H-two-O… has the two different types… so it is a compound… and then why is it an element as well?”

Mairéad starts to laugh in response and Ciara quickly corrects herself, “No why is it a molecule? So many words.”

“Too many,” says Mairéad with her head in her hands, “My head hurts.”

“Oh it’s because it’s two joining together,” says Ciara.

Mairéad then takes control of the situation and ends the conversation. “Okay. Okay. We will think about our cartoon, because…” she says with the laughter and the rest join in.

“We could be going around like this all day,” agrees Ciara.

The group begin to prepare their materials to begin drawing their concept cartoon.

**EXPRESSIVE CYCLE OF EXPERIENCE**

As shown in Figure 9.5, the experience of this group tended to flow between an Expressive Cycle of Experience and a Non-Expressive Cycle of Experience. The Expressive Cycle of Experience comprised high-level DU, high-level AU and high-level SMJM experiences.

High-level DU experiences, i.e. DU experiences engaged with at Levels 4 and 5 of community, in this group involved the: asking of conceptual questions, sharing of personal understanding of a concept, and reading aloud of definitions from webpages. Mairéad and Ciara initiated the majority of these high-level DU experiences – in a sense, directing the flow of experience to DU. In Excerpt III, for example, Mairéad brings the group to high-level DU experience as she shares her understanding of the relationship between the concepts of element and atom, “I thought an element is the same thing as an atom” (lines 1-2) – an experience to which Maeve also actively contributes (lines 3-6). In terms of the flow of experience after high-level DU experiences, Mairéad almost exclusively directed the flow of
experience at the outset of session but this gradually became equally shared among group members. For example, Mairéad directs the flow of experience to high-level AU after the high-level DU experience described above, as she suggests an exemplar, “so that’s H… on its own,” (lines 6–7) – an experience to which Maeve again actively contributes by also suggesting an exemplar of another concept (line 8).

High-level AU experiences included activities such as: giving concrete examples of a concept and/or related concepts, giving non-examples of a concept, creating the concept cartoon, discussing how concepts can be included in the concept cartoon, etc. These experiences tended to be initiated more often by Mairéad but all group members engaged with these high-level AU experiences. This indicates that although Mairéad was more inclined to direct the flow of experience to high-level AU (particularly from high-level DU), this was well-received and participated in by the group at large. In Excerpt III, for example, Mairéad suggests an exemplar of an element, “well that is H,” and Ciara actively contributes to this experience, while Maeve listens to the discussion (lines 20–24). The flow of experience after high-level AU was most often directed, by Mairéad, to either SMJM or high-level DU experiences: high-level AU usually led to further experiences within the Expressive Cycle. After the example given above, Ciara and Maeve direct the flow to high-level DU experience as they introduce definitions that consider the meaning of the concept of atom (lines 25-29).

SMJM experiences included: sharing judgements of personal understanding, sharing judgements of group understanding, sharing judgements of ease of learning, and sharing confidence judgements of statements. Sharing judgements of personal understanding were by far the most common at the outset of the session, and over time judgements of ease of learning and confidence judgements became more common. At the outset of the session, Mairéad, again, initiated most of the SMJM experiences, but group members engaged with these experiences about equally – again, indicating that such experiences were well-received by the group. In Excerpt I, for example, Mairéad directs the flow of experience to an SMJM experience, “We need, like, physical means to do this because I’m getting so confused,” (lines 56-57) and Ciara actively engages with this experience (line 58).

Mairéad was particularly active in sharing judgements of her own understanding with the group. As the session progressed, Maeve and Ciara began to direct the flow of experience to SMJM experience. After SMJM experiences, the flow of experience was equally as likely to be directed to other experiences within the Expressive Cycle as it was to experiences within the Non-Expressive Cycle. After the SMJM experience just mentioned in Excerpt I, Maeve directs the flow of experience to a high-level AU experience (lines 59-60). When Mairéad
directed the flow of experience after SMJM, she tended to direct it to experiences within the Non-Expressive Cycle. This often occurred when frustration was conveyed in the SMJM experience, resulting in disengagement by one or more members. In response to this, Mairéad would then perhaps summarise the agreed upon understanding or make a practical suggestion for moving forward with the task. In Excerpt III, for example, Mairéad initiated an SMJM experience and frustration became obvious in the group (lines 34-38). In response to this, Mairéad directed the flow of experience to a middle-level AU experience in which she summarised the conceptual exemplars which the group had already reached agreement upon (lines 39-49). Overall, SMJM experiences appeared to serve the group as follows:

- admissions of a personal (or group) lack of understanding allowed opportunities for empathy and resulted either in further experiences within the Expressive Cycle, as group members attempt to explain concepts (e.g. Excerpt VII lines 12-15), or, if frustration dominated the group atmosphere, a brief respite in the Non-Expressive Cycle of Experience;
- unintentional admissions of a personal lack of understanding in my presence (as the facilitator) resulted in a reduction in the level of community and engagement with the Non-Expressive Cycle as long as I remained present (e.g. Excerpt I lines 35-51);
- positive confidence judgements in a statement sometimes interrupted the flow of experience if one of the group members lacked confidence in the same statement (e.g. Excerpt VII lines 20-23).

The secondary data sources for this case study related to the group members’ metacognition. In their reflective journals, both Maeve and Mairéad made positive judgements of the progress in their conceptual understanding. They both judged that their own understanding of the differences between compound, mixture and element had improved. They also both made specific reference to the difficulties they had distinguishing the concept of element from that of atom. The relevant portions of this secondary data are provided below.

Maeve. … thinking that an element is the same as an atom which I had previously thought… Something I learned about in chemistry in the SuBATOMIC class today was the difference between compounds, elements and mixtures.

Mairéad. As we looked up each definition it became clear the difference between each. However, the difference between an element and an atom was not clear and so we had to seek clarity from Muireann… I now have a rough idea what the difference is between a compound, mixture, elements and molecules are… I found making the cartoon educational to myself, it tested my real understanding of the topic.
The social media comments of the group members during the week of the Concept Cartoon SuBATOMIC session did not relate to their experience of the session itself. However, after the session I published a new section on the SuBATOMIC website. This section combined a “Misconceptions” and a “Check Your Understanding” webpage for the conceptual area of Classification of Substances. These pages were interlinked such that beside each group of alternative conceptions on the ‘Misconceptions’ webpage, a user could click on a ‘Learn’ button that directed him/her to the relevant portion of the ‘Check Your Understanding’ webpage. All group members made references to this webpage in their social media activities.

Ciara: I agree with [student name] as I too find this page very helpful and easy to follow. This page has really cleared up the misconceptions I had the first week doing the concept cartoon as I was unclear of the differences between a compound, element etc.

Mairéad: The new page- check your understanding-classification of substances is brilliant! A compound, mixture etc. are all explained in simple English, with easy to remember examples.

Maeve: I agree with Mairéad, the new misconceptions page says very clearly what a compound, mixture and element etc. are and I find it very helpful to have the learn button beside the misconceptions as it is a fast way to find the correct answer.

All three judged that this learning experience improved their understanding, with Ciara making reference to some unspecified alternative conceptions she had during the Concept Cartoon SuBATOMIC session, which she now believes she has resolved. This suggests that the group members developed an awareness of conceptual confusion during the session, which they then believe they resolved using the website. It is interesting that they did use the website to address this conceptual area – although the website was there for their use, they were not under an obligation to use it for this particular purpose. It is possible that the awareness which they developed during the session, motivated them to resolve their conceptual issues when a convenient opportunity arose to do so.

High-level DU and AU experiences formed the basis of the conceptual discussion carried out by this group in this session. The Expressive Cycle often followed a pattern wherein the meaning of a concept (or concepts) was discussed in a high-level DU experience, the understanding developed was then tested by suggesting exemplars and non-exemplars of the concept(s) in a high-level AU experience, before the group would share their judgement of their own or of the group’s understanding in an SMJM experience. In Excerpt III, for example, there are several iterations of flowing between high-level DU and high-level AU experiences, which are then followed by an SMJM experience (lines 18-38).
The Non-Expressive Cycle comprised PPM experiences, and low- and middle-level DU and AU experiences. The Non-Expressive Cycle of Experience tended to occur for very brief periods of time in the body of the session (e.g. Excerpt I lines: 29-30 and 45-51; Excerpt III lines: 39-49; Excerpt VII: lines 31-34). Within the body of the session, the group discussed the meaning and connection between various concepts. However, this cycle of experience occurred for longer periods of time at the outset of the session, wherein the group prepared to begin their task and revised their understanding of concepts, and at the end of the session, wherein the group was focused upon creating a concept cartoon based on their discussions within the body of the session. This has not been depicted in the excerpts provided; however, evidence of this can be observed in Figures 9.3 and 9.4 at time stamps 2:20-4:05, 4:20-4:55 and 32:35-33:55.

Low-level DU and AU experiences included those in which the group members silently: read conceptual information, wrote notes in their notepads, wrote down their own versions of the concept cartoon, etc. Often it was impossible to identify who initiated low-level DU experiences as there appeared to be some silent and simultaneously agreement to engage with these experiences. Middle-level DU and AU experiences involved reading definitions aloud, and summarising previously agreed upon conceptual understanding and exemplars (e.g. Excerpt I: lines 48-49 and lines 62-65). Mairéad and Ciara were most likely to initiate these middle-level DU and AU experiences, with Ciara being more likely to introduce definitions or exemplars from the web and Mairéad more likely to summarise the group understanding. Middle-level DU and AU experiences typically flowed into other Non-Expressive Cycle Experiences (i.e. further middle-level DU/AU experiences, low-level DU/AU experiences or PPM experiences). Low- and middle-level DU and AU experiences in this group were generally opportunities for the group members to collect themselves, revise their understanding, or introduce further information to the group, before ultimately embarking again upon further high-level discussions within the Expressive Cycle of Experience (e.g. Excerpt I, lines 29-32). PPM experiences included activities such as: discussing/describing a learning resource, strategy decisions/discussions, and preparing or organising their materials for writing. Again, Mairéad and Ciara most often initiated these experiences. PPM experiences appeared to serve several functions in the group. They often provided the group with a brief respite from conceptually-heavy discussions (e.g. Excerpt I, lines 50-51). They could also communicate attitudes about learning in the group and/or cue other group members to continue conceptual discussions. In Excerpt I, for example, Mairéad expressed some frustration at the lack of clarity in a phrase that Ciara has introduced. Mairéad then
mentioned, in a PPM experience, that she had some relevant content open in her web browser (line 6); this revealed that she was not intending to disregard the phrase introduced by Ciara, and this may have been important in cuing Ciara to continue the conversation.

Examining the Non-Expressive and Expressive Cycles more generally, the Expressive Cycle of Experience was the basis of conceptual discussions and any changes to, or reinforcing of, the meaning of concepts took place within the context of these types of experiences. Meanwhile, the Non-Expressive Cycle appeared to be the basis for a number of different types of activities. Within the body of the session, it primarily appeared to function as a brief respite from conceptually-heavy discussions. This usually occurred after deep frustration had been conveyed in an SMJM experience, resulting in disengagement. In response to this, a group member would initiate a Non-Expressive Cycle of Experience by suggesting a practical strategy such as searching the web for the meaning of the offending concept (PPM experience), leading to the search for this concept (low-level DU), and so on. At the outset of the study, this cycle allowed the group members to revise their understanding as individuals, as they sought out definitions on the web but did not discuss them. In this way, the group engagement with the Non-Expressive Cycle of Experience, allowed them to ultimately engage in a more meaningful way in the Expressive Cycle by giving them the space to rest, think, and reflect, as well as the opportunity to revise. In a few cases, the Non-Expressive Cycle of Experience also served to hide embarrassment or lack of confidence in their conceptual understanding. However, this occurred only in my presence or in my perceived-presence (i.e. when the group believed I was within earshot of them or may have overheard their discussion). Considering the entire session, these types of Non-Expressive Cycles were atypical.

The flow of experience observed in this case study draws a comparison with models of learning such as the Science Curriculum Improvement Study (SCIS) Learning Cycle (Lawson et al. 1989). This model comprises three phases: exploration, concept introduction and concept application. The flow of experience in this group has some similarity with this model, given the tendency to flow between DU experiences, in which conceptual definitions were sought out and introduced, and their meanings discussed, and AU experiences, in which the group then applied this understanding by developing exemplars, non-exemplars, and a concept cartoon. This Learning Cycle was adapted by other researchers to include such factors as investigation, prediction, evaluation, and assessment (Good 1989; Lavoie 1992; Barman 1997). Many of these activities are subsumed into the broader categories of DU and AU in the current study. For example, ‘exploration’ in this study might be considered to be the low-level DU activities in which information about concepts was sought out. In Case
Study A, the body of the session involved moving between these activities quite rapidly rather than slowly progressing from one type of activity to another. Blank (2000) adapted the learning cycle to include ongoing metacognitive judgements and monitoring – which the author referred to as ‘Status Checks’ in the adapted model. The observations of the flow of experience in Case Study A lend validity to such a model based on the frequency and influence of SMJM on the group activities.

SMJM experiences played a significant role in the flow of experience in this case study. This will become even clearer when seen in relief against the flow of experience for Case Study B. Previous research has shown that better metacognitive judgements and monitoring is associated with better conceptual understanding, deeper knowledge structures, and better academic outcomes among third-level students and pre-service science teachers (Wang et al. 1990; Anderson and Nashon 2006; Isaacs and Fujita 2006; Haidar and Naqabi 2008; Young and Fry 2008; Doganay and Demit 2011; Saribas et al. 2013). Furthermore, past research has found that metacognition can be socially shared (Vauras et al. 2003; Khosa and Volet 2014; Molenaar 2014). This is a process by which members of a group can regulate the collective activity of the group (Vauras et al. 2003). Khosa and Volet (2014) observed such socially shared metacognitive regulation among small-groups engaged in science learning tasks and Molenaar et al. (2014) found that individual members with better developed metacognition were more likely to engage in these kinds of interactions. The metacognition of one member of a group has been shown to be a key factor in the collective knowledge development of the group (Anderson and Nashon 2006).

The SMJM experiences observed in Case Study A become more significant in the light of this past literature. They are, firstly, notable for their frequency when seen in relief against some of the other case studies. It is also notable that Mairéad almost always directed the flow of experience to SMJM and was also most likely to direct the flow of experience in general. This suggests that she has a reasonably well-developed metacognition in terms of metacognitive judgements and monitoring (evidenced by the former), and also in terms of overall metacognitive strategies (evidenced by the latter). It is also important to note that, although Mairéad may have most often directed the flow to SMJM and other experiences, both Ciara and Maeve engaged well with these experiences – this latter point being the reason for such high levels of community throughout the body of the session. This suggests either the presence of socially shared metacognition, or, at minimum, the influence of one individual's metacognition (i.e. Mairéad’s) on the collective activity of the group.
(b) Relational Dialectics and the Community-Oriented Group Experience

Examining the same narratives using RDT contrapuntal analysis revealed a number of dialectical tensions within this group. In the previous section, I discussed how the group experience flowed between cycles of expressiveness and non-expressiveness. RDT studies have previously identified this as a dialectical tension. However, in this context I have discussed a *behavioural* trend rather than a relational dialectic. RDT does not refer to behaviours but the *meaning* that makes sense of these behaviours. The relational dialectics identified in the narratives created for this case study group intersect with this behavioural trend in the sense that they lend meaning that makes sense of this trend. I identified three main dialectics with the first two appearing to have the greater impact on the group experience. These dialectical tensions were as follows:

- **Should already understand – desire to learn**: this is a sub-dialectic of a wider *denial – acceptance* dialectic. It is a tension between a desire to learn and understand chemistry, and a judgement that they should already understand these concepts.

- **Openness – self-protection | closedness**: this is a sub-dialectic of a wider *expression – non-expression* tension. Openness about one’s thoughts, ideas, and opinions was in tension against both self-protection, i.e. the need to protect oneself from the potential judgements of others, and closedness, i.e. maintaining the privacy of one’s thoughts, ideas, and opinions.

- **Learner – teacher**: this is a tension between the group viewing their role as learners of chemistry subject matter and as teachers of chemistry subject matter.

**Should Already Understand – Desire to Learn**

*Should already understand* and *desire to learn* were at odds with one another in that *should already understand* meant that there was no need to consider the meaning of the concepts prior to setting about the task of creating a concept cartoon, while *desire to learn* meant that concepts should be discussed and clarified prior to undertaking the task. The *should already understand* discourse is one that is laden with judgement, i.e. one is expected to understand these concepts based on their prior learning in their STE programme, while the *desire to learn* discourse is laden with acceptance of the reality that, despite this prior learning, they do not understand these concepts and that is acceptable.

The main interplay between *should already understand* and *desire to learn* was diachronic, in which one or the other discourse was dominant depending on my presence as the facilitator (i.e. a segmentation interplay), or one or the other discourse became dominant over time (i.e. spiralling inversion). An example of the former may be seen in Excerpt I, lines 27-47. The *desire to learn* discourse had been dominant as the group had an open and honest discussion...
for some time prior to this selected segment. The *should already understand* discourse became dominant when I was within perceived earshot of the group: Mairéad was overwhelmed with embarrassment as she hid, engaged in embarrassed laughter, and so on. At that moment, Mairéad was anticipating that the ‘overheard’ group utterance, “But what’s an atom though?” would be met with my disapproval.

The more common interplay was one in which the *desire to learn* discourse rose to dominance, such that it was almost completely dominant throughout the body of the session, with a few intermittent occasions in which the *should already understand* discourse became dominant. This interplay may have resulted from a particular moment near the outset of the session. Baxter (2011) refers to experiences that alter the interplay between discourses as ‘turning points’. The turning point in question is depicted below and occurred when the group first began to work together. It corresponds to 01:50 – 2:15 of Figure 9.3.

Maeve and Ciara look to Mairéad as she states the topic area in which they are working, “So anyway, okay, we’re dealing with mixtures, compounds and elements.”

Mairéad begins to write in her notepad and Ciara and Maeve organise their personal items to prepare for the task. Mairéad enters search terms into the laptop she is sharing with Maeve. “Okay,” she says, “So, if we find out… what a compound actually is, and what a mixture actually is and what an element actually is.” She looks towards Ciara who begins to write in her notepad as Maeve leans in to look at Mairéad’s search progress on their shared laptop.

“I don’t know,” says Maeve, in a quiet voice as she pulls her jumper to cover her mouth. “I have no idea,” says Mairéad. “That’s being so honest with you… which is terrible but sure, look it.”

The important moment occurred when Mairéad suggested a strategy for approaching the task, while also making an admission of a lack of understanding to the rest of the group in an SMJM experience. She then said “I have no idea [about the meaning of the concepts]. That's being so honest with you… which is terrible but sure, look it.” Here we see the presence of both *desire to learn* and *should already understand* and the interplay is constituted synchronically. She is pointing out that it is a negative reflection upon her that she doesn’t already understand these concepts, i.e. they should already be understood, while also seeking to remedy this situation. The phrase “but sure, look it,” is something of an Irish colloquialism which is often used to end a conversation or a disagreement. In this context, Mairéad is acknowledging that they *should already understand* these concepts, but in reality they *don’t*, and there is no point in dwelling upon that. In the language of RDT, she is essentially suggesting that they entirely marginalise the *should already understand* discourse and make the *desire to learn* discourse dominant. This moment may have been central to the group’s experience of this tension, given that this represents, overall, how this tension was
constituted for the remainder of the session. This discourse underpinned much of the group experience within the Expressive Cycle of Experience.

In the secondary data, Mairéad made reference to a sense of relief at the idea of being ‘not alone’ in her confusion. This appears to relate to the *should already understand – desire to learn* dialectic. Her comments reflect a belief that she should already understand these chemistry concepts, but that she is relieved that she is not the only person that doesn’t understand.

**Mairéad:** I was surprised to find out I was not alone on my table in not knowing what exactly each of these were… I was glad to see I was not the only one confused on the topic.

She also mentioned on social media, “I was not alone in my group,” in reference to her confusion about the distinction between the concepts of compound, mixture, element, atom, and molecule. In her final reflection in her reflective journal, Mairéad highlighted this as one her main takeaway points from SuBATOMIC, “I learned from SuBATOMIC that everybody has misconceptions and it is okay to admit it.”

The *should already understand – desire to learn* dialectic has been categorised as a sub-dialectic of a *denial – acceptance* dialectic. The latter being a tension between a denial of barriers to conceptual understanding and an acceptance of barriers to understanding. This supradialectic was identified based on observations from all four case studies and it will also be discussed in the context of Case Study B. *Denial – acceptance and should already understand – desire to learn* appear similar to the *judgement – acceptance* dialectic, identified by Bridge and Baxter (1992), among dyadic friendships in the workplace, i.e. the tension between a requirement for judgement or critical evaluation in the context of the workplace, and a need for affirmation and acceptance in the context of friendship. A similar tension was noted by Kramer (2004) in a group setting (a community theatre group) between tolerance/acceptance of the behaviours of others, and judgement of the behaviour of others. The distinction between these *denial – acceptance and judgement - acceptance* dialectics is due to the fact that, although the denial of a barrier was laden with judgement (i.e. the denial occurs because the barrier *shouldn’t* be present, indicating an underlying judgement), it is not of itself a judgement or an evaluation – rather it is the avoidance of judgement. Furthermore, the judgement and acceptance noted by Baxter and Bridge, and Kramer, is directed towards another person, while in Case Study A, and the other case studies, it is directed towards the group – including oneself as a member of that group. It is possible that the *denial – acceptance* dialectic could, itself, be considered a sub-dialectic of *judgement – acceptance* or an idiosyncratic presentation of *judgement – acceptance* occurring in learning communities and there is certainly commonality between the two.
The other main dialectical tension was between a discourse of openness and one of either self-protection or closedness. This was previously alluded to when discussing how, at times, the Non-Expressive Cycle functioned as respite for the group from conceptually-heavy discussion or as an opportunity to privately revise their understanding, while, at other times, it served to hide embarrassment or lack of confidence in their conceptual understanding. This latter case being an example of the self-protection discourse at work. An example of this can also be observed in Excerpt I, lines 39-50, in which Mairéad hides her face in embarrassment and declares “Oh Jesus Christ!” in response to my being within perceived-earshot of the group, resulting in the group then briefly engaging in the Non-Expressive Cycle of Experience. This is a diachronic segmentation interplay between the openness and self-protection discourses, as self-protection became dominant only when I was within perceived-earshot, i.e. the group members sought to protect themselves from my anticipated judgement of them by retreating to low-risk discussion or private activities (e.g. looking silently at a laptop screen). The should already understand – desire to learn dialectic and the openness – self-protection dialectic formed an interconnected web, with the judgement-laden should already understand discourse creating the need for the self-protection discourse.

Their private revision of concepts at the outset of the session is made sensible through the discourse of closedness, wherein they sought at that time to maintain the privacy of their own thoughts. The Expressive Cycle of Experience is founded upon the discourse of openness, as the group openly shares their own conceptual understanding, their own thoughts on possible exemplars of concepts, and their own judgements and knowledge monitoring. In real time, the group did engage with the openness discourse and the closedness discourse in a turn-taking manner. Although this suggests the tension was constituted diachronically, this was not the case. The tension between openness and closedness was constituted synchronically in a recalibration interplay, i.e. the tension was reconstructed such that it became complementary rather than contradictory. The discourse of closedness was more commonly an opportunity to revise personal understanding or summarise previously agreed upon group understanding. This opportunity for reflection and gathering oneself, in turn, allowed the group members to engage more fully in the discourse of openness.

The openness – closedness dialectic, a sub-dialectic of expression – non-expression, is one that is commonly identified in the RDT literature on dyadic relations (Baxter 1990; Pawlowski 1998; Baxter and Erbert 1999). Interestingly, Kramer (2004) did not find evidence of this dialectic within his study on the relations in a group setting. However, Prentice and Kramer (2006) did observe a participating – remaining silent dialectic within a whole-class discussion setting. In
this case, students experienced the tension in response to instructor behaviours as well as their anticipation of how their participation would be received by other students. This *participating – remaining silent* dialectic was not identified by Prentice and Kramer (2006) as being associated with the supra-dialectic of *expression – non-expression*. However, it does appear to be such, as it lends meaning to reasons why students engage in expression or do not engage in expression in their behaviours. In Case Study A, the term *openness – closedness* has been used; however, this is more a reflection of the behavioural condition of expressing themselves openly or not expressing themselves. It is possible that the meaning which makes sense of this behaviour was that of, or similar to, the participating – remaining silent dialectic. The *openness – self-protection* dialectic has also been noted in past research (Baxter 2011, p. 74). Baxter notes that “in enacting discretion, parties can protect one another’s face and sustain their often fragile social connection.” There is strong evidence for this in Case Study A.

**Teacher - Learner**

The tension between the teacher discourse and the learner discourse did not appear to have a significant impact on the group behaviour or experience in this case study. However, I did observe that at the outset and body of the session, the learner discourse was dominant over the teacher discourse. This was evidenced by their discussion of the meaning of concepts as *learners* of those concepts, rather than discussing them in the context of a teaching scenario or their merit amongst students. This can be seen throughout all of the excerpts. However, they did occasionally adopt the teacher perspective when they attempted to apply the understanding which they had developed to creating a concept cartoon. An example of such a moment can be seen in Excerpt II, where the group adopts the perspective of teachers creating a teaching resource. There is some indication in Excerpt II, taking into account that it flows from the context of Excerpt I, that learner and teacher perspectives might be constituted in a complementary way: once they have, as learners, understood the concepts, they can then apply them as teachers. However, there is insufficient evidence in the case study to fully support this possible interplay.

The teacher discourse became dominant over the learner discourse towards the end of the session, as the group focused upon creating the concept cartoon. As such there was generally a diachronic interplay between the discourses wherein initially the perspective of a learner was dominant and over time, the perspective of a teacher became dominant (i.e. spiralling inversion interplay). However, this interplay was largely the result of the time constraints of the session and is not necessarily a true reflection of how the tension between teacher and learner perspectives was constituted for this group. The turning point in this interplay may
be seen in Excerpt VII, lines 31-34 (reproduced below), and it demonstrates the central role of time constraint in constituting this interplay.

Mairéad then takes control of the situation and ends the conversation. “Okay. Okay. We will think about our cartoon, because…” she says with the laughter and the rest join in. “We could be going around like this all day,” agrees Ciara.

The group begin to prepare their materials to begin drawing their concept cartoon.

This tension has not been previously noted in the literature and is likely unique to learning groups and among pre-service teachers (and others who formally adopt a teacher role). This tension will be further explored in Case Study B where it was better defined and had a stronger influence on the overall experience of the community-oriented group.

(c) Relational Dialectics and Conceptual Discourses
I am going to focus upon three conceptual tensions, the first two of which are deeply related. These conceptual tensions are:

1) compound and molecule are mutually exclusive concepts (alternative discourse) – a molecule is a group of two or more atoms joined chemically together (scientifically-acceptable discourse),

2) all compounds are molecules, but not all molecules are compounds (alternative discourse) – some compounds are molecules and some are not molecules (scientifically-acceptable discourse),

3) the terms element and atom are synonyms (alternative discourse) – an element is composed of atoms of the same type, which are entities made up of electrons, protons and neutrons (scientifically-acceptable discourse).

The first two of these tension-filled discourses are highly related in terms of the concepts and also in the way that they were introduced over the course of the session. I will focus on the first two tensions together and then upon the last tension.

CONCEPTUAL DISCOURSES ABOUT THE DISTINCTION BETWEEN COMPOUND AND MOLECULE
The phrase “all compounds are molecules, but not all molecules are compounds” was introduced from a web-based resource by Ciara. However, the meaning which the group attributes to this phrase is that compound and molecule are mutually exclusive concepts (Excerpt I, lines 2-13). Throughout the early group discussions, this idea is represented by phrases such as: ‘a molecule can be H₂ or O₂, but then a compound is a mixture of any of them,’ ‘a molecule has to be same elements coming together. A hydrogen and an oxygen coming together is a compound,’ and ‘when two of the same thing come together that’s a
molecule.’ Also, within the context of the discussion, phrases such as ‘H₂ is a molecule,’ and ‘H₂O is a compound,’ are also examples of the discourse surrounding this alternative conception. The opposing discourse which is more scientifically-acceptable is that a molecule is a group of two or more atoms joined together, meaning that either an element or a compound can be composed of molecules. This scientifically-acceptable discourse is initially only represented by definitions read aloud from the web. These discourses are contradictory. However, this contradiction is not made explicit as no member of the community-oriented group adopts the scientifically-acceptable discourse at any point in these early discussions, as represented in Excerpt I. Therefore, this tension is constituted in a hidden, indirect manner. The alternative discourse has complete dominance in the community-oriented group throughout Excerpt I, with the scientifically-acceptable discourse being completely marginalised. The group never discusses the meaning of the definitions they introduce and maintains the dominance of the alternative discourse.

The alternative discourse is discussed at some length within the Expressive Cycle of Experience, while a discussion of the scientifically-acceptable discourse is hindered. Discussion of the latter doesn’t take place as both times a scientifically-acceptable definition is introduced from the web, the group diverges to other experiences. The first time a definition is introduced by Ciara in Excerpt I, lines 31-32, the group engages in an SMJM experience. Frustration is a central characteristic of this experience (lines 33-34). This flows into Ciara also sharing a judgement of her personal understanding of a concept but it is about a concept tangentially related to the discussion (lines 35-38). At this moment, desire to learn is dominant but should already understand has a hidden presence as evidenced by Ciara’s nervous laugh and perhaps even Mairéad’s frustration. Openness is dominant over closedness or self-protection. The reason for the lack of discussion appears to be the introduction of the concept of atom. The second time a definition is introduced by Mairéad (Excerpt I, lines 48-49), it is followed by the re-introduction of the Non-Expressive Cycle of Experience as they share information about the web resources which they are using (lines 50-51). However, this occurs as a result of the experiences preceding it (lines 39-47). The group reaction to my perceived-presence demonstrates the dominance of the should already understand discourse, which, in turn, results in the dominance of the self-protection discourse. This underpins the avoidance of the discussion of the scientifically-acceptable discourse.

However, the alternative discourse is discussed within the Expressive Cycle of Experience throughout Excerpt I. Desire to learn entirely dominates over should already understand, and openness dominates over the self-protection or closedness discourses at these times. We also see SMJM experience in which frustration is a characteristic, but a PPM experience conveys that
the conceptual discussion should be continued (Excerpt I: lines 4-6), i.e. desire to learn dominates PPM and the PPM comment conveys this discourse to other members of the community-oriented group. It is important to note that the result of the differences in treatment of these conceptual discourses is that the tension between them is constituted in an *indirect*, antagonistic interplay: the alternative discourse and the scientifically-acceptable discourse never directly or explicitly delegitimize one another.

Once I join the group for a protracted period of time (depicted in Excerpts IV, V and VI), this particular alternative discourse does not arise again. However, the scientifically-acceptable discourse forms a part of the tension between the discourses of ‘all compounds are molecules, but not all molecules are compounds’ and ‘some compounds are molecules and some are not molecules.’ Initially, a significant amount of time is spent discussing the group understanding as it stood at that point (depicted in Excerpt IV). Towards the end of this discussion, the experiences depicted in Excerpt V occurred. The group reintroduced the phrase ‘all compounds are molecules, but not all molecules are compounds’ but on this occasion attributed to it the literal meaning of the phrase. In response to this I say, “That’s true,” (line 10), not having thought through the implications of this statement. This proves to be a turning point in the tension between these discourses as I will show in a moment. After that point, I went on to explain the meaning of the concepts introduced and this is depicted in Excerpt VI. During this explanatory portion, the scientifically-acceptable discourses are given complete dominance. The alternative discourses exist only in an indirect, hidden manner, in that I am refuting them without ever giving them voice. Both the alternative and scientifically-acceptable discourses in this case arose within Non-Expressive Cycle Experiences. The alternative discourse arose as a repetition of the phrase “all compounds are molecules, but not all molecules are compounds” and the scientifically-acceptable discourse arose as the group listened to me while I voiced this discourse and delegitimated the alternative discourse. The discourses within the experience of the community-oriented that were dominant in this discussion were *closedness,* and *desire to learn.* However, it is the turning point that is particularly notable in these experiences.

The group’s final discussion of these concepts is represented in Excerpt VII. The tension between the discourses of ‘compound and molecule are mutually exclusive concepts,’ and, ‘a molecule is a group of two or more atoms joined together’ appears to be one in which the alternative discourse has been completely marginalised, as Mairéad notes that water is both a molecule and a compound. However, there may now be some confusion about whether
the terms compound and water are synonyms. In relation to the second tension between the discourses of ‘all compounds are molecules, but not all molecules are compounds,’ and, ‘some compounds are molecules and some are not molecules,’ Ciara re-introduces the alternative discourse that ‘all compounds are molecules, but not all molecules are compounds’ (lines 10-11). This is challenged by the scientifically-acceptable discourse as Mairéad notes that salt is a compound but not a molecule (line 16). This tension is constituted in a direct, antagonistic struggle in which both discourses are present and challenge one another’s legitimacy. In this antagonistic struggle, we see the impact of my earlier words, ‘that’s true,’ which I consider a turning point in the tension between these discourses. Note how the alternative discourse is largely filled with repetitions of the phrase which I inadvertently legitimated earlier in the session (lines 10-11, 18 and 20-21). The support for this discourse is largely its repetition verbatim on three occasions, accompanied by the conviction that, “that’s right.” However, the scientifically-acceptable discourse relies upon an example that refutes the alternative discourse (lines 16 and 19). Both of these discourses have been legitimated by me earlier in the session and it seems likely that this is the reason why there is, ultimately, no resolution. Mairéad does not appear convinced by the alternative discourse, though Ciara and Maeve do appear to be convinced by it. At the end of the excerpt (lines 23-34), the tension is constituted ambiguously; it is dealt with ambiguously as the group decides to simply move on, resulting in everybody considering themselves correct in their thinking. This type of ambiguous interplay is often referred to as a neutralisation interplay (Baxter 2011). This final discussion occurred within the Expressive Cycle of Experience. The discourses of desire to learn and openness dominated in the group during this discussion. The dominance of these discourses appears to support the direct, antagonistic struggle between the conceptual discourses earlier in the excerpt. The discussion is ended without resolution as a result of the ‘that’s true’ turning point and, possibly, the time constraints of the session. It is possible, even likely, that the tension between these two discourses would have ultimately been one in which the scientifically-acceptable discourse became dominant were it not for the presence of this turning point.

**Discourses about the Distinction between Element and Atom**

The tension between the discourse of ‘element and atom are synonymous terms,’ and that of ‘an element is composed of atoms of the same type,’ began to arise early in the session (possibly towards the end of Excerpt I) but became much more explicit after this point, as

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178 I will not discuss this further as this particular discourse is only expressed in a single line of the narratives.
shown in Excerpt III. The scientifically-acceptable discourse of ‘an element is composed of atoms of the same type’ arises in opposition to this alternative discourse. Initially, the alternative discourse has dominance (Excerpt III, lines 1-20) before the tension between the discourses becomes constituted in a direct, antagonistic struggle; the discourses are made explicit and are presented in opposition to one another (lines 22-34). During this direct, antagonistic struggle between the discourses at the group-level, the scientifically-acceptable discourse begins to dominate, while the alternative discourse is marginalised. This is quite clear as Maeve appears to continue to align with the alternative discourse, but this discourse is ignored, in favour of the scientifically-acceptable discourse (lines 33-54), i.e. by the end of the discussion the tension is constituted by disqualification.

This discussion takes place within the context of the Expressive Cycle of Experience, with the Non-Expressive Cycle of Experience appearing to provide moments of respite from the conceptually-heavy discussion. In terms of the dialectical tensions, openness appears to be entirely dominant over either closedness or self-protection, while desire to learn entirely dominates over should already understand. These discourses support the direct, antagonistic interplay between the conceptual discourses. SMJM experiences that convey frustration are present in this discussion, as they were in the previous discussions related to molecule and compound. However, the distinction is that rather than resulting in closedness, self-protection or should already understand rising in dominance, they result in short breaks from the conceptual discussion rather than an ending of the discussion. This is a product of the reframing interplay between openness and closedness.

Once I join the group, Maeve informs me that they don’t understand the difference between element and atom. This is depicted in Excerpt IV. Maeve continues with the alternative discourse, while Mairéad presents the scientifically-acceptable discourse. At this stage, I neither explicitly refute nor legitimise either discourse, instead allowing the discourses to simply be expressed by each group member. As such the tension is constituted in an ambiguous way. Once I begin to explain the meaning of element and atom in Excerpt VI, the alternative discourse becomes entirely marginalised, as I refute it with the scientifically-acceptable discourse. At this stage, the discourse appears to become even more dominant within the group, as Maeve too appears to marginalise the alternative discourse (Excerpt VI: lines 9-10). Initially, openness, and desire to learn are dominant in the element-atom discussion. The tension between these concepts at this point is ambiguous as Mairéad and Maeve appear to be making statements which are similar but to which they are attributing different meanings (Excerpt IV: lines 4-14). The alternative discourse, eventually, is explicitly given voice by Maeve (Excerpt IV: line 33) and this occurs on upon a backdrop of openness and
desire to learn discourses. My delegitimisation of the alternative discourses and the dominance of the scientific discourse occurs within the Non-Expressive Cycle (Excerpt VI).

The final reference to these discourses about element and atom was brief and it appears that the scientifically-acceptable discourse was simply re-iterated and accepted (Excerpt VII: lines 4-5). This suggests the continuing dominance of the scientifically-acceptable discourse regarding element and atom. However, the direct, antagonistic interplay between these discourses in the group, followed up by my delegitimisation of the alternative discourses appears to have been key in the ultimate dominance of the scientifically-acceptable discourse.

Comparing the interplay of discourses reveals that the antagonistic struggle between scientifically-acceptable and alternative discourses was central to the occasions in which the scientifically-acceptable discourses became dominant among the group. The presence of the noted turning points was also important to the final interplay and shows that turning points may determine how the group experiences conceptual discussions.

The alternative conception that ‘all molecules are compounds’ has been previously noted among third-level learners (Stains and Talanquer 2007) and PSSTs (Kahveci 2009). Papageorgio and Sakka (2000) also identified the alternative conception that the terms element and atom are synonymous. However, the idea that the concepts of molecule and compound are mutually exclusive was not identified by any of the studies located using the literature review method noted in Section 2.1. However, the value of this case study is in demonstrating the experience of addressing the issue of alternative conceptions using RDT as a sensitising theory. Past research has not taken this approach.

The positive outcome associated with a direct, antagonistic interplay between conceptual discourses over and above an indirect, antagonistic interplay between the discourses leads to a reflection upon the long-held suggestion that it is necessary for learners’ alternative conceptions to “be directly confronted” (McDermott 1984) and that “new knowledge should be explicitly contrasted with prior knowledge” (Labudde et al. 1988). This case study demonstrates that even when such conflict between scientifically- and alternatively-conceived ideas occurs, it does not necessarily lead to the adoption of scientifically-acceptable conceptions. In Case Study A, a turning point was observed which undermined this process. In other case studies, the interplay between dialectical tensions within the group experience also undermined this process. Case Study A demonstrates that direct, antagonism is an essential element but, in combination with other case studies, it also demonstrates that it is not the only essential element – an interplay between relational dialectics within the wider community-oriented group that is favourable to positive attitudes and behaviours towards
learning is also essential. In this case study, that favourable interplay was one of recalibration of the openness – closedness dialectic, and dominance and marginalisation of desire to learn and should already understand, respectively.

**SUMMARY OF MAIN FINDINGS**

There are a number of important observations related to the experience of the community-oriented group in this case study. The importance of these observations will become clearer as seen in relief against Case Study B. The main observations to note are:

- the disqualification interplay of the should already understand – desire to learn dialectic and the reframing interplay of the openness – closedness dialectic supported the group in engaging productively with the Expressive Cycle of Experience;

- SMJM experiences were common and in some cases proved to be central to the experience of this learning group, as noted in relation to the turning point in the should already understand – desire to learn dialectic;

- the presence of a direct antagonistic struggle between conceptual discourses appeared to be the most beneficial for the group in terms of addressing their alternative conceptions. The desire to learn and openness discourses were dominant at these moments in the group;

- the presence of a turning point determined the manner in which tensions were constituted in this group.
9.3 CASE STUDY B
This case study focuses upon four SuBATOMIC participants, three females and one male. Michael and Aoife sat at one side of the table. Michael had his laptop open in front of him, while Aoife mostly made use of her personal notepad. She also took out her mobile phone during the session and used it for searching and reading conceptual information. During the session, Michael was also seen to use his mobile phone; however, he appeared to be responding to text messages. Bríd and Una sat on the other side of the table. Bríd was directly opposite Michael, and Una was directly opposite Aoife. Una had her laptop in front of her. This case study took place within the context of the Cooperative Learning Part 1 of the SuBATOMIC learning programme. The focus in this session was upon preparing an explanation of the conceptual area of covalent bonding that would be suitable for their peers.

This group did attempt to form a learning group; however, during much of the session, Michael and Una appeared to favour spending time searching for and repeating definitions as their main strategy. They did not appear to want to, or perhaps were unable to, participate in discussions of their personal understanding of concepts. Bríd and Aoife were more favourable towards discussing their personal understanding of concepts. There tended to be an unspoken but competing approach to completing the task as a result of this. However, all members of the group seemed comfortable when it came to discussing their personal understanding with the pedagogical arena. Where discussion was sustained among most or all members of the group, it tended to be when discussing a pedagogical approach rather than their conceptual understanding.

(a) Flow of Experience
A breakdown of the percentage of primary data categorised at each Community Goals code and Levels of Community code is provided in Table 9.6. This community-oriented group spent approximately 35% of the session engaging at high levels of community and a similar amount engaging at middle-level community experiences. Compared with Case Study A, they spent more of the session engaging at middle-levels of community and less time engaging at high-levels of community. They were also more inclined to engage with Off-Task experiences compared to Case Study A. Of particular note in Case Study B is the proportion of time engaged in PPM experiences, being almost twice as high as that for Case Study A, and engaged in SMJM experiences, being almost half that for Case Study A.
Table 9.6 Breakdown of coding for Case Study B as a percentage of duration

<table>
<thead>
<tr>
<th></th>
<th>% at Low-Levels of Community</th>
<th>% at Mid-Levels of Community</th>
<th>% at High-Levels of Community</th>
<th>Goal as % of Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application of Understanding (AU)</td>
<td>1.66%</td>
<td>19.21%</td>
<td>79.13%</td>
<td>11.90%</td>
</tr>
<tr>
<td>Developing Understanding (DU)</td>
<td>55.62%</td>
<td>25.60%</td>
<td>18.78%</td>
<td>44.29%</td>
</tr>
<tr>
<td>Off-Task</td>
<td>16.16%</td>
<td>7.68%</td>
<td>76.16%</td>
<td>10.67%</td>
</tr>
<tr>
<td>Practical and Pragmatic Matters (PPM)</td>
<td>1.73%</td>
<td>77.74%</td>
<td>20.54%</td>
<td>27.53%</td>
</tr>
<tr>
<td>Sharing Metacognitive Judgements and Monitoring (SMJM)</td>
<td>2.52%</td>
<td>50.45%</td>
<td>47.03%</td>
<td>5.62%</td>
</tr>
</tbody>
</table>

Total Duration                        | 27.17%                       | 38.67%                       | 34.15%                       |                      |

Figures 9.6 and 9.7 provide the visual representation of the flow of experience for this community-oriented group and Figure 9.8 provides a representation of the patterns I observed in the flow of experience. Like Case Study A, this group tended to flow between an Expressive and a Non-Expressive Cycle of Experience. There are two important distinctions to note about the flow of experience in Case Studies A and B:

- SMJM does not feature in either cycle of experience in Case Study B. This is because the narratives demonstrated that these experiences did not influence the flow of experience for the group; SMJM experiences were, essentially, ignored by the group at large.

- In Case Study B, the Non-Expressive Cycle formed the body of the session, with the Expressive Cycle being intermittently engaged in for brief periods of time. This is opposite of the pattern observed in Case Study A.
Figure 9.6 Flow of Experience for Case Study B (Part 1)

Figure 9.7 Flow of Experience for Case Study B (Part 2)

Legend for Flow of Experience Diagrams

- Community Only
- Community-Facilitator
- Developing Understanding (DU)
- Application of Understanding (AU)
- Practical and Pragmatic Matters (PPM)
- Off-Target (OT)
- Sharing Metacognitive Judgements and Monitoring (SMJM)
- Multiple Goals (Mult)
Figure 9.8 Patterns in the Flow of Experience for Case Study B

SMJM

PPM

Middle-level DU

Low-level DU

Non-Expressive Cycle

Expressive Cycle

High-level DU

High- and Middle-Level AU

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EXCERPTS FROM THE NARRATIVES

The following excerpts are grouped together according to the conceptual discussion taking place in the community-oriented group. Within that grouping they are presented in chronological order and the time stamps corresponding to Figures 9.6 and 9.7 are provided at the outset of each excerpt. The full set of narratives may be found in Appendix J. Excerpts I, II, III and IV depict experiences in which the group was focused upon addressing the concept of polarity. Excerpts V, VI, and VII relate to their views on the impetus for bonding.

Excerpt I

This excerpt depicts time stamp 8:20-12:45 of Figure 9.6.

Michael and Una look at their laptops, as Aoife tucks a piece of hair behind her ear and suggests, “You’d have to say what polar is first wouldn’t you?” Brid agrees with her and attempts to explain polarity before she is interrupted by Una.

“This is the only thing they say… about non-polar and polar,” says Una. Brid looks at the laptop screen agreeing that it doesn’t say much on the topic. “We’ll try the next one,” says Una. She and Michael search and read from their laptops for a moment before she reaches for the task sheet in the centre of the table. Aoife and Brid stare into space and Michael continues to look at his laptop screen, while Una flicks through the task sheet. After a few moments she says, “Where do you even start like?” before proceeding to enter in a web address. Aoife and Brid are waiting for their peers as they gaze in an unfocused way upon the laptop screens or table and Aoife takes out her mobile phone to search for information. Una asks Michael whether he has looked up a particular webpage and he confirms that he has.

“I’m looking for non-polar covalent bonds,” says Michael, “and I’m getting… jack”. After some time, Michael finds a definition that he thinks may be useful. As he speaks Una and Aoife continue to look at their devices and Brid looks at him. “Non-polar covalent bonds form when the electronegativity values are very similar.”

Una looks up from her laptop having recalled something but is interrupted by Michael, “Isn’t it something to do with, isn’t it—”

“—Okay,” he says, “This is a polar bond definition first I think we should go with yeah?” He looks up at Brid who agrees that is a good idea. Una also agrees. After a moment of the group looking at their devices Michael says, “This is the definition of a polar, okay. ‘A polar bond is a covalent bond between two atoms where the electrons forming the bond are… polar molecules’, he says looking up at Brid. “That’s what it says here. chemistry-dot-about-com.” Una and Aoife continue to look at their devices.

“That doesn’t really explain it though,” says Brid and Michael agrees. “It just says it’s polar, like.”

“Let’s see if I can open it up a bit more,” says Michael.

Brid makes a suggestion and Aoife looks up as Michael and Una look at their respective laptops, “Could you just say that the electrons in the bond are more, are am, attracted to one side of the bond?”

“Yeah,” agrees Aoife, adding that, “They’re unequally distributed.”

“Yeah, like partial negative and partial positive,” says Brid.

Michael jumps into the conversation cutting off something Aoife was about to say, “Okay so here we go. This is the definition. ‘A polar bond is a covalent bond between two atoms where the electrons forming the bond are unequally distributed.’” Aoife and Brid agree and
Aoife begins to write in her personal notepad while glancing at her mobile phone. Michael continues, “This causes the molecule to have a slight electrical dipole… moment, where one end is slightly positive and the other is slightly negative. Polar bonds are the dividing line between covalent bonding and pure ionic bonding. Examples: water is a polar bonded molecule.”

After a moment looking at their devices again, Bríd suggests, “Should we draw out water?” “It’s a bit heavy though isn’t it?” asks Michael as he looks at Aoife. “Yeah I think it is,” says Una as she continues to look at her laptop screen. “It’s very long,” says Bríd, “But at the same time, it’s explaining to us not to students” “If you had a, like—“ starts Una as she turns her attention towards Bríd and Michael. “We can just put it into our own words sure,” says Aoife looking up from her mobile phone and notepad. “Yeah,” says Una, “If, even a picture or something would be…”

Aoife, Una and Michael return their attention to their devices as Bríd adds, “It does make sense. It’s just very long-winded like.” “Yeah, I totally tuned out,” says Una with a wave of her hand. The group members return to looking at their respective devices for a moment. Aoife, looking at her phone, says, “See that goes on to talk about dipole moments.” She lifts her head to look at Michael and Bríd, and Una gives her attention to the conversation, “So that means we’d have to explain dipole moments as well.” Michael agrees with her.

“Yeah,” says Bríd, “and then you’d have to go on to, like, electronegativity—“ “It does highlight all those words,” says Michael, “like covalent bond, atoms, electrons, and dipole.” The other three group members all listen. “Maybe just to have a look and see does it give us any images?” Bríd agrees with him.

Excerpt II

This excerpt depicts time stamp 13:30-15:20 of Figure 9.6.

“Is there a chemistry for dummies?” asks Michael, looking up from his laptop. Aoife smiles weakly at him though neither Bríd nor Una react. “Don’t take it personal,” he says, “I’m talking about myself here.” Aoife returns to taking notes and Michael looks back to his laptop. Bríd picks up the task sheet, apologising to Una who must move to give her access, and flicks through it while the other group members continue for some time to look at their devices.

Eventually Aoife looks up and Bríd says, “It’s a good definition if you just kinda break it down and not use all the words, say.” Aoife agrees that it would good if they could break down the definition. After a few moments of looking at their devices, Bríd suggests, “Non-polar covalent, could you just say it’s distributed equally like?” Nobody responds to her as they continue to look at their devices.

Michael looks up from his laptop. “So, so where are we going with this then?” he says, indicating the notes that Aoife has taken. “What’s the next question there Bríd?” he asks. “The non-polar covalent as well… you have to explain that too,” she says as Michael and Aoife give her their attention. “Well for that you could just say the electrons that are in the bond are distributed equally. There’s no partial charge.” Michael leans back in his chair and says, “We need something like an image don’t we. I might just put in images of covalent bonds.”
**Excerpt III**

This excerpt depicts time stamp 19:30-21:10 of Figure 9.7.

A definition catches Michael's eye and Aoife joins her voice to his towards the end of the
definition, “There’s a very simple… a covalent bond ‘a bond formed between two or more
atoms by a sharing of electrons.’” Aoife takes her seat while Michael remains standing,
looking at Una and Bríd who return the look.

“Yeah,” says Bríd smiling, “That’s like what we have.”

“That’s very straightforward, isn’t it?” says Michael. Brid and Una agree with him that it is a
good definition. They look down at their devices and books for a moment.

“Sharing of electrons,” repeats Una.

Michael considers how this definition fits in with their previous conversation, while Una and
Aoife give their attention to their laptop/book, “Am… if I look up… do we need to go
down the route of dipole and that with that definition? That explanation?”

“With that explanation that you called out there?” asks Una, as she looks up and then shakes
her head to say ‘no.’

Aoife looks up from her book at Michael. “But you see we have to explain polar then and
dip—, with polar then you kind of have to explain dipole.”

“Yeah,” agrees Bríd nodding her head. Una and Aoife returning to look at their laptop/book.

“Well let’s see what it says about polar,” decides Michael. He realises that it may take him
some time to find that definition in the book as he says, “But then… I guess polar could be
anywhere.”

Each group member looks at their respective devices or books. Bríd offers her own thoughts
on the meaning of polarity, “Like, polarity just happens when the electrons that are being
shared aren’t shared equally.” Aoife murmurs some agreement but neither she nor Una look
up from their laptop/book.

“Okay. This is a polar **covalent** bond,” says Michael who, still standing in place, has found a
definition.

Una momentarily interrupts as she has also found a definition, “It’s a covalent—.” She
realises that Michael is speaking and gives her attention to him.

“The ease with which an electron… cloud of an atom or a molecule is distorted by an outside
influence…”

“No,” says Una, quickly dismissing the definition, and turns back to her laptop.

“…thereby introducing a dipole moment,” finishes Michael.

Una introduces a definition that she has found on the internet and Michael gives her his
attention, “I have one here. I have one that it’s ‘a covalent bond in which the shared pair of
electrons is attracted more to one of the joined atoms than to the other.’”

“Yeah,” says Brid, “H-Cl is a good example of that actually.” Michael looks between Brid
and Una, appearing somewhat lost, as they continue to talk. “In that case, Cl is one type, is
partially negative ‘cause the electrons are—“

“So it’s attracted to… depending on the polarity,” says Una, leaning back and dismissively
waving her hand.

“Yeah.”

“It’s attracted to one.”

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**Excerpt IV**

This excerpt depicts time stamp 32:50-33:15 of Figure 9.7.

“Back to the drawing board lads,” says Bríd wryly and rubs her eyes. Michael looks up momentarily as Una begins to speak, “I think we should just kind of get an example, two examples, one of polar…” “One of non-polar, yeah,” says Aoife. “And then just work with those two for the whole thing,” says Una as she looks towards the other group members. Bríd nods her head in agreement and, as she gestures towards the notepad I was previously writing on, says, “So we could just use that one for the polar example.” Una and Aoife agree with this and Aoife begins to write in her notepad. “We could just, like, take O-two or something,” she says and after a moment adds, “cause a diatomic molecule is non-polar.”

**Excerpt V**

This excerpt depicts time stamp 15:25-16:35 of Figures 9.6 and 9.7.

“Am… ‘why do atoms form covalent bonds’”, says Bríd as she reads from the task sheet, “The clue is energy ‘check out relevant website section.’” Bríd looks up from the task sheet to Aoife and back again. “Why do atoms form covalent bonds?” she says and after a moment comes up with a response “cause they want to have a full outer shell.” “Yeah,” agrees Aoife. Michael and Una continue looking at their laptops. As Aoife starts to write this down, Michael looks up from his laptop asking, “Should I have a look at images of covalent bonds? Maybe that would spark something would it?” Aoife stops writing, and Michael and Bríd give her their attention. “Do we have to have this all typed up and printed out like?” she says. “I don’t know. I, I don’t know,” says Michael before he returns to looking at his laptop. Una looks up from her own laptop and turns to Bríd as she scratches her head. “What are we looking for a definition of?” For the next one now, it’s ‘why do atoms form covalent bonds?’” says Bríd. Una starts to enter search terms on her laptop and Aoife returns to writing notes in her notepad. Michael continues to look at his laptop. “Can they just be put in our words or do they have to be proper definitions?” asks Bríd. Aoife looks up from her writing, “I’d say they could be put in our words.” Una contributes to the conversation with a definition on the web. She leans back in her chair as she reads aloud and the other group members give her their attention. “Covalent bonding takes place. It’s the easiest way for all the atoms to get a noble gas configuration is by gaining electrons.” She turns towards Bríd as she finishes reading. “Yeah,” say Bríd and Aoife in unison, and Bríd nods her head. Michael leans forward toward Bríd and brings the palms of his hands up to meet each other. “There has to be a simpler way,” he says. He stays this way looking between the other three group members as they continue talking. Aoife points at Una’s laptop as she says, “That’s to become more stable though, like.” “Yeah,” agree Bríd and Una. “Pretty much like… to get a full outer shell,” says Aoife. “I think I like that one,” says Una. Bríd says, “They want to have, like, eight electrons in the outer shell.”
Una adds to Bríd’s statement. “And they get them by getting them ‘on loan,’” she says, making a quotes gesture. She leans back in her chair again and extends a hand to her laptop. “Like I’m taking that right off of that.” Aoife writes in her personal notepad, while Michael continues to sit with palms together looking around at the other group members.

Excerpt VI

This excerpt depicts time stamp 22:10-23:35 of Figure 9.7.

Brid lets out a yawn and then sits forward in her chair. “Is it just definitions we’re giving or are we supposed to go into more detail after then?” she asks as she and Michael look at each other. She clarifies, “Like not extreme detail but brief kind of like explaining.” Una puts away her phone and leans forward in her chair, while Aoife continues to write.

Michael sneezes and all of the other group members offer him a, “Bless you.” Someone sitting at a different group gently teases Michael.

He then responds to Bríd’s previous contribution. “Am… so do we need to get the definitions first and then… present it, or teach it, then?” Aoife has stopped writing and is listening to Michael. Bríd and Una are also giving him their attention.

“Yeah. I think we should,” says Bríd. Aoife also agrees with her, before returning her attention to her book. “Like you can’t… if you’re in a group of students you can’t just tell them, you have to say, like, why this happens.” Una nods her head in agreement with Bríd.

“Cause you’re bringing this to the next group, right,” says Michael. You’re the expert in covalent bonding. So we should have… some kind of structure or some kind of…” Bríd and Una agree with him.

“Covalent bonding goes on to…” says Una gesturing a sequence with her hand.

Michael takes up her train of thought. “Covalent bonding goes on to this, goes on to this, goes on to this. So each question should lead into the next one shouldn’t it?”

“Yeah,” agrees Bríd. Una returns her attention to her laptop.

“I, I, I… maybe I’m wrong,” says Michael.

Una turns to Bríd, “Are they leading into the next…?”

“They’re all linked though, like,” says Bríd in response. Una returns her attention to her laptop.

“So… we should be all in agreement of what a covalent bond is,” says Michael. “We should all be taking that definition to the next table.” Aoife looks up from her book, using her finger to hold her place.

“Yeah cause we’re all going to be saying the same,” agrees Bríd.

“So should we all be taking down the stuff?” wonders Bríd.

Aoife jumps into the conversation to read aloud a definition she has found, as Michael and Bríd give her their attention. “It says here, it’s just really simple as well. The chemical bond formed by sharing a pair of electrons is known as a covalent bond.”

Brid and Michael nod their approval. Michael adds, “I would go with simplicity more than…”

“If we start off saying that and then build it up,” suggests Bríd and Aoife agrees.

“I think then we should explain the octet rule,” says Aoife, looking between her notes and Brid and Michael, “because then you have to say why they bond. To form eight d’you know.” Michael turns around in his chair to retrieve his notepad from his bag, while Aoife returns her attention to her book.
“Why do two ions form a bond?” I ask, looking around at the group who are giving me their attention. After a moment, I answer my own question. “So one is plus and one is minus, so it’s a force of attraction between the two.” I then take an oxygen molecule as an example of a covalent bond and I hold each hand out in front of me to represent each oxygen atom. “So what you have is that each one has a nucleus which is positive and electrons which are negative. So, what’s happening really is that the electrons from this atom,” I say, as I gesture to one hand, “while they are attracted to their own positive nucleus, also become attracted to this, ah, nucleus of the other atom. So that’s why they actually end up sharing. Okay?” I pause for a moment and the group members nod their heads.

**Expressive Cycle of Experience**

In this case study, the Expressive Cycle of Experience comprised high-level DU experiences, and high- and middle-level AU experiences. Where this cycle was present, the experience of the community-oriented group flowed from DU to AU to DU experiences, and so on. However, experiences that have been categorised as within the Expressive Cycle were rare in this case study. Occasions when these experiences actually formed a sustained Expressive Cycle were even rarer. It was more commonly the case that the experience was ended prematurely, usually as a result of a group member interrupting to re-establish or maintain the continuation of the Non-Expressive Cycle.

High-level DU experiences were often categorised as high-level given that they occurred as part of a wider interaction that involved other Community Goals (as opposed to meeting the criteria for a high level of community in their own right). For example, in Excerpt III, the DU experience at lines 38-41 involves only a single group member sharing her personal thoughts. However, this takes place as part of a wider interaction represented by lines 24-41 (and beyond), in which both Una and Bríd share their personal thoughts – with Bríd applying her understanding to develop exemplars. Similarly, at the beginning of that interaction, Michael reads a definition aloud as does Una (lines 28-29 and 33-34). A definition from an outside source does not constitute someone’s personal thoughts. However, this was also categorised as high-level given that it is part of the wider interaction. High-level DU experiences in this case study involved reading a definition aloud about as often they involved expressing one’s personal understanding of a concept. This conveys much about both the depth of conceptual discussion and the comfort-levels of the group members in discussing the meaning of concepts. Perhaps it also conveys that the group lacked confidence in the accuracy of their conceptual understanding.
Middle-and high-level AU experiences typically involved those in which the community-oriented group focused upon applying:

- syntactical understanding of covalent bonding to devising a suitable explanatory sequence (e.g. Excerpt III: lines 9-16),
- pedagogical understanding of explanatory techniques to suggesting suitable techniques for explaining a concept (e.g. Excerpt II: line 17),
- general pedagogical understanding of clarity of explanation to discussing the explanatory power of definitions (e.g. Excerpt II: lines 7-8), and
- conceptual understanding of chemistry to suggesting and/or discussing conceptual exemplars (e.g. Excerpt IV: lines 7-10).

More often than not, high-level AU experiences formed part of an extended Expressive Cycle of Experience. In the remainder of cases, the experience was ended prematurely before an extended cycle could occur. Middle- and high-level AU experiences accounted for a higher proportion of the audio-visual data than high-level DU. It is interesting to note that all of the high-level DU experiences in these narratives focused upon the expression and/or development of understanding of chemistry concepts. However, it was pedagogically-oriented knowledge and understanding that was most often applied in the AU experiences, rather than understanding of chemistry concepts. This, in combination with the low duration of high-level DU experiences and the scarcity of occasions in which group members expressed their conceptual understanding within these high-level DU experiences, suggests that the group was uncomfortable with holding in-depth discussions about chemistry concepts in the context of either developing or applying their understanding. In the few cases where an AU experience focused upon the application of conceptual knowledge, these occurred as part of an extended Expressive Cycle of Experience.

Extended Expressive Cycles were rare. However, one example may be observed in Excerpt III. Just prior to this excerpt, the community-oriented group was engaged in a Non-Expressive Cycle of Experience as Michael and Aoife obtained books that had been stacked near the top of the room by me for the pre-service science teachers’ use (depicted in Figure 9.7: 18:05-19:25). They also spent time quietly reading the books. This flowed into the Expressive Cycle at the start of Excerpt III (lines 1-16). The cycle starts with a DU experience (Michael introduced a definition from one of the books at lines 1-5), then flows to AU (he briefly applied his understanding of clarity of explanation to discussing the explanatory power of the definition at lines 6-7), then briefly back to DU (Una repeated the main point of the definition), before flowing back to high-level AU (as Michael and others applied
syntactical understanding of covalent bonding to devise a suitable explanatory sequence at lines 9-16). The cycle then ends as Michael makes the decision to search for information about polarity in a PPM experience (lines 17-18).

It was much more common for Expressive Cycle experiences to be cut short by the re-establishment or maintenance of the Non-Expressive Cycle, rather than for them to run their course within the flow of the Expressive Cycle. There are several examples of this in Excerpt 1. After a Non-Expressive Cycle of Experience prior to Excerpt I (depicted in Figure 9.5 at 6:50-7:35), Aoife applies her syntactical understanding of covalent bonding to suggest a different sequence for their peer-focused explanation of the topic, “You’d have to say what polar is first wouldn’t you? (line 2)” This then flows into a DU experience in which Bríd attempts to express her personal understanding of polarity (lines 2-3) but she is interrupted before she can complete her contribution as Una continues the Non-Expressive Cycle of Experience and the rest of the group then continues within this cycle (line 4-17). After this Non-Expressive Cycle has run its course, Una attempts to express her personal understanding of the concept (lines 18-19). She is also interrupted before she can complete her contribution as Michael introduces a PPM experience in which he decides the group should seek information about polar covalent bonds (lines 19-20). The group then continues within the Non-Expressive Cycle of Experience (lines 20-28). Once this Non-Expressive Cycle has run its course, Bríd gives her personal understanding of polarity and Aoife responds with her personal understanding, in a high-level DU experience (lines 29-33). This experience is also interrupted when Michael continues the previous Non-Expressive Cycle by reading a definition for a polar covalent bond aloud (lines 34-41).

These examples demonstrate how Expressive Cycle experiences can flow naturally from the community-oriented group having engaged in the Non-Expressive Cycle of Experience; the Non-Expressive Cycle has the potential to support engagement with the more challenging Expressive Cycle. However, the reluctance of Michael and Una to disengage with the Non-Expressive Cycle and engage with more in-depth discussions prevents this group from making progress in their understanding in the examples provided. Michael and Una repeatedly display a tendency to re-introduce or maintain the Non-Expressive Cycle of Experience when group members make contributions that have the potential to lead to more in-depth discussions about conceptual understanding.
The following conclusions can be made about the Expressive Cycle in this community-oriented group:

- The Expressive Cycle of Experience was rarely engaged in by the community-oriented group;
- The Expressive Cycle was often ended prematurely as a result of the re-establishment of the Non-Expressive Cycle;
- Conceptual discussions occurring in DU experiences that were at a high level of community, were usually not in-depth discussions and tended to be more superficial in nature. This suggests discomfort and possibly a lack of confidence among the group members;
- High-level AU experiences tended to be pedagogically-oriented rather than focused on chemistry concepts. This also suggests a reluctance to discuss conceptual understanding.

**NON-EXPRESSIVE CYCLE OF EXPERIENCE**

The Non-Expressive Cycle of Experience was the most common flow of experience engaged in by the community-oriented group. The Non-Expressive Cycle consisted of PPM experiences, low-level DU experiences, and middle-level DU experiences. There was no particular order in which these experiences flowed, but PPM experiences often initiated the cycle. The Non-Expressive Cycle flowed into the few Expressive Cycles noted in the previous section, and it also flowed into attempts to enter this cycle, though these attempts were unsuccessful. Therefore, the Non-Expressive Cycle may be necessary for the group to enter the more challenging Expressive Cycle. However, the desire of members of the group to remain within the Non-Expressive Cycle of Experience was also usually responsible for the failed attempts to move into the Expressive Cycle of Experience. In this case study, therefore, the Non-Expressive Cycle was something of a double-edged sword.

PPM experiences consisted of: describing/discussing a learning resource (e.g. Excerpt III, lines 17-19), strategy descriptions or decisions (e.g. Excerpt I, lines 12-13), and physical preparations for writing/searching (e.g. Excerpt II, lines 4-5). Michael was the main initiator of these experiences, with Una also occasionally initiated them. Neither Bríd nor Aoife actively engaged with these experiences. These types of PPM experiences and those focusing on strategy decisions were the most common PPM experiences in the narratives. There was also one PPM experience to which the above categories did not apply. This experience was initiated by Una (Excerpt I, line 52) who gives a practical response to an SMJM comment from Bríd. She tells Bríd that she wasn’t listening to the definition that had been read aloud.
when Bríd suggests that the definition is sensible. However, just prior to this Una has contributed to a conversation about the definition (Excerpt I, lines 43-51). This suggests that her PPM statement, made with a dismissive wave of her hand, is not entirely true and it may be a defensive response to allow her to avoid discussing the definition in a conceptual way.

Low-level DU experiences involved searching and reading information about a concept (e.g. Excerpt I, line 53) as well as experiences in which I explained a concept or a pedagogical idea while the group listened (e.g. Excerpt VII). Low-level DU experiences flowed either into or from other experiences within the Non-Expressive Cycle (e.g. Excerpt I, lines 14-17). Middle-level DU experiences in the group involved either a group member calling out some conceptual information from an external/authoritative source, or a group member sharing her/his personal understanding while other members largely ignored this contribution. In this case study, the former formed part of a Non-Expressive Cycle of Experience. Michael and Una tended to initiate these types of middle-level DU experiences. The middle-level experiences in which a group member shared her/his personal understanding but was interrupted or ignored were often preceded and followed by experiences in the Non-Expressive Cycle. However, these experiences seem to be less part of the Non-Expressive Cycle, than attempts to move the group to the more expressive experiences. For example, in Excerpt II, Bríd gives her personal understanding of non-polar covalent bonds (lines 9-10). The following experience is low-level DU (lines 10-11), not because it flows from Bríd’s contribution, but because the other group members ignore her contribution. Had the group engaged with this middle-level DU experience, it would likely have become, or flowed into, a high-level DU or AU experience. This represents a general resistance to engaging with the Expressive Cycle of Experience.

As previously noted, the Non-Expressive Cycle often functioned to prevent the flow of experience from entering Expressive Cycle experiences. However, the Non-Expressive Cycle has also been shown to flow into the Expressive Cycles. The Expressive Cycle starting at line 24 of Excerpt III is initiated by Michael calling out a definition which is then discussed by the group. Without the Non-Expressive Cycle experiences immediately preceding this, group members would not have had an opportunity to revise their understanding, or learn about, this concept. Although the Non-Expressive Cycle did have a restrictive impact on the group’s engagement with more challenging expressive experiences, it was also the foundation that supported the few Expressive Cycles which did occur.
Based on my analysis, the following conclusions can be made about the Non-Expressive Cycle of Experience in this case study:

- The Non-Expressive Cycle dominated the flow of experience in the community-oriented group;
- Expressive Cycle experiences were often interrupted or drawn to a premature end by the re-establishment of the Non-Expressive Cycle. PPM was often the experience that re-established the Non-Expressive Cycle;
- Attempts to enter the Expressive Cycle were often ignored by the group members, who favoured low-level DU experiences over expressive experiences;
- The Non-Expressive Cycle was necessary for the Expressive Cycle to occur;
- Overall, the Non-Expressive Cycle had both a restrictive and supportive impact on the flow of experience in the narratives.

**SHARING METACOGNITIVE JUDGEMENTS AND MONITORING**

SMJM experiences did not form part of either the Expressive or Non-Expressive Cycles of Experience; they had little to no impact on the flow of experience where they occurred. These experiences were typically brief and not participated in by the group-at-large. Although the types of activities upon which these SMJM experiences focused were similar to those in Case Study A, the frequency of different types of activities varied from Case Study A. In Case Study A, sharing judgements of personal understanding were the most common types of SMJM experiences, but they are the least common in Case Study B. Similarly, sharing judgements of confidence and the ease of learning/task were least common in Case Study A, but were the most common of the SMJM experiences in Case Study B.

SMJM experiences flowed from experiences within either the Non-Expressive or Expressive Cycles. SMJM experiences in which confidence judgements or judgements of the ease of the task/learning were shared, were often not participated in at high levels of community. For example, in Excerpt I, Bríd shares her doubts about the usefulness of a definition which has been introduced within a Non-Expressive Cycle (line 26-27). The other group members do not engage with this experience, and Una and Aoife do not even acknowledge this contribution. Michael then quickly re-establishes the Non-Expressive Cycle as he decides that more information should be sought out on the web (line 28). The sharing of confidence judgements did not appear to have an impact on the flow of experience. For example, in Excerpt I, Una implied that the task/learning is difficult to achieve (line 9). None of the other group members respond to this comment or acknowledge it and the group carries on.
as it already was. This suggests that the sharing of confidence judgements and ease of learning, generally, did not provide opportunities for empathy in this group.

Michael was the only group member to share a judgement of his personal understanding of the concepts related to polarity. He implied that he didn’t understand the concepts being discussed as he said, “Is there a chemistry for dummies?” (Excerpt II, line 1). He quickly clarified that he was referring to himself rather than other members of the group. However, the other group members did not actively engage in this experience, and Bríd and Una did not even acknowledge Michael’s contribution. This has no impact on the group, as they continue as they would have if Michael had never revealed this (Excerpt II, lines 3-6). Based on my analysis, SMJM experiences did not provide opportunities for empathy among this community-oriented group – or, at least, these opportunities were not engaged with by the group – and SMJM experiences did not form part of either the Non-Expressive or Expressive Cycles of Experience.

The flow of experience in this community-oriented group was somewhat similar to the SCIS Learning Cycle model, which is composed of the phases: exploration, concept introduction and concept application. The natural tendency of the group was to flit between these types of experiences. This tendency to move quickly between these experiences appears to be a hindrance to their learning and task progress in a way that was not observed in Case Study A. Comparing Figures 9.6 and 9.7 with Figures 9.3 and 9.4 demonstrates that this tendency to move rapidly between types of experiences was common to both groups. However, the central distinctions between these two sets of figures is the extent of engagement at high-levels of community and the comparative scarcity of SMJM experiences in Case Study B.

Case Study B is also distinct from Case Study A in terms of AU experiences, as these occurred almost exclusively within the realm of pedagogically-oriented contexts for the Case Study B community-oriented group. Furthermore, unlike in Case Study A, SMJM experiences were not a central feature of the flow of experience for this community-oriented group.

Considering the superficial nature of the learning experience in this group, and that better metacognitive judgements and monitoring is associated with better conceptual understanding, deeper knowledge structures, etc. (Haidar and Naqabi 2008; Young and Fry 2008), this lends some support for learning cycle models which explicitly include metacognitive phases Blank (2000). The lack of engagement by the group in the SMJM experiences which were present, also suggests that the group did not benefit from socially shared metacognition (Khosa and Volet 2014; Molenaar 2014), and, therefore, the collective activity of the group was less well-regulated (Vauras et al. 2003) than for the Case Study A.
group. This can be observed in the frequent re-introduction of the Non-Expressive Cycle, where the Expressive Cycle would likely have served the group better in completing the task.

(b) Relational Dialectics and Community-Oriented Group Experience
In examining the narratives created for this case study, four main dialectical tensions were observed in the experience of the group. The dialectical tensions are as follows:

- *Denial of conceptual understanding – acceptance of conceptual understanding*; this was a sub-dialectic of the wider *denial – acceptance* dialectic and was a tension between a denial of the presence of conceptual confusions and an acceptance of the presence of conceptual confusions.

- *Expert Resource – Community Resource*; this related to the group approach to the session and the supremacy which was placed on outside ‘expert’ resources (e.g. websites, books, etc.) or the resources within the community-oriented group (e.g. group members ideas, prior learning, etc.). I consider this to be an idiosyncratic presentation of the *expression – non-expression* dialectic noted in previous RDT literature.

- *Learner – Teacher*; this related to the group perspective and attitude towards the session, in which there was a tension between adopting a position as learners of the subject matter, and as teachers of the subject matter.

- *Simplicity – Comprehensiveness*; this was a tension between a discourse of simplicity in conveying conceptual information, and a discourse of comprehensiveness in conveying conceptual information. It is related to the *Learner – Teacher* dialectic.

**DENIAL OF CONCEPTUAL UNDERSTANDING – ACCEPTANCE OF CONCEPTUAL UNDERSTANDING**
As with Case Study A, I observed a tension between the denial and acceptance of barriers in this community-oriented group. This, again, largely related to the conceptual understanding of the group. Throughout the case study, there was a tendency to behave as though every group member understood the concepts and, in seeking out information about the concepts, they were merely seeking a suitable presentation of these concepts for the benefit of others. However, it was clear that at least some group members did not, in fact, understand the meaning of concepts, i.e. a denial of the existence of conceptual confusions. On other occasions, the group, or specific group members, were accepting in their own or others lack of conceptual understanding or need to improve their understanding, i.e. an acceptance of the existence of conceptual confusions. The typical interplay upon which this tension was constituted was one in which *denial* dominated while *acceptance* was marginalised.
The denial of conceptual understanding – acceptance of conceptual understanding dialectic is constituted in a diachronic interplay, with denial being dominant. Throughout the narratives, group members engaged in tactics that avoided in-depth conceptual discussion. This dialectic and the interplay upon which it is constituted is depicted in a typical experience in Excerpt I, lines 18-52. The first definition introduced by Michael is nonsensical and illogical, ‘A polar bond is a covalent bond between two atoms where the electrons forming the bond are polar molecules,’ (lines 22-24). This claims that electrons can be polar molecules and is likely a misreading of a definition. Nonetheless, rather than anyone admitting any difficulty in understanding this nonsensical definition, the group suggests that the definition is simply not comprehensive enough and that it needs to be ‘opened up,’ (lines 26-28). The second definition introduced is scientifically-acceptable (lines 34-41), but rather than engage in any discussion, the group once again considers its appropriateness for the audience to which they will present it and avoids considering its meaning (lines 42-49). We also see Aoife suggest that “we can just put it into our own words sure” and although this may be possible for Aoife, it doesn’t appear to be possible for the group and this seems quite obvious throughout the narratives. Una then also claims that she ‘tuned out’ when she feels social pressure to engage with Bríd about the meaning of the definition (line 52). This is despite the fact that Una clearly was listening and had made contributions about the appropriateness of the definition prior to this. Another example of this interplay may be seen in Excerpt III, lines 20-40. Conceptual contributions in this portion of the excerpt are, again, largely ignored rather than discussed. Michael’s lack of clarity on the group utterances led by Bríd is almost painfully obvious (e.g. lines 35-36) but Una also lacks clarity and her dismissiveness towards a deeper conceptual conversation is typical within the narratives (lines 38-41). The dominance of denial over acceptance among this community-oriented group, lends meaning to the behavioural tendency to engage in these kinds of avoidance tactics, such as re-establishing the Non-Expressive Cycle and almost exclusively applying their pedagogically-oriented understanding rather than their conceptual understanding in AU experiences.

There were a few moments within the session where acceptance of conceptual understanding and denial of conceptual understanding were simultaneously present. One such moment is shown in Excerpt II, lines 1-6, in which Michael admits his own lack of conceptual understanding but the rest of the group does not engage with this discourse, either to accept his admission or to contribute their own admission. This is so much the case, that Michael anticipates that no one else feels the same and clarifies that he is the only person with this issue. In this example, acceptance of conceptual understanding is delegitimised by the denial of conceptual understanding discourse, due to the group’s choice to ignore the former discourse.
The denial of conceptual understanding and acceptance of conceptual understanding has been categorised as a sub-dialectic of the denial – acceptance dialectic. It is an idiosyncratic presentation of this supra-dialectic that is distinct from the idiosyncratic presentation noted in Case Study A, i.e. the should already understand – desire to learn dialectic. Although both of these sub-dialectics are judgement-laden, in Case Study B this was often associated with other group members, while in Case Study A it was usually associated with the group, including one’s self. For example, Michael’s admission that he lacked understanding was ignored by the community-oriented group, which is suggestive of a denial of other group member’s conceptual confusions: there was no room for such a discussion in Case Study B. While in Case Study A, similar experiences led to other group members empathising in some way and often admitting that they, too, were experiencing similar barriers to developing better conceptual understanding. This is reflective of the interplays upon which both of these tensions were constituted. In Case Study A, the should already understand discourse was marginalised and the desire to learn discourse was dominant. The turning point in this tension was pivotal in this interplay. In Case Study B, the denial of conceptual understanding was made dominant and the acceptance of conceptual understanding was marginalised. There was no turning point which influenced this interplay, rather the two discourses did not come into discursive contact at all. This highlights both the importance of these turning points and, possibly, the need for some discursive contact between discourses.

**Expert Resource – Community Resource**

In the approach to the task and to learning, there was a tension between discourses surrounding the supremacy given to different resource types. There was a discourse in which the task should be approached by finding external ‘expert’ resources and simply using these resources to complete the task (i.e. the expert resource discourse), and a discourse in which the task should be approached by using the resources of the community-oriented group, such as their own thoughts, words, prior learning, etc. (i.e. the community resource discourse). The tension between these discourses can be readily observed throughout the excerpts. In Excerpt V, for example, Bríd and Aoife engage with their own mental resources as they suggest a response to a task question and appear satisfied to proceed with this (lines 3-6). The expert resource discourse arises as Michael suggests that they seek out an image from the web that can explain the concept (lines 6-7). Una continues within the expert resource discourse and Bríd also adopts it (lines 11-13). Once an expert resource produces a definition which they are mostly satisfied with, they adopt it (lines 18-22). The tension is also quite obvious throughout Excerpts I and III, where it presents itself in a similar interplay – an indirect, antagonistic struggle in which expert resource has dominance.
The discourses came into discursive contact in Excerpt VI. Bríd questioned their approach to the task (lines 1-4), as she suggested engaging in more explanatory detail once they have identified a definition with which they are satisfied. Note that she anticipated resistance to this, adding, “like not extreme detail but brief kind of like explaining,” (line 3). The suggestion here appears to be one of moving towards an integration of the discourses – one where both discourses are partially adopted. However, in that particular moment, the discourses are actually constituted in an indirect struggle. The discourses are treated somewhat ambiguously: Michael and Bríd believe they are in some agreement with one another about how to proceed with the task. This can be observed in lines 7-12. However, the meaning which Michael actually attributes to Bríd’s suggestion is one focused upon structure and the order of definitions (i.e. lines 13-18 and 24-25, and there are two other examples of this in the extended narrative). All group members come to agreement with this approach and the community resource discourse continues to be marginalised. This interplay between the tensions was observed throughout the session.

I am categorising this tension as an idiosyncratic presentation and sub-dialectic of the expression – non-expression dialectic. This is due to the fact that the expert resource – community resource dialectic is central to the behavioural cycle between the Expressive and Non-Expressive Cycles noted in the flow of experience. The interplay between these two discourses, i.e. the total dominance of the expert resource discourse, lends itself to a cycle between long periods of the Non-Expressive Cycle, as the group seeks out and reports on definitions from the web, and brief periods of the Expressive Cycle, in which the focus was often upon pedagogical knowledge. The interplay lends meaning to this pattern of behaviour. Consider an alternative interplay: the tension between expert resource and community resource could have been recalibrated such that expert resources allowed for better quality community resources, and community resources allowed for the identification of the most relevant expert resources. Such an interplay would likely lend itself to an entirely different pattern of behaviour as regards the Expressive and Non-Expressive Cycles.

The expert resource – community resource dialectic and the tensions of openness – self-protection | closedness in Case Study A, are both sub-dialectics of the expression – non-expression dialectic. In Case Study A, experiences in which self-protection was dominant over openness had a similar impact on behaviours as the experiences in which expert resource was dominant over community resource in Case Study B. Both of these tensions were constituted in the same type of interplay. The distinction between the two case studies, is that openness was also in tension against closedness and this tension was constituted in a recalibration interplay. The presence of dialectic tensions related to expression – non-expression is not problematic from the perspective of science.
educators – what is problematic is certain interplays between these tensions. Case Studies A and B demonstrate the destructive impact of one diachronic interplay for this tension on a community-oriented group, and the beneficial impact of a particular recalibration interplay.

**Teacher - Learner**

The interplay in which the *teacher–learner* tension was constituted was, somewhat, synchronic, in that one perspective often led to the other, and vice versa. However, the *teacher* discourse appeared to be more dominant than the *learner* discourse. In Excerpt I, the *teacher* perspective is adopted at line 2: Aoife expressed her syntactical understanding of covalent bonding in an attempt to devise a more suitable explanatory sequence. The *learner* perspective was adopted from lines 4-19: the group sought out information that clarified for them the meaning of polar and non-polar covalent bonding. The *teacher* discourse can also be observed at lines 42-49: they considered the explanatory power of a definition. The group tended to be more at ease when engaging with the *teacher* discourse and achieved higher levels of community for more sustained periods of time when engaged with this discourse.

However, the *learner* discourse was rarely wholly present, as evidenced by the fact that the group usually struggled to engage in discussion of concepts but was limited to seeking out and repeating definitions. This was not the case for the *teacher* discourse as the group tended to engage with pedagogical issues with relative ease. This trend was impacted upon by the *expert resource – community resource* interplay; the group could not engage wholly with the *learner* discourse as long as they adopted an approach in which discussion of chemistry concepts was avoided in favour of seeking an expert report on the meaning of a concept and inserting it into their task product. In turn, the *expert resource – community resource* interplay was impacted upon by the *denial – acceptance* interplay. Therefore, these tensions were inter-related.

**Simplicity - Comprehensiveness**

The final discourses to be discussed in the group experience are those of *simplicity* and *comprehensiveness*. These discourses arose intermediately throughout the session. *Simplicity* was a discourse in which an ‘easy’ or ‘clear’ way to explain a concept to others was considered favourable, while *comprehensiveness* was a discourse in which a ‘complete’ explanation was considered the favourable approach. Some examples of the *simplicity* discourse in Excerpt I occur at lines 43-45, wherein Michael suggests a definition is ‘too heavy’ to form an explanation, and lines 47-48, wherein Aoife suggests that *simplicity* can be achieved by rewording the definition. In Excerpt VI, Aoife suggests a definition is suitable as a result of its *simplicity* and Michael agrees that, “I would go with simplicity,” (lines 29–31). The *comprehensiveness* discourse may be observed in Excerpt I, where Aoife suggests adding in the
meaning of polar to their explanation (line 2), where Michael seeks to ‘open out’ a definition (line 28), and where the group decides that terms such as ‘dipole moment’ and ‘electronegativity’ need to be added to their explanation (lines 53-57).

Overall, the interplay between these discourses in the group swings between an antagonistic and a non-antagonistic struggle. An antagonistic struggle can be observed in comments such as ‘it’s a bit heavy though, isn’t it?’ (Excerpt I, lines 47-48), “It says here, it’s just really simple as well,” (Excerpt VI, lines 47-48) and “I would go with simplicity more than…” (Excerpt VI, line 32). Comments such as these reflect an either-or tension or antagonistic struggle; a suitable explanation can either be simple or comprehensive. However, the group regularly represented both discourses in their utterances. For example, in Excerpt I, Bríd suggests that “It’s [a definition] is very long. But at the same time, it’s explaining to us not to students,” (line 45) and Aoife suggests that “we can just put it in our own words sure,” (line 47). Una adds that a picture may be helpful (lines 46-49) in achieving simplicity. These comments continue to view simplicity and comprehensiveness as being somewhat at odds. Bríd’s point that ‘it is very long’ and later that ‘it’s very long-winded,’ suggests a lack of simplicity as a negative thing. However, her note about the audience, ‘it’s explaining to us not to students,’ shows a preference for comprehensiveness for this particular audience. Aoife and Una’s contributions suggest agreement that the definition lacks simplicity in favour of comprehensiveness, but demonstrate a belief that simplicity can be achieved via language and images while maintaining the comprehensiveness of the definition. In these latter cases, the interplay is a non-antagonistic one.

This interplay is obviously related to the learner – teacher interplay and occurs within the context of the teacher discourse. It is also related to the denial of conceptual understanding – acceptance of conceptual understanding and expert resource – community resource dialectics, in that dominance of denial of conceptual understanding and expert resource discourses over their counterparts led to discussions in a pedagogical context.

(c) Relational Dialectics and Conceptual Discourses
Two conceptual areas were focused upon in the case study: the meaning of polarity, and the impetus for bonding. As a result of the interplay between dialectical tensions noted within the community-oriented group experience, the conceptual discussions were stunted. Rather than explicitly competing discourses among the group members, an ‘expert’ resource supplied an initial idea which was then gradually built upon. This was reflected in the group members’ comments in the secondary data. Every group member made reference to the session as improving their memory, rather than improving their understanding. Some of the
comments made were that the session “[from Bríd] helped jog my memory,” “[from Una] was useful in revising my knowledge,” and “[from Aoife] refreshed my memory.”

Discourses about Polarity

In relation to polarity, there was only one discourse engaged in by the group: polar covalent bonds form when differences in electronegativity cause electrons to be unequally distributed between the bonding atoms. This is a scientifically-acceptable discourse. It was largely expressed through definitions from the web and books, but was also the only discourse engaged in when group members were sharing their own understanding. This discourse can be observed throughout Excerpts I, II, III and IV.

The scientifically-acceptable discourse was built up upon over time. In Excerpt I, Bríd gives her personal understanding of a polar bond, “the electrons in the bond are more, am, attracted to one side of the bond,” (lines 30-31). This is a largely scientifically-acceptable viewpoint, though incomplete and imprecise in terminology. Aoife connects this with the idea of electrons as “unequally distributed,” (line 32). This is then connected to terms ‘partial negative’ and partial positive’ (line 33). After a definition has been introduced by Michael, Aoife suggests that the concept of dipole will need to be included in their explanatory sequence. Bríd adds that electronegativity will also need to become part of the explanatory sequence (lines 34-57). In this way, the scientifically-acceptable discourse was built up gradually. There is some resistance to the scientifically-acceptable discourse, as evidenced by a continuing recourse to the expert resource discourse throughout the excerpts. Group members expressed their personal understanding in a way consistent with the scientifically-acceptable discourse, but this was not accepted by the group which continued to seek out some other explanation or discourse on the web. There could be many reasons for this, including a lack of conceptual understanding, a lack of confidence in other group members, or the discourse of simplicity (wherein group members considered the scientifically-acceptable discourse to be lacking in simplicity). However, no alternative discourse is openly expressed by the group. The scientifically-acceptable discourse is dominant throughout the session,

179 She says ‘more attracted to one side of the bond’ as though the bond were a physical entity. Rather, she should have said more attracted to one of the atoms or nuclei. However, I interpreted this to be imprecision in terminology rather than an alternative conception – this interpretation does appear to be correct given the contributions elsewhere in the excerpts.
with the resistance to this discourse being present but hidden. Therefore, there is a diachronic tension between the scientifically-acceptable discourse and a hidden discourse.

Although the scientifically-acceptable discourse was the dominant conceptual discourse, is the experience described in Excerpts I, II and III a successful outcome in terms of the development of conceptual understanding? I would argue that it is not. The scientifically-acceptable discourse may be the dominant ‘voice’ in the group, but there is clearly some discourse (or discourses) present that is resistant to this scientifically-acceptable discourse (as evidenced by the clear reluctance among some members of the group to adopt it). This phantom, undermining discourse has not been delegitimised, as it was not expressed by the group. It appears to remain a phantom as a result of the interplay of the expert resource – community resource, and denial – acceptance dialectical tensions. The dominance of expert resource and denial resulted in the scientifically-acceptable discourse arising, but it also led to the inability of the group to share their personal understanding of this discourse or to give voice to the reason for their resistance to this discourse. Within a denial discourse, group members cannot admit any confusions or conceptual divergence from the expert resource. The dominance of expert resource over community resource in the expert – community interplay, meant that group members’ personal understanding was not valued by the group-at-large. The interplay of the teacher-learner dialectic also undermined open and honest discussion, as the learner perspective was not wholly present.

**DISCOURSES ABOUT THE IMPETUS FOR BONDING**

There were two main discourses about the impetus for bonding observed in the narratives:

- atoms form covalent bonds to gain a full outer shell, by borrowing electrons, which allows them to achieve stability (i.e. the alternative discourse), and
- atoms form covalent bonds as a result of electrostatic attraction between nuclei and electrons (i.e. the scientifically-acceptable discourse).

The tension between these discourses was also constituted in a diachronic interplay – in this case an interplay of segmentation. The scientifically-acceptable discourse was present only when I was with the group and was given dominant voice by me. At no time when I was present, did group members express the alternative discourse. They did not engage with me about the meaning of concepts at all. The alternative discourse was built up piece by piece, as shown in Excerpt V, to form a complete discourse on impetus for bonding.

The alternative discourse can be observed as it is built up in Excerpt V. Initially, Bríd introduces the impetus for bonding as being, “‘cause they want to have a full outer shell,” (line 4). A little later a definition from the web legitimises this discourse (lines 19-22). Michael
appears to be resistant to this discourse based on its perceived lack of simplicity (lines 23-24) and Aoife responds to this by connecting a full outer shell to stability, “that’s to become more stable though,” (lines 26-30). At each stage, the group-at-large supports the new element of the discourse. Finally, Una adds a new element from a web-based resource – “They [atoms] get them [electrons] ‘on loan’,” (lines 31-33). This discourse as the final dominant one in the group is confirmed in Excerpt VI as all group members agree that it should be added to their notepads (lines 34-35)

The scientifically-acceptable discourse arises only in Excerpt VII and it is only expressed by me. At no time was I able to engage the group in discussing their conceptual understanding and the meaning they attributed to concepts. The group-facilitator experiences can be observed in Figure 9.7 from 26:05-32:40: all of the experiences, with the exception of an SMJM experience, are at low- and middle-levels of community. As a result, the alternative and scientifically-acceptable discourses never came into discursive contact with one another. This is a segmentation interplay: when I was present, the scientifically-acceptable discourse was given the dominant voice, and when only the group members engaged with one another, the alternative discourse was given the dominant voice. As such there is no antagonistic, or even non-antagonistic, discursive contact between the discourses.

This lack of discursive contact arises largely as a result of the erroneous definitions introduced by web-based resources – resources which were considered to be within the expert resource discourse – as evidenced by Una’s assertion that the ‘on loan’ element must be correct because, “I’m taking that right of that [the web-based resource],” (Excerpt V, line 33). The interplay between denial and acceptance had less consequence for the discourses about the impetus for bonding. Michael resisted the alternative discourse but this appeared to be due to his perception that it was not simple enough, and he favoured the simplicity discourse within the simplicity – comprehensiveness dialectical tension. The teacher–learner discourse was something of an influence also, as, once the alternative discourse had been built up (i.e. in Excerpt V), the group adopted the teacher perspective as they considered how to present this discourse (i.e. Excerpt VI). As a result, there was no further consideration of the legitimacy of the discourse. The interplay between the dialectical tensions among this community-oriented group was not favourable to the kind of direct, antagonistic interplay between conceptual discourses that was observed in Case Study A. Rather the conceptual discourses in Case

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180 The community also confirms the ‘on loan’ portion of the discourse by entering it in their notepads – this occurred shortly after the end of Excerpt VI but has not been depicted.
Study B were founded upon a diachronic segmentation interplay, or upon an indirect, hidden struggle wherein only one discourse was expressed and the other was a ‘phantom’ discourse. I do not classify either of these interplays, as observed in this case study, as supportive of a favourable conceptual outcome.

The alternative conception that the primary impetus for bonding is for atoms to obtain a full outer shell has been well documented in the literature (Taber 1998b; Tan and Treagust 1999; Toplis 2008; Kind and Kind 2011; Taber et al. 2012). This alternative conception is commonly considered part of an alternative framework, i.e. an organisation of ideas upon which alternative conceptions arise (Taber 1998b). The alternative conception that ‘atoms need a full outer shell to become stable’ has been postulated to be part of the same alternative framework as the conception that the impetus for bonding is for atoms to gain a full outer shell (Taber 1998b; Taber et al. 2012). The dominant conceptual discourse among the Case Study B group, suggests some adherence to this alternative framework.

**CONCLUSION**

The findings described in this chapter were based on an analysis which was founded upon Stein’s philosophy of empathy and community, using Baxter’s (2011) RDT as a sensitising theory. This resulted in a perspective which is less about alternative conceptions as particular cognitive structures in the minds of learners, but which reframes the problem of alternative conceptions as one of persons relating with one another. This perspective maintains the focus upon PSSTs’ experience which was central in addressing the research question. This reframing of the problem of alternative conceptions led to the observation of a number of relational dialectics which gave meaning to the flow of experience in the community-oriented groups and the experience of each community-oriented group’s engaging in conceptual discussions in which alternative conceptions in chemistry arose.

The denial – acceptance dialectic has not been previously identified in RDT research (Baxter 2011; Halliwell 2015). This supra-dialectic is likely unique to learning groups and communities, which have not been well-researched in the RDT literature (Prentice and Kramer 2006). It is related to the judgement – acceptance dialectic observed among dyadic friendships and community settings (Bridge and Baxter 1992; Kramer 2004), given the judgement-laden nature of the discourse of denial. The denial – acceptance dialectic presented in idiosyncratic ways for each of the two groups which were the focus of this chapter. In Case Study A, it presented as a tension between should already understand and desire to learn. The interplay upon which this tension was constituted was one of disqualification; desire to learn was dominant while should already understand was marginalised. A turning point at the outset
of the session was pivotal in creating this interplay, as a group member explicitly gave voice to these tensions, bringing them into discursive contact, leading her to openly state a favourable interplay between these tensions. In Case Study B, the denial – acceptance dialectic presented as a tension between denial of conceptual understanding and acceptance of conceptual understanding. In this case, denial was given the dominant voice. The different interplays between these tensions gave meaning to the tendency in Case Study A to engage with SMJM experiences that involved sharing a judgement of personal or group understanding, while in Case Study B the tendency was to not engage with SMJM experiences of this nature. Where these experiences did occur, the interplay gives sense as to the group’s tendency to ignore such contributions – the dominance of denial did not allow for sharing judgements of understanding that suggested the existence of conceptual confusions.

The expression – non-expression supra-dialectic also presented in idiosyncratic ways in the groups. In Case Study A the community-oriented group experienced a tension between openness and both self-protection and closedness. Openness – self-protection was often constituted in the diachronic interplay of segmentation, wherein my proximity to the group was associated with the dominance of a discourse of self-protection. This interplay lends meaning to the group’s re-engagement, at these times, with the Non-Expressive Cycle of Experience, which comprised: low- and middle-level DU and AU experiences, and PPM experiences. However, closedness was constituted in a recalibration interplay with openness. This interplay was one in which closedness was reframed as being complementary with openness. This lends meaning to the flow of experience in which the group naturally flowed from one Cycle of Experience to the other, but were able to continue the conceptual discussion. In Case Study B, the expression – non-expression dialectic presented as an expert resource – community resource dialectic, with each pole of the tension referring to the supremacy given to different types of resources. This tension was constituted such that expert resource tended to dominate over community resource. This lends meaning to the large extent to which the group engaged with the Non-Expressive Cycle, and how this cycle often hindered conceptual discussion.

The teacher – learner dialectical tension has not been previously observed in the literature and it is likely a dialectic that is unique to those adopting, in some capacity, formal teacher roles. This tension did not appear to lend meaning to the flow of experience in Case Study A. In Case Study B, this was constituted in an interplay in which both discourses were present in the group, but the learner discourse was never wholly present. The latter being due to inter-relations with the denial – acceptance and expert resource – community resource dialectical tensions, whose interplays were unfavourable to the learner discourse. The interplay between the teacher – learner tension gives meaning to the group’s tendency to focus upon pedagogical issues.
within the Expressive Cycle, to the neglect of conceptual issues. The *simplicity* – *comprehensiveness* tension has a relationship to this tension, given that it arose within the context of the *teacher* discourse. The interplay upon which this tension was constituted was synchronic, with both discourses often being simultaneously present in the group.

These relational dialectics, particularly the sub-dialectics of *denial* – *acceptance* and *expression* – *non-expression*, were the foundation upon which the interplay between conceptual discourses arose. In Case Study A, a direct, antagonistic interplay between alternatively-conceived and scientifically-conceived discourses was observed to lead to more favourable group outcomes than an indirect interplay between discourses. Observing the experience of the Case Study B group in discussing polarity and, particularly, in discussing the impetus for bonding, lends further support to this conclusion. The general lack of discursive contact between opposing discourses led to focus upon a single discourse for which further support was then sought out from expert resources. Such an interplay, and the associated behaviours, cannot be considered to favour successful educational outcomes, given that the single discourse could be alternatively- or scientifically-conceived and the interplay ensures that the group will never discover which is which. Some discursive contact with another discourse, regardless of its accuracy, at least provides the group with an opportunity to deepen their conceptual understanding as they refute or defend the discourses. As such, I am suggesting that, not only should alternative conceptions be directly targeted, but scientific conceptions should be explicitly tested in group learning environments.

The dialectics within the groups’ experiences (e.g. *denial* – *acceptance*, etc.), and the interplay upon which they were constituted, can lend some insight into the experiences which can support the creation of community-oriented learning environments in which this suggestion may be possible. In Case Studies A and B, the interplay upon which the sub-dialectics of *expression* – *non-expression* and *denial* – *acceptance* were constituted appears to have been a central factor in the flow of experience and the resulting interplay of conceptual discourses. Based on these case studies, a diachronic interplay for these supra-dialectics in which either *non-expression* or *denial* are given dominance over their counterparts can be hypothesised to be destructive to community-oriented learning environments, though the same cannot be said where their counterparts are dominant. Synchronic interplays in which these dialectics are recalibrated or integrated may be hypothesised as associated with more favourable conceptual discourse interplays – however, this all depends upon *how* the discourses are recalibrated or integrated. In Case Study A, a recalibration in which *closedness* became supportive of *openness* was observed to be favourable. Further research is required to determine other ways that this dialectical tension (and others) may be reframed or integrated.
The Stein – RDT framework which underpinned this aspect of the study led to perspective on the problem of alternative conceptions that encompassed all aspects of the human person in the process of relating to one another. The first stage of the analysis ‘Obtaining an Overview of the Experience of the Community-Oriented Group’ involved both the direct coding of the audio-visual data and the creation of narratives based on the audio-visual experience. The coding process and the creation of narratives involves the interpretation of the researcher. Within other research frameworks, this might be considered a flaw or a limitation of the research. However, Stein’s phenomenology of empathy supports the validity of the researcher as a valid tool for the interpretation of data – particularly audio-visual data wherein the researcher has access to the person(s) being observed in a way that is quite similar to a face-to-face interaction. The physical, verbal, emotional, expressive and other communicative capacities of a person are available to the researcher in the audio-visual data, with the added advantage of repeated viewings to refute or confirm initial interpretations. Furthermore, a second coder can also access this data as another valid tool for interpretation to add greater reliability to the interpretation. By adopting a framework in which I was a valid research tool, it was natural to create narratives rather than traditional transcriptions. In doing so, I was making what was evident to me upon viewing the audio-visual data (e.g. the qualitative distinction between a nervous laugh and a humorous laugh), accessible to a wider who cannot access this data. This method of presenting the sense of PSSTs’ experience in the form of narratives is likely to be only one way that Stein’s phenomenology could influence analysis strategies and methods. Further consideration of her phenomenology in the science education research community could lead to other new research perspectives.

Once the narratives were created, Baxter’s RDT became an obvious partner to Stein’s phenomenology. The contrapuntal analysis, carried out as recommended by Baxter (2011), then allowed additional meaning to be derived from PSSTs’ experience of addressing alternative conceptions in a community-oriented environment. The tensions identified as a result of applying RDT, and the interplays on which these tensions were constituted, demonstrate particular experiences that influence learning outcomes. These tensions should be taken into account in the design of future learning programmes and interventions. For example, the denial-acceptance tension, and the interplay on which it was constituted, was found to have a knock-on effect on the expression – non-expression tension and the learner – teacher tension in this study. Future learning programmes could anticipate this issue among PSSTs at the outset of the learning programme by discussing the issue openly with PSSTs, asking them to remain aware of this tension as they work together, asking them to explore this tension in their own groups prior to engaging in conceptual work or after a short period.
engaging with conceptual work. Excerpts from the narratives in this study could even be used to demonstrate the potential hindrance of the denial discourse and what this tension looks like in a real-world situation. Teaching PSSTs about the tensions they will, or are likely to, experience and encouraging them to reflect on whether these tensions are present in their own interactions could allow PSSTs to have more control of their own learning process. This would be a fruitful area for future research that attempts to address alternative conceptions.

There are certainly more dialectical tensions than were identified in this study that are relevant to PSSTs working in community-oriented learning environments and other interplays between tensions that have a positive influence on learning outcomes. Different contexts are likely to result in other dialectical tensions and/or other interplays. For example, future research might examine the experience of PSSTs learning in third-level educational environments that are of a formal nature, e.g. tutorials, workshops or lectures. There may be some dialectical tension(s) surrounding PSSTs’ concerns about their grades, mastery in the topic in the context of their formal role as learners, and other relevant forms of goal setting. These were not overtly observed in this study and this may be due to voluntary nature of the blended learning programme: they had no concerns about performance or grading but were more focused on proficiency in the conceptual areas. The presence of more performance-related dialectical tensions may entirely alter PSSTs’ experience and may also alter the interplays between the kinds of dialectical tensions observed in this study. Future research from the Stein – RDT perspective into the dialectical tensions present in more formal educational contexts would provide additional insight into the impact of the current design of formal educational contexts and how they might be adapted to better support PSSTs in developing their conceptual understanding.
Chapter 10 Conclusion

The findings of this research study in relation to each research question will be briefly summarised in this chapter. The limitations associated with these strands of research and the main novel aspects of the research will also be briefly highlighted. The quantitative and qualitative strands of research will then be integrated with a view to examining how the insights from one strand of research can lend insight into other strands of research. Finally, the implications for science and chemistry education, and the implications for science and chemistry education research will be discussed. At the end of this chapter, I have included a personal reflection upon the research process.

10.1 SUMMARY OF THE RESULTS AND FINDINGS

In this section, the results and findings previously described and discussed in Chapters 5-9 will be briefly reviewed in relation to each research question.

(a) Research Question C1

The quantitative strand from Phase 1 of this research study, which was presented and discussed in Chapters 5 and 7, related to the following central (or major) research question:

Does the model of STE (concurrent or consecutive) on which PSSTs are enrolled have an effect on the prevalence of alternative conceptions about fundamental chemistry concepts, taking into account other variables such as subject specialism, year of study (for those on the concurrent model), degree classification (for those on the consecutive model), and previous second-level school experiences?

The perspective taken to addressing this research question was based on postpositivism and involved the administration of an alternative conceptions diagnostic instrument to PSSTs across Ireland. The analysis found that the model of STE did have an effect on the prevalence of the alternative conceptions included in this study – primarily, in the area of chemical bonding. Those on concurrent STE programmes were less likely to hold alternative conceptions in this area than those on consecutive STE programmes. This finding was interpreted as being the result of the differences in the PSSTs’ perceptions of their future roles at the outset of their third-level education. Those following the concurrent model make the decision to become teachers at the outset of their third-level learning of science and chemistry, while those following the consecutive model make this decision after they have completed this learning of subject matter. Such differences in perceptions of future roles impacts upon motivation for goal-setting about course material with a perceived-relevance and upon learning approaches to this material (Creten et al. 2001; Oyserman et al. 2002; Kover
and Worrell 2010). This, in turn, has been shown to impact upon learners’ ability to retain in memory course material that has perceived relevance (Murayama and Elliot 2011).

This memory retention was also considered to be a factor in the prevalence of alternative conceptions among concurrent and consecutive PSSTs, in light of the findings in relation to the year of study of PSSTs following the concurrent model. Concurrent PSSTs in their first year of study were less likely to have alternative conceptions in chemistry, particularly in the area of chemical bonding, than those in subsequent years of study. Given that specialising in chemistry was found to have no impact on the conceptual understanding of PSSTs, despite studying significantly more chemistry than their peers, this was interpreted as being due to PSSTs’ memory of fundamental chemistry concepts fading over time (Arzi and White 2007). As a result, alternative conceptions are developing or re-asserting themselves. This memory-loss effect may have had more effect on PSSTs following the consecutive model of STE due to differences in goal-setting and the perceived-relevance of chemistry course material at the outset of their third-level education.

Upper-second-level study of chemistry was found to be the most powerful predictor of the prevalence of alternative conceptions among PSSTs. PSSTs who had studied the subject at upper-second-level were less likely to have alternative conceptions than their peers who had not studied the subject. This was the case regardless of the model of STE, the year of study for concurrent PSSTs, or PSSTs’ subject specialism. The last time PSSTs explicitly encountered the kind of fundamental chemistry concepts included in this study, would have been in their study of upper-second-level chemistry and/or in their first year of study of their degree programme (i.e. in introductory general chemistry modules). Given the continuing predictive power of the condition of having studied or not studied upper-second-level chemistry, regardless of year of study, model of STE, etc., this suggests that memories of this educational experience have a lasting impact upon PSSTs’ conceptual understanding. In fact, study of upper-second-level chemistry was a more powerful predictor of performance for consecutive PSSTs than for concurrent PSSTs. This suggests that the concurrent model is somewhat more successful than the consecutive model at providing an equalising experience for PSSTs without past study of chemistry at upper-second-level. This may also be due to the differences in perceptions of future roles among PSSTs following either model at the outset of their third-level science and chemistry education.

The additional study of chemistry associated with specialising in chemistry was not associated with the prevalence of alternative conceptions among PSSTs following either model of STE. The academic performance of consecutive PSSTs on their prior science/chemistry degrees
also had no impact on their alternative conceptions. These findings, in addition to the increase in alternative conceptions of concurrent PSSTs after their first year of study and the long-lasting impact of upper-second-level education, suggest that the chemistry education taking place in third-level education is not building a foundation in basic chemistry concepts: a PSST who has the minimum of third-level chemistry education but has studied upper-second-level chemistry will have fewer alternative conceptions about basic chemistry concepts than those who experience the maximum of third-level education in chemistry but have not studied the subject in upper-second-level education.

(b) Research Question M2
The analysis and the discussion of this analysis, presented in Chapters 6 and 7, related to the following minor research question:

Does a blended learning programme improve PSSTs’ understanding of fundamental chemistry concepts?

In order to address this research question, a blended learning programme was created. The approach to the design of the blended learning programme, SuBATOMIC, was informed by Stein’s philosophy of empathy and community, as well as the findings in relation to Research Questions (RQs) C1 and M1. The programme was designed to approach PSSTs in an authentic way, by engaging with them as a group of future teachers, rather than attempting to teach them SMK. As such, it was hoped that PSSTs’ SMK would develop along with their PCK. The approach to answering the research question was one largely based on postpositivism and involved the use of a diagnostic instrument. Further details of the SuBATOMIC learning programme may be found in Section 3.10.

The results were somewhat disappointing – there was no statistically significant difference between the prevalence of alternative conceptions among the Blended Learning Group and a control group (named the Conventional Group). However, the analysis was limited in statistical power, owing to a small sample size, and, therefore, statistical significance could only be attributed to large effect sizes. Medium and small effect sizes were observed in relation to the PSSTs’ alternative conceptions about PNM and chemical bonding, respectively. In these cases, the Blended Learning Group had fewer alternative conceptions about fundamental chemistry concepts than the Conventional Group. These differences appeared to be the result of the Blended Learning Group having primarily benefited those with the lowest conceptual understanding, when compared with the Conventional Group.

The difference between the Blended Learning Group and the Conventional Group was greater in the area of PNM than in the area of chemical bonding. This outcome was
interpreted as being the result of differences in: the treatment of PNM and chemical bonding within the face-to-face sessions of the programme, the level of integration between the online and face-to-face components for the two conceptual areas, and the topics themselves. Chemical bonding is widely recognised as one of the most difficult areas in chemistry in which to gain conceptual understanding (Taagepera et al. 2002; Unal et al. 2006; Kind and Kind 2011). Chemical bonding involves the interaction between many abstract ideas and is, itself, founded upon the area of PNM, thus, giving it an additional layer of complexity when compared with the area of PNM (Taber 2002; Coll and Treagust 2003). There is little doubt that this contributed to the disappointing results in relation to chemical bonding.

The SuBATOMIC programme took a more PCK-focused approach in the face-to-face sessions in which the PSSTs addressed the area of PNM. These face-to-face sessions involved the creation of teaching resources that could aid them in addressing the alternative conceptions of their future students. The face-to-face sessions in which the area of chemical bonding was addressed, involved the creation of a resource that could be used by their peers for revision prior to teaching a lesson and the modelling of teaching strategies. The PCK-focused sessions, therefore, were more successful in engaging with PSSTs in their authentic roles as future teachers. The connection between developing SMK and PCK has been recognised by some researchers as a two-way process (Sperandeo-Mineo et al. 2006; Nilsson 2008) and, therefore, the better linkages between PCK and SMK in relation to PNM may have contributed to the better performance noted in this area.

The online and face-to-face components of the blended learning programme were also better integrated during the weeks in which PSSTs addressed the area of PNM than during the weeks in which they addressed chemical bonding. This was simply due to the time-intensive nature of creating web and multimedia resources for the SuBATOMIC website each week. As a result, there was better consistency between the face-to-face sessions and online component during the PNM-focused phase of the programme. Webpages that supported and extended PSSTs’ efforts in the face-to-face session were published in a timelier manner for the PNM-focused phase when compared with the chemical bonding-focused phase. The PNM web-based resources also made better use of the multimedia capabilities of web technology and provided learner feedback. The integration of face-to-face and online learning components is central to the effectiveness of a blended learning programme (Garrison and Vaughan 2008) and, therefore, it seems likely that the gradual separation of these components during the chemical bonding-focused phase of the programme contributed to the disappointing results in relation to chemical bonding.
The findings presented and discussed in Chapter 8 related to the following research question:

How do PSSTs approach conceptual questions in a quantitative alternative conceptions diagnostic instrument?

This phase of the research was founded upon the philosophy of constructivism and involved the application of an inductive thematic analysis to semi-structured interview transcripts from PSSTs who had completed the alternative conceptions diagnostic instrument used to address RQs C1 and M2. The analysis revealed five approaches, summarised as follows:

- **Balancing of Factors**: this involved introducing a number of concepts/factors considered to be relevant and weighing them against one another to select a response.
- **Pure Algorithm**: this referred to the application of an algorithm, with either no ability to discuss or no attempt to discuss the underlying concepts. It was only applied to diagnostic items involving mathematical calculations.
- **Concept Consideration and Immediate Consistent Response**: PSSTs discussed their concepts and then, often almost immediately, selected a response that was consistent with these concepts. This was the most common approach used by PSSTs.
- **Elimination**: this involved considering multiple response options in an attempt to discern which were false and which were true.
- **Concept Consideration and Algorithm**: PSSTs considered concepts which they believed to be relevant and also applied an algorithm to select a response option. This is distinct from the Pure Algorithm approach in that PSSTs were able to connect the algorithm to underlying chemistry concepts.

Non-approaches were also identified in which PSSTs guessed the response option or selected a response as they felt drawn to it because ‘it looks right’ or ‘it sounds right’. These were relatively uncommon. Past research on alternative conceptions has also carried out semi-structured interviews for which a diagnostic instrument forms the interview protocol (e.g. Sanger 2000; Tan *et al.* 2005). These research studies tend to focus solely upon instrument validation or other issues. However, some of the approaches identified in the current study, such as Balancing of Factors, Pure Algorithm, and, Concept Consideration and Immediate Consistent Response, may also be observed in interview transcripts from these studies (Nakhleh and Mitchell 1993; Sanger 2000; Tan *et al.* 2005). A process of Elimination and non-approaches have also been identified in past research on multiple-choice items, with Elimination being typically observed in a negative light (Nakhleh and Mitchell 1993; Kitsantas 2002; Harlow and Jones 2004).
Nyachwaya et al.’s (2011) assertion that diagnostic items lead to ‘choice-making’ approaches and not ‘sense-making’ approaches was found to be a somewhat bleaker view than reality. Although some of these approaches could be presented as choice-making approaches, in most cases, the approaches were carefully considered and did involve a lot of sense-making. Balancing of Factors, Concept Consideration and Immediate Consistent Response, and Concept Consideration and Algorithm, were all found to involve sense-making. Even the Elimination approach was, occasionally, observed to be a carefully considered approach combining sense-making with choice-making.

Nonetheless, there was evidence that less considered approaches were also used by PSSTs in their approach to diagnostic items. Elimination sometimes presented as a less considerate approach than mentioned above. The Pure Algorithm approach was observed to be one devoid of any sense-making; the algorithm was sufficient for them to make a choice. The PSSTs that were interviewed relied on an Elimination approach more often in chemical bonding and equilibrium diagnostic items than in the other conceptual areas. The Pure Algorithm approach was used more often in equilibrium and stoichiometry than in the other areas. Equilibrium was very poorly understood and the issue in this area appeared to be less one of alternative conceptions than one of a total lack of any kind of understanding leading to an inability to discuss concepts in this area. This is likely the reason for the greater use of the choice-making approaches in this conceptual area. The use of less-considered Elimination approaches in the area of chemical bonding may also be a reflection of the confidence and/or low conceptual understanding in this area – PSSTs relied upon alternatively-conceived ideas far more than scientifically-conceived ideas in this conceptual area. In the area of PNM, PSSTs relied upon alternatively-conceived ideas only slightly more than scientifically-conceived ideas in responding to diagnostic items. PSSTs also used more of the sense-making approaches in the area of PNM, suggesting that they may have more confidence and/or more well-developed conceptual understanding in this area.

The analysis of the interview transcripts associated with Research Question M1 also led to some unexpected findings. The interview appeared to take place on a negative affective background for the PSSTs, as evidenced by mannerisms and statements such as nervous laughter, repeatedly apologising for a lack of understanding, and making other negative statements about their emotional state. Over the course of the interviews, the PSSTs spontaneously introduced reflections upon previous educational experiences. These reflections tended to depict past learning experiences in a negative light. PSSTs engaged in reflections upon their upper-second-level educational experiences in chemistry far more than any other type of educational experiences. PSSTs also made references to their
retention/recall of course material encountered in upper-second-level and third-level educational experiences. They also reflected on their Teaching Practice experiences – typically in a positive light.

(d) Research Question C2
The approach to answering this research question was founded upon Stein’s philosophy of empathy and community, using Baxter’s (2011) Relational Dialectics Theory (RDT) as a sensitising theory. This perspective reframed the problem of alternative conceptions as a problem of persons relating with one another, rather than a problem situated primarily within individual cognitive structures. The research question was as follows:

How do PSSTs experience the issue of alternative conceptions in chemistry in a community-oriented, blended learning environment?

The findings, presented and discussed in Chapter 9, related to two case studies. These findings demonstrated that the experience of a number of relational dialectics in these two community-oriented groups, and the interplay upon which these dialectics were constituted, gave meaning not only to the behaviours within the group but also to the interplay between conceptual discourses in the group. There were three main dialectical tensions observed in the two groups:

- **Denial – Acceptance;** this was a tension surrounding PSSTs’ awareness of barriers to conceptual discussions. There was a tension between the acceptance of these barriers and the denial of these barriers.

- **Expression – Non-Expression;** this was a tension with regard to the extent to which PSSTs desire to share their personal thoughts, understanding, etc. and their desire to withhold this kind of information.

- **Learner – Teacher;** this tension related to the differing perspectives adopting by groups: they sometimes saw themselves as learners of chemistry, and at other times saw themselves as teachers of chemistry.

The interplay between these tensions gave meaning to the extent to which groups engaged in open and honest discussion about the meaning of chemistry concepts, and the extent to which groups engaged in experiences in which metacognitive judgements and monitoring were shared. The group’s engagement with these metacognitive judgements and monitoring experiences was one of the central distinctions between the two community-oriented groups observed. The findings provided some evidence of socially shared metacognition, which influenced the collective activity of the group. This socially shared metacognition was supported by an interplay between denial and acceptance in which acceptance was given
dominance over denial, and an interplay between expression and non-expression in which non-expression was reframed as complementary with expression. Conversely, these experiences appeared to be limited in the presence of an interplay between denial and acceptance in which denial and non-expression were dominant over their counterparts.

Conceptual discourses were identified about a number of chemistry concepts. Discourses based on alternative conceptions about the distinction between the terms molecule and compound, and the distinction between the terms element and atom included that:

- compound and molecule are mutually exclusive concepts,
- all compounds are molecules, and
- element and atom are synonymous terms.

In the area of impetus for bonding, the following discourse, based on alternative conceptions, was observed: atoms form covalent bonds to gain a full outer shell, by borrowing electrons, which allows them to achieve stability. The discourses based on alternative conceptions were usually in tension, in some capacity, with discourses based on more scientifically-acceptable ideas. Polarity was also discussed in one of the case studies. In this case, only a scientifically-acceptable discourse was engaged in by the group. More favourable group learning outcomes were observed where there was some discursive contact between alternative discourses (i.e. discourses based on alternative conceptions) and scientifically-acceptable discourses. A direct, antagonistic struggle between alternative and scientifically-acceptable discourses allowed the groups an opportunity to deepen and challenge their collective understanding. Indirect struggles between discourses were not observed to provide such opportunities.

The relational dialectics within the experience of the community-oriented group gave meaning to the observed interplay between conceptual discourses. Direct, antagonistic struggles between conceptual discourses occurred when a group experienced the dominance of acceptance discourse and the denial discourse was marginalised. In accepting their own barriers to conceptual understanding, e.g. a barriers such as the presence of a conceptual confusion, a group was able to move forward in their attempt to develop better conceptual understanding. In the presence of a recalibration interplay between expression and non-expression, in which non-expression involved viewing private revision or group learning summaries as a way to support higher engagement with expressive and open experiences, the group was supported in moving forward in discussing their collective understanding. However, indirect interplays between conceptual discourses were given meaning in the context of the dominance of denial and non-expression over their discursive counterparts.
The relational dialectics were also deeply inter-related, with the interplay upon which one dialectic was constituted interacting with the interplay of the other dialectics. For example, the dominance of the teacher discourse over the learner discourse was associated with less discursive contact between conceptual discourses. However, this is, likely, less a reflection of the learner–teacher dialectic and more a reflection of the inter-related nature of this dialectic with other dialectics. The teacher discourse often rose to dominance as a consequence of the dominance of denial of barriers over acceptance of barriers. In viewing themselves as ‘experts’ and ‘teachers’ in an interplay where this discourse was dominant, a group reduced opportunities for the acceptance of barriers discourse to gain dominance, and vice versa. Similarly, non-expression often rose to dominance where the groups experienced a dominance of denial of conceptual barriers over acceptance of barriers.

10.2 LIMITATIONS OF THE RESEARCH

The limitations of the quantitative strand of Phase 1 of this research study, i.e. research related to RQ C1, were associated with the ‘missing’ variables for the regression models presented in Chapter 5. The variables included were primarily related to PSSTs’ formal educational experiences. However, the resulting models could not account for large amounts of the variance in the data. Variables related to metacognition, teaching experience of chemistry, reasoning ability, and learning approaches would have been useful to include in the models in order to account for more of this variance.

The integration between the face-to-face and online components of the SuBATOMIC blended learning programme proved to be a limitation for the quantitative strand of Phase 2, i.e. research related to RQ M2. Over time, these two components gradually became divorced from one another, owing to the time intensive nature of creating multimedia materials and web-based resources. This reduced the effectiveness of the learning programme, making it difficult to ascertain whether the disappointing results in relation to chemical bonding were due to this fact, due to the greater SMK-focus of the chemical bonding face-to-face session, or due to issues related to the topic itself. Furthermore, the small sample size, of approximately thirty PSSTs, in the Blended Learning and Conventional Groups meant that the statistical power of the comparison tests was only sufficient to attribute significance to differences associated with large effect sizes. This makes it difficult to ascertain whether the medium and small effect sizes noted between the two groups are ‘true’ differences or merely statistical ‘noise’.

The qualitative strand of Phase 1, i.e. the research related to RQ M1, involved semi-structured interviews with PSSTs using the diagnostic instrument as the interview protocol.
The limitations associated with this strand of research are largely related to my own inexperience with this data collection method at that time. On some occasions, I failed to ask important probing questions and on other occasions, I sometimes lacked clarity in my questioning skills. Furthermore, the approaches to responding to diagnostic items that were identified may be more reflective of approaches in a semi-structured interview environment, rather than a ‘test-taking’ environment. This point is further discussed in Section 10.4 in the context of integrating the research strands.

The data collected to address RQ C2, i.e. the qualitative strand of Phase 2, was not collected for the purpose of identifying relational dialectics. The data collection methods were considered appropriate for gaining insight into PSSTs’ experiences of addressing alternative conceptions in chemistry. Upon exposure to this data, a tension between certain behaviours in the groups was observed. This lead to a review of the research literature, and ultimately, to Baxter’s (2011) RDT. Furthermore, the secondary data was intended to form a greater part of the analysis – representing the community-oriented groups in the online component of the blended learning programme. However, the PSSTs did not engage with concepts in either the reflective journal data or the social media data. This lead to the audio-visual data being the primary data source. As a result of this, the data is more representation of PSSTs’ experience of addressing alternative conceptions in a community-oriented small-group environment, rather than a community-oriented blended learning environment. It would also have been useful to obtain a second coder to assess the reliability of the discourses identified in the data. However, this was not achieved as a result of time constraints.

10.3 **NOVELTY OF THE RESEARCH**

A number of the research findings from the current study have not, to the best of my knowledge, been noted in past research studies. For example, upper-second-level chemistry experience was found to be a more important factor in PSSTs’ conceptual understanding than their subject specialism or any measure relating to additional study of third-level chemistry, and the conceptual understanding of PSSTs in relation to the abstract topic of chemical bonding was found to be better among concurrent PSSTs when compared to consecutive PSSTs.

However, the primary source of novelty in this research study is due to the introduction of the philosophy of Edith Stein to the context of Science Education Research (SER) for the first time. The philosophy of Stein allowed Phase 2 of this research study to become one more focused upon the *lived experience* of PSSTs and on maintaining a holistic a view of them as human persons throughout the qualitative analysis. The investigation that took place in
Phase 2 of the current study could, of course, have been founded upon a different philosophy—social constructivism is an obvious option that comes to mind. However, this would likely reduce the holistic focus on lived experience which is absolutely central to Stein’s works. Furthermore, Stein explicitly accounts for human persons’ access to objective knowledge through intersubjectivity. For researchers whose personal stance reflects the value of knowledge for its truth/objectivity rather than its usefulness, and for whom the regular accusations of relativism within strands of constructivism are troubling (Suchting 1992; Phillips 1995; Matthews 2002), Stein’s works provide a more natural foundation.

This research study also introduces the sensitising theory of RDT developed by Baxter (2011) to the context of SER. This theory, in combination with the philosophy of Stein, led to a research perspective which reframed the problem of alternative conceptions from one of conceptions as cognitive structures in the minds of learners, or conceptions as socially-constructed among groups of learners, to one of alternative conceptions as a problem founded upon the tensions experienced by learners relating to one another as a community. This led to a number of interesting observations about PSSTs’ experience of relational dialectics and the influence that this experience appears to have on their behaviours, such as their engagement with metacognitive experiences, and upon the interplay between conceptual discussions. Particular interplays between opposing conceptual discourses were also observed to be more or less favourable. This line of research could prove to be a fruitful direction for research into the problem of alternative conceptions in the future.

10.4 INTEGRATING THE RESEARCH STRANDS
Many of the findings associated with each research question, have implications for, and lend insight into, the findings associated with other questions. These insights and implications related to factors contributing to alternative conceptions, addressing alternative conceptions, and the value of diagnostic instruments such as that used to address RQs C1 and M2. This integration of the research strands will now be presented according to each of these areas.

(a) Factors Contributing to Alternative Conceptions in Chemistry
In addressing RQ C1, the previous study of upper-second-level chemistry was found to be the most powerful predictor of performance in an alternative conceptions diagnostic instrument. Additional study of chemistry, in the context of subject specialism, model of STE, and increasing years of third-level study, was not associated with a decrease in the prevalence of alternative conceptions and, in some cases (i.e. the consecutive model of STE and increasing years of study for concurrent PSSTs), was associated with an increase in alternative conceptions. This was attributed to a memory-loss effect: over time PSSTs are forgetting content that is unused or perceived as irrelevant. This suggests that third-level
educational experiences are not meeting PSSTs’ needs. They are not providing an equalising experience in introductory chemistry modules for PSSTs with and without past study of upper-second-level chemistry, and more advanced modules do not appear to be providing sufficient connections between advanced chemistry concepts and fundamental chemistry concepts. This conclusion was supported by the unexpected findings associated with RQ M1, as PSSTs repeatedly reflected upon the impact of their second-level educational experiences when considering chemistry concepts, despite the fact that some of them were specialising in chemistry and in their final year of study in a concurrent STE programme.

The analysis associated with RQ C1 led to the creation of predictive models for which there were large amounts of unaccounted variance. This suggests that other factors are more important in predicting the prevalence of alternative conceptions among PSSTs than educational measures. The findings arising from the analysis associated with RQs M1 and C2 indicate that factors such as academic emotions, metacognition, and the nature of educational experiences relating to one another may be more central to understanding the problem of alternative conceptions. PSSTs were observed to experience academic emotions such as shame and embarrassment (RQ M1). Such emotions may impact upon their experience of the dialectical tensions observed when addressing RQ C2. Academic emotions such as shame may lend themselves to educationally unfavourable interplays between such dialectical tensions as denial – acceptance and expression – non-expression. For example, in the case studies associated with RQ C2, behaviours associated with shame (such as covering one’s face in embarrassment) were observed to coincide with an interplay between expression and non-expression in which non-expression dominated. This, in turn, led to the premature end of a period of conceptual discussion. Metacognition, and particularly the open sharing of metacognitive judgements and monitoring, was observed to be central to experiences in which groups had productive discussions about conceptual discourses. This sharing from one member of a group, could benefit the whole group if they engaged with it. Therefore, metacognition and academic emotions are likely to be contributors to the variance that was unaccounted for by the models associated with RQ C1.

Finally, emphasis must be placed upon the impact of particulars of PSSTs’ experiences in addressing alternative conceptions. The interplay between conceptual discourses appears to be central to the collective understanding of the group. Direct, antagonistic interplays appear to be more favourable than indirect interplays or interplays in which discourses do not come

181 See Chapter 9, Section 9.2.
into discursive contact. The interplay between conceptual discourses is, itself, founded upon the interplays in the community-oriented group experience. Within the same blended learning programme, vastly different interplays between conceptual and relational dialectics were observed. In light of this, the small amount of variance accounted for by broad educational categories in the predictive models is likely also due to the failure of this method to account for the vastly difference learning experiences of PSSTs within such categories.

(b) Addressing Alternative Conceptions in Chemistry
The blended learning programme created for this study, SuBATOMIC, was not overly successful in addressing PSSTs’ alternative conceptions in chemistry according to the findings associated with RQ M2. This is in line with much of educational research literature in which attempts were made to address alternative conceptions among various groups of learners (Winthu r and Volk 1994; Bowen 2000). It is also not surprising in light of the findings associated with RQ C1, in which many of PSSTs’ educational experiences did not influence the prevalence of alternative conceptions. SuBATOMIC was more successful in addressing alternative conceptions in PNM than in chemical bonding, and as previously noted, the integration between online and face-to-face components, and the PCK-focus or SMK-focus given to activities within the two conceptual areas likely contributed to this. The findings of RQ C2, also shed light on the mixed outcome of the SuBATOMIC programme.

Although the SuBATOMIC groups were presented with the same tasks in each session, and the same opportunities during the online component, the lived experience of these groups varied widely. Even within a single community-oriented group, in a single SuBATOMIC face-to-face session, the experience of addressing one conceptual area could be qualitatively different from the experience of addressing another conceptual area. The diagnostic instrument used in this study, did not attempt to account for these differing experiences. The case studies associated with RQ C2 demonstrated that direct, antagonistic interplays between alternative and conceptual discourses created opportunities for the groups to increase the depth of their conceptual understanding, while indirect interplays did not provide such opportunities. These direct, antagonistic interplays were founded upon the interplays and inter-relationships between the dialectical tensions observed within the experience of the community-oriented group and the behaviours resulting from these interplays, such as engagement with experiences in which metacognition was socially shared.

However, the analysis of the two groups participating in the SuBATOMIC programme is not generalisable. There are likely other dialectical tensions at play in learning communities in different contexts with different goals. Furthermore, there are likely more types of
interplays between both conceptual discourses and community-oriented group experience dialectics than were observed in these two groups, and some of these may be more or less favourable to educational outcomes. This study highlights the importance of identifying these dialectical tensions and the interplays upon which they are constituted in order to gain greater insight into the problem of the alternative conceptions, and the types of experiences which are more or less favourable to addressing them.

(c) The Value of Diagnostic Instruments

An alternative conceptions diagnostic instrument was developed and validated as part of this study. It was used to address RQs C1 and M2. In investigating PSSTs’ approaches to answering diagnostic items within this instrument, as part of RQ M1, five rational approaches were identified as well as a number of non-rational approaches, such as guessing, etc. Although, past research has suggested that approaches to answering diagnostic items are ones devoid of sense-making (Nyachwaya et al. 2011), the current research found that most of the PSSTs interviewed did engage in sense-making in answering most of the items. This suggests that diagnostic items do have value in representing PSSTs’ conceptual understanding about the specific concepts which the item was designed to assess.

However, this strand of the research may be viewed in a different light on the basis of the findings associated with RQ C2. This latter strand of research took a perspective in which ownership of statements, or utterances, made by persons relating to one another is attributed, not only to the party actively communicating, but also to the person to whom the communication is directed. In Chapter 9, a number of experiences were highlighted in which an utterance or utterances, and the experience in which they were made, were directly impacted upon by the communicating party anticipating the response from other parties. This is an example of the nature of this shared ownership of utterances. Therefore, the ownership of the semi-structured interviews and the approaches identified there-in, belongs to both the participating PSSTs and me, as the interviewer. Therefore, PSSTs may have adapted their approaches and utterances based on their anticipation of my reactions, attitudes, and beliefs. As such, these approaches belong to both of us and may not be reflective of the approaches which they would take were they completing the instrument in isolation. In fact, it seems likely that their approaches would be different, given that the two experiences (interview and ‘test-taking’) are quite distinct and the relational dialectics experienced in the two situations and/or the interplays upon which they are constituted are likely to be different.
10.5 IMPLICATIONS FOR CHEMISTRY AND SCIENCE EDUCATION

This study has demonstrated that third-level chemistry education is not levelling the playing field for learners that have and have not studied chemistry during upper-second-level education. This has implications for the first year of study in chemistry/science degree programmes, being the most obvious time in which this should be addressed. The introductory chemistry modules experienced during the first year of degree programmes are not providing a sufficient foundation in fundamental chemistry concepts. Such modules need to explicitly address the content of second-level chemistry, adopting more learner-centred approaches. This study also implies that more advanced chemistry modules need to contain explicit links to fundamental chemistry concepts encountered during introductory chemistry modules, in order to mitigate the memory-loss that was found to be detrimental to PSSTs’ understanding in this study. Furthermore given the importance and long-lasting impact of upper-second-level chemistry education, improving upper-second-level chemistry education is likely to provide significant and long-lasting returns for students of chemistry at third-level.

PSSTs following the consecutive STE model have been shown to be at a disadvantage when compared with PSSTs following the concurrent model. This suggests that consecutive PSSTs must be presented with opportunities during their STE programmes to address their understanding of the concepts which they will teach. In the Irish system, these programmes do not provide courses with the goal of developing SMK. However, the reciprocal relationship between PCK and SMK allows for this to be achieved within subject-specific pedagogical methods modules. STE programmes and pedagogical methods modules are already attempting to fulfil the needs of PSSTs in multiple areas identified in the literature, leaving limited time to address the issues raised in this study. A blended learning approach to such modules could allow for connections to be made between PCK and SMK without significantly reducing the contact hours available to address other important issues.

This study demonstrates that simply providing the opportunities suggested above is not sufficient, of itself, to aid PSSTs in addressing their alternative conceptions in chemistry. The specific experience of this opportunity is just as, if not more, important in addressing conceptual understanding. Experiences of shame and embarrassment about levels of conceptual understanding may underpin interplays between denial and acceptance discourses in which denial of conceptual understanding is given the dominant voice. This also has implications for the interplay upon which dialectics such as expression – non-expression are constituted. All of which underpin the manner of interplay in which conceptual discourses are experienced. Therefore, once STE programmes and chemistry/science degrees have
created opportunities in which conceptual understanding of fundamental concepts can be addressed, they must then focus upon creating learning environments that support experiences which are favourable to educational outcomes. The inclusion of metacognitive experiences within these wider learning experiences was observed to be important in this study. Therefore, the use of learning cycles which include metacognition in their structure (e.g. Blank 2000) may be suitable as a basis for designing these learning opportunities. Further research is required to determine how to support learning communities in finding favourable interplays between relational dialectics. This will be further addressed in the next section.

10.6 IMPLICATIONS FOR CHEMISTRY AND SCIENCE EDUCATION RESEARCH
This research study has a number of implications for the methods used in future SER. It also introduced a new philosophy to the SER context which future researchers may wish to consider. The findings of the current study present some potential directions for future research. These implications will be presented as they relate to future qualitative, quantitative, and mixed methods research. These categories are not hard and fast, with suggestions for one type of research often having cross-over with other types of research, rather the implications have been placed within the research types which are most likely to be relevant.

(a) Qualitative Research
RDT as a sensitising theory with which to investigate PSSTs’ experience of addressing alternative conceptions proved to be a fruitful area in which to gain insight into the problem of alternative conceptions. A number of relational dialectics, founded upon a number of interplays, were observed in the current research study. However, there are likely to be more relational dialectics experienced by learners in different contexts. There are also likely to be interplays not identified in the current study which are favourable to educational learning outcomes. This area requires future qualitative research to continue this investigation. The audio-visual data method used in this study allowed for the identification of relational dialectics and their interplays in real-time. However, it would have been useful to use an approach in which those observed in the audio-visual data, viewed the data shortly after the session, and took part in an interview about the observational data. Such a method would allow for better insight into the relational dialectics experienced within the audio-visual data.

Once such additional insight into PSSTs’ experience of relational dialectics has been further researched, it will become necessary to shift the focus of research investigating learning programmes/interventions from one of effectiveness in remediating alternative conceptions to one of effectiveness in creating an environments that lend themselves to favourable interplays upon which the relational dialectics are constituted. Perhaps the creation of such
environments may involve creating an awareness among learning groups or communities of the dialectics that they are experiencing. Thus, allowing them to determine which interplays will be suitable for them by attempting to create explicit ‘turning points,’ in which they actively decide how the tension should play out in the group. An example of the success of this was observed in Case Study A, presented in Chapter 9, wherein a turning point determined the interplay between denial and acceptance.

(b) Quantitative Research

The quantitative research strands in this study have implications for the methods used in future quantitative research. The findings in relation to RQ C1, demonstrate that upper-second-level study chemistry is the most important predictor of performance in an alternative conceptions diagnostic instrument, while PSSTs’ subject specialism is not a predictor of performance. Past research has found that PSSTs with a chemistry specialism outperform non-specialists in similar diagnostic instruments (e.g. Kind and Kind 2011). However, these studies did not control for or consider PSSTs’ previous upper-second-level study. The results presented in Chapter 5 demonstrated that the variance attributed to PSSTs’ subject specialism in comparison testing (i.e. t-tests, ANOVAs, etc.) is actually associated with their upper-second-level chemistry experience. This was likely also the case in past research investigating the impact of subject specialism, leading to false positive results. Future research carrying out similar investigations in relation to subject specialism, as well the impact of advancing study of chemistry, must control for this variable in order to obtain valid results.

The regression models developed to address RQ C1 could not account for large amounts of the variance in the data. This indicates that there are more important factors impacting upon PSSTs’ alternative conceptions in chemistry. Metacognition was hypothesised to be one of these factors, and the findings in relation to RQ C2 support this hypothesis: the extent to which groups engaged in metacognitive experiences had a strong influence on the overall experience of the group in discussing chemistry concepts. Therefore, any future attempts to understand the factors contributing to conceptual understanding should include a measure of metacognition as part of their research. Teaching Practices (TP) were spontaneously reflected upon in the interviews carried out in relation to RQ M1. Teaching experiences have also been shown in past research to impact upon conceptual understanding and alternative conceptions (e.g. Morine-Dershimer 1989). The regression models created in the current study could not account for PSSTs’ TP as no data was collected on how much chemistry had been taught on TP. Therefore, future research with PSSTs should include a measure of their experience teaching the concepts being assessed by any diagnostic instrument. The better performance of concurrent PSSTs, compared with consecutive PSSTs, in the current
research study was attributed to the arrest of the memory-loss effect. This arrest was interpreted as being due to differences in learners’ perceptions of the value of chemistry course material during their third-level study of chemistry as a result of differences in their perceptions of their future roles; the concurrent PSSTs perceived their future role as teachers of science from the outset of their third-level study of chemistry, while the consecutive PSSTs, generally, would have perceived their future role as teachers of science some time after they had completed all study of the subject. Further research is need to confirm the impact of future role expectations on PSSTs’ perceptions of the importance of course material relating to fundamental concepts in chemistry.

(c) Mixed Methods Research

The current research study attempted to identify PSSTs’ approaches to answering diagnostic items. However, the findings in relation to this aspect of the study may be more reflective of PSSTs’ approaches to diagnostic items in the context of a semi-structured interview environment, rather than a ‘test-taking’ environment. A more appropriate approach may be to obtain audio-visual data of PSSTs answering diagnostic items using a think-aloud approach. Alternatively, the approaches identified in this study could be described in a multiple-choice format, in addition to other open-ended methods, with PSSTs selecting an approach after they respond to each diagnostic item.

An exploratory aspect relating to the research-to-practice gap was included during the investigation of RQ M2. This suggested that the approach to the blended learning programme – one that engaged with PSSTs in their role as future teachers – may have contributed positively to PSSTs’ perceptions of the importance of SER and the frequency with which they engaged with SER. It is particularly notable that PSSTs in the Conventional Group experienced a severe decrease in their perceptions of the importance of SER after TP, while the Blended Learning Group continued to consider SER to be very or highly important. Future research could investigate PSSTs’ experiences of TP with a focus upon this phenomenon and assess the viability of a blended learning approach prior to and/or during TP in bridging the research-to-practice gap. This approach could also be extended to, and investigated for, in-service teachers in the context of professional development courses. Such studies would be best served by mixed methods in order to gain both an understanding of the depth of these experiences, and to assess the generalisability of these findings.

Much more qualitative research is required to investigate the relational dialectics of PSSTs while addressing their conceptual understanding in different contexts. Assuming such research took place, it would also be fruitful for researchers with a quantitative focus to have
an instrument which could provide a basic outline of the relational dialectics experienced and the interplays upon which they are constituted. Mixed methods researchers could provide such an instrument by combining qualitative research on this issue with further qualitative and quantitative methods to develop and validate such an instrument.

10.7 PERSONAL REFLECTION ON THE RESEARCH PROCESS

The research process was one that developed over time, in tandem with my own development as a researcher. It is interesting that, although the qualitative strand of Phase 1 appears to be less impactful than other research strands, it was the lynchpin around which the research developed in Phase 2. During the semi-structured interviews, I got a sense of the distress experienced by PSSTs when they were discussing their conceptual understanding. This led me to seek a new way to engage in Phase 2 of the research: one that was respectful of them as people with many types of experiences in life. It was this desire that led me to review the philosophical foundations of the study. Within this review, I began to question the accepted wisdom of constructivism as the foundation for SER. This led to my engagement with the philosophical works of Edith Stein, which reshaped the research study and resulted in a reframing of the problem of alternative conceptions.

In hindsight, there are a number of interesting points about this process. My perception of the distress of PSSTs during the interview process was founded upon my ability to empathise with them, and empathy was a central factor in Stein’s work which drew me, initially, to this philosophy. Furthermore, Baxter (2004) has noted that one element of RDT relates to an obligation to critique dominant voices and discourses. She refers to this as a process of “discrowning,” (Baxter 2004). In my questioning of the accepted wisdom of constructivism as a foundation for SER, I was attempting, however modestly, to ‘discrown’ this dominant discourse within SER. A philosophical and theoretical stance in research, is intended to present the position of the researcher and, in light of these unintentional coincidences between my engagement with the research and my selected philosophical and theoretical stances, I am confident that these do indeed reflect my stance as a researcher. It was never my intention to suggest that constructivism was ‘wrong,’ and I do not believe that has been suggested in this thesis. Rather, it was my intention to suggest that it is not the only, or possibly not even the ‘best’, philosophical foundation upon which research can be guided. Just as the PSSTs involved in this research study have shown themselves to be unique people whom experience similar learning activities in different ways, so too are researchers unique, and expanding the philosophical and theoretical stances upon which SER is founded can only be a positive thing.
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Appendix A  

Sample of Information Sheets and Consent Forms

INFORMATION SHEET FOR BLENDED LEARNING PROGRAMME

Title of Project: An Investigation of the Alternative Conceptions in Chemistry held by Pre-Service Science Teachers (PSSTs) in Ireland and the Development of Effective Strategies, Methods and Materials to Improve Pre-Service and In-Service Chemistry Teachers’ Understanding of Chemistry

The Study: This project is investigating PSSTs’ alternative conceptions in chemistry. The main research questions of this project are:
• What alternative conceptions do pre-service science teachers hold?
• Does the mode of entry into the teaching profession (consecutive or concurrent) have an effect on the alternative conceptions of PSSTs?
• What are PSSTs’ experience of a blended learning programme to address alternative conceptions in chemistry?
• Does a blended learning programme improve PSSTs’ understanding?

Participation Information: You will be required to take part in an intervention programme on a voluntary basis. As part of this programme you may be asked to take a pen-and-paper type test on alternative conceptions in chemistry. This programme consists of a number of workshop and tutorial type sessions last approximately 50 minutes. You may at a later date be contacted to participate in an interview about this programme.

There are no risks involved in this study. All information gathered will remain confidential and used only for the purpose of this study. The information gathered will be stored safely with access only available to the investigator.

You are under no obligation to participate in this study. Should you have any questions or do not understand something, please contact me and I will clarify any issues that you are concerned about.

Contact details: Muireann Sheehan  
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Foundation Building,  
University of Limerick,  
Limerick.  
muireann.sheehan@ul.ie

Peter Childs  
Chemical and Environmental Sciences,  
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University of Limerick,  
Limerick.  
peter.childs@ul.ie

If you have concerns about this study and wish to contact someone independent, you may contact
The Chairman of the University of Limerick Research Ethics Committee,  
c/o Vice President and Academic and Registrar’s Office,  
University of Limerick,  
Limerick.  
Tel: 061-202022
CONSENT FORM FOR BLENDED LEARNING PROGRAMME

Consent Section:

I, the undersigned, declare that I am willing to take part in research for the project entitled “An Investigation of the Alternative Conceptions in Chemistry held by Pre-Service Science Teachers in Ireland and the Development of Effective Strategies, Methods and Materials to Improve Pre-Service and In-Service Chemistry Teachers’ Understanding of Chemistry”.

- I declare that I have been fully briefed on the nature of this study and my role in it and have been given the opportunity to ask questions before agreeing to participate.
- The nature of my participation has been explained to me and I have full knowledge of how the information collected will be used.
- I am also aware that my participation in this study may be recorded (video/audio) and I agree to this. However, should I feel uncomfortable at any time I can request that the recording equipment be switched off. I am entitled to copies of all recordings made and am fully informed as to what will happen to these recordings once the study is completed.
- I fully understand that there is no obligation on me to participate in this study.
- I fully understand that I am free to withdraw my participation at any time without having to explain or give a reason.
- I am also entitled to full confidentiality in terms of my participation and personal details.

______________________________________         __________________________
Signature of participant                                               Date
Appendix B    Accessing the SuBATOMIC Website

These details have been removed to protect the security of the website.
Appendix C     Quantitative Instruments used in this Study
Demographic Survey from Phase 1

SECTION A: Personal Information - Please fill in the relevant information in the spaces provided

Gender:   Female   □   Male   □

Date of Birth (DD/MM/YY): ___________________________

Course of Study (Indicate any electives): __________________________

Year of Study: Year 1 □   Year 2 □   Year 3 □   Year 4 □

Did you study science for the Junior Certificate?   Yes □   No □

<table>
<thead>
<tr>
<th>Subject</th>
<th>Leaving Certificate Level <em>(Please tick applicable box)</em></th>
<th>Grade Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>Ordinary □   Higher □   Not Taken □</td>
<td></td>
</tr>
<tr>
<td>Maths</td>
<td>Ordinary □   Higher □   Not Taken □</td>
<td></td>
</tr>
<tr>
<td>Physics</td>
<td>Ordinary □   Higher □   Not Taken □</td>
<td></td>
</tr>
</tbody>
</table>

If Chemistry, Maths or Physics was *not taken for the Leaving Certificate*, please describe any alternative experience of these subjects that you may have:
                                                                                     
Have you heard of misconceptions in chemistry prior to this study?   Yes □   No □

If YES, please explain how you heard about this topic:
                                                                                     
                                                                                     
                                                                                     
C-1
Demographic Survey used in Phase 2

SECTION A: Personal Information – Please fill in the relevant information in the spaces provided

Gender:  □ Female  □ Male

What is your Date of Birth? (DD/MM/YY): _____________________________________

What subjects will you be qualified to teach at Leaving Certificate level on completion of your science teacher training degree? (Tick all that are relevant)

□ Biology  □ Agricultural Science

□ Chemistry  □ Mathematics

□ Physics  Other:______________________

Did you study science for the Junior Certificate?  □ Yes  □ No

<table>
<thead>
<tr>
<th>Subject</th>
<th>Leaving Certificate Level (Please tick applicable box)</th>
<th>Grade Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>□ Ordinary  □ Higher  □ Not Taken</td>
<td></td>
</tr>
<tr>
<td>Maths</td>
<td>□ Ordinary  □ Higher  □ Not Taken</td>
<td></td>
</tr>
</tbody>
</table>

What grade did you receive in the Organic Chemistry module last semester? (Only Tick One Option)

□ A1  □ B1  □ C1  □ D1

□ A2  □ B2  □ C2  □ D2

□ B3  □ C3
SuBATOMIC Website Survey

The focus of this website will be to provide student science teachers with information, resources and teaching activities that are based on Science and Chemistry Education Research. The website will inform student science teachers of common alternative conceptions (scientifically incorrect ideas that interfere with learning new concepts) about chemistry that they are likely to find among their pupils on Teaching Placement. It will also include summaries of the Junior Certificate topics so that student science teachers can revise their own understanding before teaching. The website will link to a Facebook page and Twitter account to provide a forum for student science teachers to discuss teaching activities with each other and where they can receive support from a science education graduate and researcher.

1. After reading the description above, how interested are you in this service? (Tick one box)
   - □ Extremely interested
   - □ Very interested
   - □ Moderately interested
   - □ Slightly interested
   - □ Not at all interested

2. What content or features would you most like to see included on the website? (Tick all that are relevant)
   - □ Examples of teaching activities
   - □ A list of common incorrect ideas which pupils may have about chemistry
   - □ Advice on lesson planning
   - □ Articles which summarise relevant Science/Chemistry Education Research
   - □ Examples of how to implement research ideas
   - □ Teaching resources, e.g. videos, worksheets, pictures, quizzes, etc.
   - □ Science Education Research references
   - □ Links to a Facebook page or Twitter account where I can ask for help

Please leave any other comments about what you would like to see on this website (mention additional features, content, or any other comments you may have).
3. How likely would you be to use this new website? (Tick one box)
   □ Extremely likely
   □ Very likely
   □ Moderately likely
   □ Slightly likely
   □ Not at all likely

4. How would you use this website? (Tick all that are relevant)
   □ To help me to plan lessons
   □ To get information about research for assignments at university
   □ For my own personal interest
   □ To get teaching or classroom resources
   □ Other (please specify) ________________________________
Science Education Research Survey

In this section you will be asked about how often you look at science or chemistry education research and your attitudes towards research.

1. How often do you read any kind of Science or Chemistry Education Research? (Tick one box)
   - □ Frequently
   - □ Often
   - □ Sometimes
   - □ Seldom
   - □ Never

2. When you search for research about the teaching and learning of science or chemistry, what sources do you use? (Tick all that are relevant)
   - □ Books
   - □ Research Journals
   - □ Entering key terms in a search engine (e.g. Google, Yahoo, etc.)
   - □ Lectures in university
   - □ Teaching magazines
   - □ Peers
   - □ Databases (such as Academic Search Complete, Google Scholar, ERIC, etc.)
   - □ I have never searched for research on this topic
   - □ Other (please specify) ___________________________

3. How important do you think Science Education Research is for effective science teaching? (Tick one box)
   - □ Extremely important
   - □ Very important
   - □ Moderately important
   - □ Slightly important
   - □ Not at all important
4. What barriers are there for you in accessing Science Education Research? (Tick all that are relevant)

☐ I find the language used in research articles difficult to understand.
☐ I don’t think the research is relevant to day-to-day teaching.
☐ I don’t have time to look up relevant Science Education Research.
☐ I don’t have time to read relevant Science Education Research.
☐ I don’t know how to find Science Education Research.
☐ There are no barriers for me in accessing Science Education Research.
☐ Other (please specify) ___________________________
α-version of Alternative Conceptions Diagnostic Instrument

Answer the following questions by circling the correct answer.

1. Following is a list of properties of a sample of solid sulphur:

   A) Brittle, crystalline solid.
   B) Melting point of 113˚ C.
   C) Density of 2.1 g cm⁻³.
   D) Combines with oxygen to form sulphur dioxide.

Which, if any, of these properties would be the same for one single atom of sulphur obtained from the sample?

   a) A and B only.
   b) C and D only.
   c) Only D would be the same.
   d) All of these properties would be the same.
   e) None of these properties would be the same.

2. The following drawings contain representations of atoms and molecules. Classify each of these drawings (labelled A, B, C, D and E) according to the three characteristics listed below. You should classify all five drawings for each category.

   ![Images of drawings A to E]

   **Characteristic A: State of Matter**

   ______________________ ____________________ ____________________
   solid     liquid     gas

   **Characteristic B: Physical composition of matter**

   ______________________ ____________________ ____________________
   pure substance heterogeneous mixture homogeneous mixture

   **Characteristic C: Chemical composition of matter**

   ______________________ ____________________ ____________________
   elements       compounds element and compound
3. A sample of liquid ammonia (NH₃) is completely evaporated (changed to a gas) in a closed container as shown:

Circle which of the following diagrams a, b, c, d, or e best represents what you would ‘see’ in the same area of the magnified view of the vapour?

A      B                           C     D       E

4. A 1.0 gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.

The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:

A) less than 26.0 grams.
B) 26.0 grams.
C) 27.0 grams.
D) 28.0 grams.
E) more than 28.0 grams.

What is the reason for your answer?

a) A gas weighs less than a solid.
b) Mass is conserved.
c) Iodine gas is less dense than solid iodine.
d) Gases rise.
e) Iodine gas is lighter than air.
5. Hydrogen peroxide will decompose to form water and oxygen gas according to the following equation.

\[ 2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2 \]

Hydrogen  water  oxygen
peroxide

Use the following key for diagrams

○ Oxygen  ○ Hydrogen

Which diagram is the best representation of the hydrogen peroxide before it decomposes as given by the balanced equation?

A  B  C  D  E

Which diagram is the best representation of the products after hydrogen peroxide decomposes as given by the balanced equation?

A  B  C  D  E

6. The diagram represents a mixture of S atoms and O\textsubscript{2} molecules in a closed container.

Which diagram shows the results after the mixture reacts as completely as possible according to the equation:

\[ 2\text{S} + 3\text{O}_2 \rightarrow 2\text{SO}_3 \]

A  B  C  D  E
7. The first ionisation energy of magnesium is 737.7 kJ mol\(^{-1}\) and that of aluminium is 577.5 kJ mol\(^{-1}\), as shown in the graph below. Why is the first ionisation energy of magnesium (1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\)) greater than that of aluminium (1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^1\))?

A) Removal of an electron will disrupt the stable completely-filled 3s sub-shell of magnesium.

B) The 3p electron of aluminium is further from the nucleus than the 3s electrons of magnesium.

C) The effect of an increase in nuclear charge in aluminium is greater than the repulsion between the electrons in its outermost shell.

D) The effect of an increase in nuclear charge in aluminium is less than the repulsion between the electrons in its outermost shell.

E) The paired electrons in the 3s orbital of magnesium experience repulsion from each other, whereas the 3p electron of aluminium is unpaired.

8. Which of the following affects the number of particles in a mole of the substance?

A) The type of particles (atoms, molecules, electrons etc.)

B) The mass of the particle

C) How closely the particles can be packed together

D) The size of the particles

E) None of the above

The following information will be required to answer questions 9 to 12.

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (H)</td>
<td>1.008 g</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>12.011 g</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>15.999 g</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>55.845 g</td>
</tr>
</tbody>
</table>

The following information will be required to answer questions 9 to 12.
9. Carbon atoms each contain 6 electrons. What mass of Carbon contains a mole of electrons?
   A) 12g
   B) 6g
   C) 2g
   D) 1g
   E) None of the above

10. Consider the following generic chemical reaction:
    \[ 3A + 2B \rightarrow 4C \]
    How many moles of B would you need to react completely with 5 moles of A?
    A) 1.2
    B) 1.5
    C) 2
    D) 3.3
    E) 5

11. The molecular formula of vinegar is \( \text{C}_2\text{H}_4\text{O}_2 \) and the molecular formula of sugar is \( \text{C}_6\text{H}_{12}\text{O}_6 \).
    If you had exactly 1.0g of vinegar and 1.0g of sugar, would you have the same number of atoms in each sample? (Circle the correct answer):
    Yes    No

    Explain your answer:
    _______________________________________________________
    _______________________________________________________
    _______________________________________________________
    _______________________________________________________
12. What does a 1.0 M solution of ethanol (C₂H₆O) mean?
A) A solution that has 1.0 mL of ethanol per litre (L) of solution.
B) A solution that has 1.0 mL of ethanol per litre (L) of water.
C) A solution that has 46.07 g of ethanol per kilogram (kg) of water.
D) A solution that has 46.07 g of ethanol per litre (L) of solution.
E) A solution that has 46.07 g of ethanol per litre (L) of water.

13. Which of the following best represents the ionic compound sodium chloride (NaCl)?

A B C D E

14. Which of the following best represents the position of the shared electron pair in the HF molecule?
Circle (a), (b) or (c).

(a) H : F (b) H : F (c) H: F

Please give a reason why you chose this:

A) Nonbonding electrons influence the position of the bonding or shared electron pair.
B) As hydrogen and fluorine form a covalent bond the electron pair must be centrally located.
C) Fluorine has a stronger attraction for the shared electron pair.
D) Fluorine is the larger of the two atoms and hence exerts greater attraction over the shared electron pair.
E) Hydrogen has a stronger attraction for the shared electron pair.
15. Heat is given off when hydrogen burns in air according to the equation:

\[ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \]

Which of the following is responsible for the heat?

A) Breaking hydrogen-hydrogen bonds gives off energy.
B) Breaking oxygen-oxygen bonds gives off energy.
C) Forming hydrogen-oxygen bonds gives off energy.
D) Both (a) and (b) are responsible.
E) (a), (b) and (c) are responsible.

16. Water is a common compound found in the form of a liquid and it has boiling point of 100°C. Pure sodium hydroxide forms a white solid and has a boiling point of 1388°C.

What is the reason for these differences in boiling points?

A) It is easier to break the bonds in sodium hydroxide than the hydrogen-oxygen bonds in water molecules.
B) This is due to the difference in the strengths of the bonds in sodium hydroxide and in the force of attraction between the molecules in water.
C) The boiling point in sodium hydroxide is higher because it is a solid and water is a liquid.
D) Sodium hydroxide is made up of a metallic element (sodium) and this causes an increase in the boiling point.
E) Ionic bonding is always stronger than covalent bonding.

17. Consider the following reaction:

\[ \text{H}_2 (g) \text{ and I}_2 (g) \rightarrow 2\text{HI} (g) \]

If H₂ and I₂ are mixed together and allowed to come to equilibrium, what would the graph of the concentration of H₂ look like over time?(Note: Temperature remains constant)

Circle one answer:  A  B  C  D  E
18. The figure represents a portion of an equilibrium mixture of two compounds related by the reaction $2A \rightleftharpoons B$.

![Equilibrium Mixture Diagram]

Which of the following must be true of this equilibrium?

A) $K > 1$
B) $K = 1$
C) $K < 1$
D) $K = 0$
E) $K < 0$

19. Given the structural formulas of the following three compounds:

![Structural Formulas]

Which of these compounds are isomers?

A) Compounds A and B
B) Compounds A and C
C) Compounds B and C
D) Compounds A, B and C
E) None of these are isomers of each other
20. Two students come up with different Lewis structures for N₂H₄. Student X (see below) placed a single bond between the central atoms and lone pair of electrons on each. Student Y placed a triple bond between the central atoms and included no lone pairs. Both structures account for all the electrons and neither structure has any formal charge separation.

Circle the correct answer below.

X) \[ \begin{array}{c}
\text{H} \\
\text{N–N} \\
\text{H}
\end{array} \quad \text{Y)} \[ \begin{array}{c}
\text{H} \\
\text{N≡N} \\
\text{H}
\end{array} \]

What is your reason for choosing this answer?

A) Structure X is incorrect because lone pairs cannot exist on adjacent atoms.
B) Structure X is incorrect because nitrogen forms triple bonds when possible.
C) Structure Y is incorrect because nitrogen never forms triple bonds.
D) Structure Y is incorrect because nitrogen cannot form five bonds.
E) Structure X and Y are both correct as they are resonance structures of each other.

21. If the pathway of a reaction has multiple steps, the overall reaction rate

A) depends on the slowest step.
B) is independent of reactant concentration.
C) depends upon the collision rate.
D) depends on the fastest step.
E) depends on the first step.
β-version of Alternative Conceptions Diagnostic Instrument

Answer the following questions by circling the correct answer.

1. Following is a list of properties of a sample of solid sulphur:
   i. Brittle, crystalline solid.
   ii. Melting point of 113˚ C.
   iii. Density of 2.1 g cm⁻³.
   iv. Combines with oxygen to form sulphur dioxide.

Which, if any, of these properties would be the same for one single atom of sulphur obtained from the sample? (Circle the correct answer)
   a) A and B only.
   b) C and D only.
   c) Only D would be the same.
   d) All of these properties would be the same.
   e) None of these properties would be the same.

2. A 1 g sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together have a mass of 27 g. The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the mass after heating be: (Circle the correct answer)
   A) less than 26 g
   B) 26 g
   C) 27 g
   D) 28 g
   E) more than 28 g

What is the reason for your answer? (Circle the correct answer)
   a) A gas weighs less than a solid.
   b) Mass is conserved.
   c) Iodine gas is less dense than solid iodine.
   d) Energy is conserved.
   e) Iodine gas is lighter than air.
3. In the diagrams below (labelled 1-5), the atoms of different elements are represented by the symbols:

- ■
- ●
- ○
- ◯
- △

a) Each diagram represents one of the following:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a solid</td>
<td>a liquid</td>
<td>a gas</td>
</tr>
</tbody>
</table>

In the box beneath each diagram, write one letter to say what you think it represents.

```
1   2     3      4        5
```

b) Each diagram also represents one of the following:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>one or more elements</td>
<td>one or more compounds</td>
<td>mixture of elements and compounds</td>
</tr>
</tbody>
</table>

In the box beneath each diagram, write one letter to say what you think it represents.

```
1   2     3      4        5
```

c) Each diagram also represents one of the following:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a pure substance</td>
<td>a heterogeneous mixture</td>
<td>a homogeneous mixture</td>
</tr>
</tbody>
</table>

In the box beneath each diagram, write one letter to say what you think it represents.

```
1   2     3      4        5
```
4. A sample of liquid ammonia (NH$_3$) is **completely evaporated** (changed to a gas) in a closed container as shown:

(Liquid) ![Liquid](image) (Gas) ![Gas](image)

Which of the following diagrams A, B, C, D, or E best represents what you would ‘see’ in the same area of the magnified view of the vapour? **(Circle the correct answer)**

A  B  C  D  E

![Diagrams A to E](image)

5. Methane reacts with chlorine to produce carbon tetrachloride and hydrogen chloride according to the following equation.

$$\text{CH}_4 + 4\text{Cl}_2 \rightarrow \text{CCl}_4 + 4\text{HCl}$$

Use the following key for diagrams

- ○ Carbon
- ○ Chlorine
- ○ Hydrogen

Which diagram is the best representation of the methane and chlorine **before it reacts** as given by the **balanced equation**? **(Circle the correct answer)**

A  B  C  D  E

![Diagrams A to E](image)

Which diagram is the best representation of the **products after this reaction** as given by the **balanced equation**? **(Circle the correct answer)**

A  B  C  D  E

![Diagrams A to E](image)
6. The diagram represents a mixture of S atoms and O\textsubscript{2} molecules in a closed container.

Which diagram shows the **results after the mixture reacts** (in the presence of a catalyst) as completely as possible according to the equation:

$$2S + 3O_2 \rightarrow 2SO_3$$

(Circle the correct answer)

A \hspace{1cm} B \hspace{1cm} C \hspace{1cm} D \hspace{1cm} E

7. Which of the following affects the number of particles in a mole of the substance?

(Circle the correct answer)

A) The type of particles (atoms, molecules, electrons etc.)
B) The mass of the particle
C) How closely the particles can be packed together
D) The size of the particles
E) None of the above

The following information may be helpful in answering questions 8 to 10.

<table>
<thead>
<tr>
<th>Element</th>
<th>Relative Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (H)</td>
<td>1</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>12</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>16</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>56</td>
</tr>
</tbody>
</table>
8. Carbon atoms each contain 6 electrons. What mass of Carbon contains a mole of electrons? (Circle the correct answer)

   A) 12 g
   B) 6 g
   C) 2 g
   D) 1 g
   E) None of the above

9. The following balanced chemical equation is for the burning of propane gas in oxygen. How many moles of carbon dioxide (CO₂) are formed when 1 mol of propane is burned? (Circle the correct answer):

   \[ C_3H_8 (g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \]

   A) 1 mol
   B) 2 mol
   C) 3 mol
   D) 4 mol
   E) 5 mol

10. What does a 1.0 M solution of ethanol (C₂H₆O) mean? (Circle the correct answer)

   F) A solution that has 1.0 mL of ethanol per litre (L) of solution.
   G) A solution that has 1.0 mL of ethanol per litre (L) of water.
   H) A solution that has 46 g of ethanol per kilogram (kg) of water.
   I) A solution that has 46 g of ethanol per litre (L) of solution.
   J) A solution that has 46 g of ethanol per litre (L) of water.

11. Which of the following best represents the ionic compound sodium chloride (NaCl)? (Circle the correct answer)

   A  
   B  
   C  
   D  
   E  

   A  
   B  
   C  
   D  
   E
12. Which of the following best represents the position of the shared electron pair in the HF molecule?

(Circle the correct answer)

(a) H : F  (b) H : F  (c) H: F

What is the reason for your answer? (Circle the correct answer)

A) Nonbonding electrons influence the position of the bonding or shared electron pair.
B) As hydrogen and fluorine form a covalent bond the electron pair must be centrally located.
C) Fluorine has a stronger attraction for the shared electron pair.
D) Fluorine is the larger of the two atoms and hence exerts greater attraction over the shared electron pair.
E) Hydrogen has a stronger attraction for the shared electron pair.

13. Hydrogen burns in air according to the equation:

\[ 2H_2 + O_2 \rightarrow 2H_2O \]

Which of the following is mainly responsible for releasing energy? (Circle the correct answer)

A) Breaking hydrogen-hydrogen bonds.
B) Breaking oxygen-oxygen bonds.
C) Forming hydrogen-oxygen bonds.
D) Both (A) and (B) are responsible.
E) (A), (B) and (C) are responsible.

14. Water is a common compound found in the form of a liquid and it has boiling point of 100°C. Pure sodium hydroxide forms a white solid and has a boiling point of 1388°C.

What is the reason for these differences in boiling points? (Circle the correct answer)

A) It is easier to break the bonds in sodium hydroxide than the hydrogen-oxygen bonds in water molecules.
B) It is due to the difference in the strengths of the bonds in sodium hydroxide and in bonding between the molecules in water.
C) The boiling point in sodium hydroxide is higher because it is a solid and water is a liquid.
D) Sodium hydroxide is made from a metallic element (sodium) and this causes an increase in the boiling point.
E) Ionic bonding is always stronger than covalent bonding.
15. Two students come up with different Lewis structures for \( \text{N}_2\text{H}_4 \). Both structures account for all the electrons and neither structure has any formal charge separation.

\[
\text{X)} \quad \begin{array}{c}
\cdot \\
N-N \\
\cdot \\
\end{array} \\
\text{Y)} \quad \begin{array}{c}
\cdot \\
N=\text{N} \\
\cdot \\
\end{array}
\]

Which statement is true of these structures? (Circle the correct answer)

A) Structure X is incorrect because lone pairs cannot exist on adjacent atoms.
B) Structure X is incorrect because nitrogen forms triple bonds when possible.
C) Structure Y is incorrect because nitrogen never forms triple bonds.
D) Structure Y is incorrect because nitrogen cannot form five bonds.
E) Structure X and Y are both correct as they are resonance structures of each other.

16. Consider the following reaction:

\[
\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})
\]

If \( \text{H}_2 \) and \( \text{I}_2 \) are mixed together and allowed to come to equilibrium, what would the graph of the concentration of \( \text{H}_2 \) look like over time? (Note: Temperature remains constant)

Circle the correct answer: A B C D E
17. Suppose that 0.30 mol PCl$_5$ is placed in a reaction vessel of volume 1000 cm$^3$ and allowed to reach equilibrium with its decomposition products: phosphorus trichloride and chlorine at 250°C, when $K_{eq} = 1.8$ for

$$PCl_5(x) \rightleftharpoons PCl_3(y) + Cl_2(z)$$

What can we say about the concentration of the PCl$_3$ gas and Cl$_2$ gas at equilibrium?

A) higher than 0.30 M  
B) lower than 0.30 M  
C) equals to 0.30 M

What is the reason for your answer? (Circle the correct answer)

a) The concentrations of all species in the reaction mixture are equal at equilibrium.  
b) All the phosphorus pentachloride turns into the products: phosphorus trichloride and chlorine.  
c) Phosphorus pentachloride partially decomposes to produce phosphorus trichloride and chlorine.  
d) The total number of moles of the products is greater than the total number of moles of the reactants.  
e) The forward reaction is favoured over the reverse reaction.

18. The figure represents a portion of an equilibrium mixture of two compounds related by the reaction $2A \rightleftharpoons B$. (Note: Temperature and pressure are constant)

Which of the following must be true of the equilibrium constant ($K$) for this mixture? (Circle the correct answer)

A) $K > 1$  
B) $K = 1$  
C) $K < 1$  
D) $K = 0$  
E) None of the above
What is the reason for your answer? (Circle the correct answer)

A) The reverse reaction is favoured over the forward reaction.
B) The forward reaction is favoured over the reverse reaction.
C) At equilibrium the concentration of reactants and products is always equal.
D) No reaction is taking place as the mixture is in equilibrium.
E) The numerical value of K constantly changes in a reversible reaction.
# Appendix D  Propositional Statements Assessed in Diagnostic Instrument

## Table D-1 List of statements defining 'chemical bonding' that were included in the instrument

<table>
<thead>
<tr>
<th>Statement No.</th>
<th>Statements Describing Chemical Bonding on Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Process of Bonding</strong></td>
</tr>
<tr>
<td>CB-1a</td>
<td>Energy is required to break the existing chemical bonds of the reactants. αβ</td>
</tr>
<tr>
<td>CB-1b</td>
<td>Energy is released when chemical bonds are formed to create the products. αβ</td>
</tr>
<tr>
<td>CB-1c</td>
<td>A single, double or triple covalent bond involves the sharing of one pair of electrons, two pairs of electrons or three pairs of electrons, respectively. αβ</td>
</tr>
<tr>
<td>CB-1d</td>
<td>Electronegativity is a measure of an atom’s tendency to attract a pair of electrons. αβ</td>
</tr>
<tr>
<td>CB-1e</td>
<td>In a polar covalent bond, the pair of electrons are still shared but they are not equally shared between the two atoms because the two atoms have different electronegativities; therefore, one atom will have a positive partial charge and the other will have a partial negative charge. αβ</td>
</tr>
<tr>
<td></td>
<td><strong>Resulting Structures</strong></td>
</tr>
<tr>
<td>CB-2a</td>
<td>Ionic structures are composed of ions that are held together by electrostatic attractions (i.e. ionic bonds) to form a crystal lattice structure. αβ</td>
</tr>
<tr>
<td>CB-2b</td>
<td>The number of ionic bonds which can be formed between any oppositely charged ions depends on the electric charge on the ions and the relative sizes of the ions. αβ</td>
</tr>
<tr>
<td></td>
<td><strong>Resulting Properties</strong></td>
</tr>
<tr>
<td>CB-3a</td>
<td>Ionic, covalent and metallic bonds all have a similar range of bond strength; some covalent bonds are stronger than some metallic and ionic bonds and some metallic bonds are stronger than ionic or covalent bonds, etc. αβ</td>
</tr>
<tr>
<td>CB-3b</td>
<td>During boiling, intermolecular bonds break but not the intramolecular bonds; higher boiling points result from the breaking of stronger bonds. αβ</td>
</tr>
</tbody>
</table>

α and β indicates the concept was included in the α and/or β version of the instrument, respectively

## Table D-2 List of statements defining 'stoichiometry' that were included in the instrument

<table>
<thead>
<tr>
<th>Statement No.</th>
<th>Statements Describing Stoichiometry for the Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Mole Concept</strong></td>
</tr>
<tr>
<td>S-1a</td>
<td>A mole is the amount of substance that contains as many particles (electrons, atoms, ions, or molecules) as there are atoms in 12 grams of carbon-12. αβ</td>
</tr>
<tr>
<td>S-1b</td>
<td>Molarity is a measure of the concentration of a solution and is the number of moles of a dissolved substance (solute) in a litre of solution. αβ</td>
</tr>
<tr>
<td>S-1c</td>
<td>The number of particles in a mole (Avogadro’s constant) is defined such that the mass of one mole of the substance (in grams) is equal to the substance’s relative atomic/molecular mass. αβ</td>
</tr>
<tr>
<td></td>
<td><strong>Stoichiometric Ratio</strong></td>
</tr>
<tr>
<td>S-2</td>
<td>The molar ratio is the ratio in which the number of moles (particles or unit cells) of the various substances react or form as expressed in a chemical equation. αβ</td>
</tr>
<tr>
<td></td>
<td><strong>Chemical Formulae</strong></td>
</tr>
<tr>
<td>S-3</td>
<td>A molecular formula indicates the numbers of each type of atom in a molecule of a substance using chemical symbols (to depict the atoms) and subscripts (to depict the number of atoms). α</td>
</tr>
<tr>
<td></td>
<td><strong>Chemical Equations</strong></td>
</tr>
<tr>
<td>S-4</td>
<td>In a balanced chemical equation, the ratio in which amounts of substances react or form are given as coefficients which represent the number of moles, particles or unit cells involved in a chemical reaction. αβ</td>
</tr>
</tbody>
</table>

α and β indicates the concept was included in the α and/or β version of the instrument, respectively
**Table D-3 List of statements defining 'equilibrium' that were included in the instrument**

<table>
<thead>
<tr>
<th>Statement No.</th>
<th>Statements Describing Equilibrium on Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reversibility of Reactions</strong></td>
<td></td>
</tr>
<tr>
<td>E-1a</td>
<td>At equilibrium forward and reverse reactions continue to take place and products and reactants continue to be removed (as they form new substances according to the reaction) and formed. $^\beta$</td>
</tr>
<tr>
<td>E-1b</td>
<td>At equilibrium the concentrations of the reactants and of the products are constant (but not necessarily equal) because as fast as reactants are being used in the forward reaction, they are being replaced by the reverse reaction. $^{αβ}$</td>
</tr>
<tr>
<td><strong>Rates and Equilibria</strong></td>
<td></td>
</tr>
<tr>
<td>E-2</td>
<td>The forward and reverse reaction rates are equal at equilibrium. $^β$</td>
</tr>
<tr>
<td><strong>Approach to Equilibrium</strong></td>
<td></td>
</tr>
<tr>
<td>E-3</td>
<td>On approach to equilibrium, the concentration of reactants will gradually decrease to some constant level (but not zero) at which point the system will be in equilibrium. $^{αβ}$</td>
</tr>
<tr>
<td><strong>Equilibrium Constant</strong></td>
<td></td>
</tr>
<tr>
<td>E-4a</td>
<td>The equilibrium constant, $K$, expresses the relationship between the units of the amount of products and reactants in a system at chemical equilibrium and can be expressed as the ratio between the concentrations of the products to the concentrations of reactants. $^{αβ}$</td>
</tr>
<tr>
<td>E-4b</td>
<td>An equilibrium constant of less than a value of 1 means that the formation of reactants is favoured over the formation of products. $^β$</td>
</tr>
</tbody>
</table>

$^α$ and $^β$ indicates the concept was included in the $α$ and/or $β$ version of the instrument, respectively
Appendix E  Reliability of \( \alpha \)-instrument and Development of \( \beta \)-instrument from the \( \alpha \)-instrument

**DIFFICULTY**

The statistic P-chart which resulted from the use of Equations 1 and 2 may be seen in Figure E.1. The average difficulty of test items was 0.31, the LCL was 0.21 and the UCL was 0.40.

As can be seen from Figure E.1, the difficulty indices range from 0.005 - 0.604. Those items below the lower confidence level (LCL) indicate items that are difficult when the ability of the group is taken into account. According to this method, nine items (39% of items on the instrument) are relatively difficult for the sample group to answer. Items that are above the UCL are easy to answer for the sample group and there are nine such items (39% of items on the instrument). The remaining five items (22% of items on the instrument) are well suited to the group’s ability and are not too difficult or too easy.

According to Posrie (2010), only 20% of those items tending to be too difficult should be discarded from an instrument. In this case, three items were discarded (Items 7, 11 and 19) with revisions applied to the remainder of the items. Items 2a, 2b, 2c, 6, 15 and 20 were
substantially revised. Item 9 also underwent a minor revision based on comments made by PSSTs during the interview process.

**ITEM DISCRIMINATION INDEX (R)**

The extreme groups method was calculated for each item in the instrument. It was intended to use the r70 technique, however, only the upper 28% and the lower 28% of performers could be isolated due to a cluster of PSSTs with the same scores around the centre point.

Table E.1 shows the resulting discrimination index (DI) for each item of the instrument.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>DI</th>
<th>Item No.</th>
<th>DI</th>
<th>Item No.</th>
<th>DI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35</td>
<td>7</td>
<td>0.06</td>
<td>15</td>
<td>0.03</td>
</tr>
<tr>
<td>2a</td>
<td>0.44</td>
<td>8</td>
<td>0.47</td>
<td>16</td>
<td>0.21</td>
</tr>
<tr>
<td>2b</td>
<td>0.02</td>
<td>9</td>
<td>0.10</td>
<td>17</td>
<td>0.35</td>
</tr>
<tr>
<td>2c</td>
<td>0.19</td>
<td>10</td>
<td>0.45</td>
<td>18</td>
<td>0.32</td>
</tr>
<tr>
<td>3</td>
<td>0.48</td>
<td>11</td>
<td>0.11</td>
<td>19</td>
<td>0.16</td>
</tr>
<tr>
<td>4</td>
<td>0.52</td>
<td>12</td>
<td>0.34</td>
<td>20</td>
<td>0.26</td>
</tr>
<tr>
<td>5</td>
<td>0.53</td>
<td>13</td>
<td>0.42</td>
<td>21</td>
<td>0.26</td>
</tr>
<tr>
<td>6</td>
<td>0.23</td>
<td>14</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The discrimination indices range from 0.02 to 0.53. A discrimination index of 0.30 is considered acceptable: 12 items meet this requirement. According to this method, those items between 0.20-0.30 require some revision (items 6, 16, 20 and 21) (item 21 was removed and item 20 was substantially revised), while those lower than 0.19 (Items 2b, 2c 7, 9, 11, 15 and 19) require substantial revision (Items 2b, 2c and 15 were substantially revised) or removal from the instrument (Items 7, 11, and 19 were removed).

**CORRELATION ANALYSIS (Φ)**

The significance (p) of the correlation between the score on each item and mastery of the content of the instrument and the associated phi-coefficients, Φ, are shown in Table E.2.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Φ</th>
<th>p</th>
<th>Item No.</th>
<th>Φ</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.22</td>
<td>0.00</td>
<td>11</td>
<td>0.28</td>
<td>0.00</td>
</tr>
<tr>
<td>2a</td>
<td>0.22</td>
<td>0.00</td>
<td>12</td>
<td>0.24</td>
<td>0.00</td>
</tr>
<tr>
<td>2b</td>
<td>0.15</td>
<td>0.04</td>
<td>13</td>
<td>0.18</td>
<td>0.01</td>
</tr>
<tr>
<td>2c</td>
<td>0.30</td>
<td>0.00</td>
<td>14</td>
<td>0.21</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.29</td>
<td>0.00</td>
<td>15</td>
<td>-0.01</td>
<td>0.91</td>
</tr>
<tr>
<td>4</td>
<td>0.27</td>
<td>0.00</td>
<td>16</td>
<td>0.08</td>
<td>0.28</td>
</tr>
<tr>
<td>5</td>
<td>0.25</td>
<td>0.00</td>
<td>17</td>
<td>0.24</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>0.25</td>
<td>0.00</td>
<td>18</td>
<td>0.10</td>
<td>0.22</td>
</tr>
<tr>
<td>7</td>
<td>0.12</td>
<td>0.08</td>
<td>19</td>
<td>0.01</td>
<td>0.92</td>
</tr>
<tr>
<td>8</td>
<td>0.24</td>
<td>0.00</td>
<td>20</td>
<td>0.24</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>0.19</td>
<td>0.01</td>
<td>21</td>
<td>0.31</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>0.18</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Items that have a correlation coefficient of 0.20 or higher are considered to have a moderate association (which gets stronger as the value increases towards 1). From Table E.2, it can be
observed that the following items do not significantly correlate with scores on the instrument: 7, 15, 16, 18, and 19. Furthermore, Items 2b, 9, 10, and 13 have only a weak association with mastery on the instrument. Items 7 and 19 were removed from the instrument. Items 2a, 2b and 2c, 15 and 18 were substantially revised. Item 16 underwent a minor revision. This decision was made based on the findings of the other item analyses and the interviews with PSSTs. Three items had a negligible association with mastery (15, 16, 19), six items had a weak association (2b, 7, 9, 10, 13, 18) and the remaining fourteen items had a moderate association (1, 2a, 2c, 3, 4, 5, 6, 8, 11, 12, 14, 17, 20, 21).

These methods and the data collected from interviews (to be discussed later) informed the revision of the instrument. A summary of the quantitative findings about the instrument are provided in Table E.4 and the legend for this may be found in Table E.3.

<table>
<thead>
<tr>
<th>Table E.3 Legend for Table H.4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Index</strong></td>
</tr>
<tr>
<td>Difficulty (P)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Discrimination (DI)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Phi Correlation (ϕ)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table E.4 Summary of reliability analyses for each item on the instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>α-item No.</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2a</td>
</tr>
<tr>
<td>2b</td>
</tr>
<tr>
<td>2c</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

As a result of these findings and those of the interviews, the following revisions were made to the instrument. Revisions were made in some capacity to all questions. Some changes were
minor changes, while others were substantial. The types of revisions made and the items to which these revisions were applied is given in Table E.5.

<table>
<thead>
<tr>
<th>Type of Revision</th>
<th>Nature of Revision</th>
<th>α-instrument Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor Revisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>Boldface instructions</td>
<td>8, 9, 12</td>
</tr>
<tr>
<td>Type 2</td>
<td>Boldface instructions and important parts of stem</td>
<td>1, 3, 6, 14, 17</td>
</tr>
<tr>
<td>Substantial Revisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>Removal of question</td>
<td>7, 11, 19, 21</td>
</tr>
<tr>
<td>Type 2</td>
<td>Stem and responses entirely changed but same format for the question (question replacement)</td>
<td>5, 10</td>
</tr>
<tr>
<td>Type 3</td>
<td>Reformatted question (e.g. changing single to two-tier question)</td>
<td>2a, 2b, 2c, 18</td>
</tr>
<tr>
<td>Type 4</td>
<td>Some revision to item stem and response options</td>
<td>4, 15</td>
</tr>
<tr>
<td>Type 5</td>
<td>Revision to item stem OR response options</td>
<td>13, 16, 20</td>
</tr>
</tbody>
</table>

Of the ten items which had difficulty associated with two or more of the indices (difficulty, discrimination and correlation), eight were substantially revised. However, Items 6 and 9 only underwent minor revision. During the course of interviews, it was found that PSSTs did not pay due attention to the phrase ‘in a closed container’ in Item 6 and, therefore, this phrase was put in boldface. It was decided not to substantially revise Item 9, as PSSTs did understand the stem and response options, however, the difficulty arose as an algorithmic response could not be applied to the item.

In addition to substantial revisions carried out based on the quantitative results, a number of substantial revisions were also made based on the findings of the interviews. The correct response options in items 4, 5, 13 were readily identifiable by some PSSTs, not because of their understanding but because the response option was familiar. For example, Item 13 used a familiar image of the crystal lattice structure of sodium chloride. Therefore, alternative response option diagrams were created using Adobe Illustrator™ to remove this familiarity. Item 18 was also substantially revised to create a two-tier question. The rationale for this change was that PSSTs during the interview used an algorithmic method to respond to the question but did not understanding the meaning of the equilibrium coefficient. Therefore, the second tier requires this component. Finally, Item 2a was also substantially revised. The reason for this had nothing to do with the question itself but as it was part of a three tier question, and the other two tiers required revision, this item was also revised as a result. The revisions resulted in 19 revised items remaining. It was decided to add another equilibrium item in order to further probe this complex area.
Appendix F Code Book for Community Goals and Levels of Community

There are two elements to the coding: 1) Community Goals, and 2) Levels of Community. All data is to be coded within both of these elements.

PART 1: COMMUNITY GOALS

There are four main codes: Sharing Metacognitive Judgements and Monitoring (SMJM), Practical and Pragmatic Matters (PPM), Developing Understanding (DU), and Application of Understanding (AU). There is also a code called Multiple (Mult) and one called Off-Task (OT). Any segment of data can only be coding in a single one of these codes. The general meaning of these codes is as follows:

- SMJM refers to one or more group members sharing their metacognitive judgements and monitoring, i.e. their ongoing awareness of their own and the group’s comprehension and task performance,
- PPM refers to one or more group members focusing on practicalities of a task, or pragmatic statements or decisions that move the task forward,
- DU refers to group activities whose primary function is to develop understanding either directly (e.g. discussing concepts) or indirectly (searching for information on a concept). The success of the activity in developing understanding is not relevant, and
- AU refers to activities in which group members attempt to apply their understanding to a new situation, example or to the task, or suggesting exemplars of a concept.
- Mult refers to occasions when two or more group members are on-task but without any common focus (e.g. one group member is AU, another DU, and another is OT).
- OT refers to the community having discussions unrelated to the task or learning/experiences related to the concepts which they are discussing.

Generally, a group activity refers to two or more members being directed towards each other or toward the same goal. Examples of identifying group activities for a group of three include:

- If two group members have started taking notes from books or webpages while the remaining group member looks casually around the room, then the group activity is the taking of notes.
- If two group members are chatting about the weather and one group member is taking notes then the group activity is chatting about the weather.

However, one person’s contribution can also lead to a segment being coded. This is usually the case for SMKM and PPM. The rationale for this is that a single person making a practical
or pragmatic decision (i.e. PPM) can alter the direction of the group, and a single person sharing their assessment of personal or group progress (i.e. SMKM) can alter group atmosphere and/or provide the group with information that can alter their approach to activities in subtle but meaningful ways. Furthermore, if all but one group member is Off-Task but they are silent then we code for the single group member that is on-task (the learning community lives through this one person at this moment in time). However, if the Off-Task group members are talking to each other, then their impact on the community is high and the community as a whole is considered Off-Task for this period of time.

In some cases, the activity and/or speech of the group may be split with two engaged in DU activity/talk and another other two (if a group of four) engaged in OT activity/talk. As the decision has been taken to code any segment in only one Community Goals code, the priority for coding has been decided as listed below.

- Statements supersede silent activities (i.e. if someone is speaking over a silent activity like searching for information, then it is the speech that is coded and not the activity). This decision has been taken because speech is more intrusive on the community than a silent activity if they are in competition with each other;

- On-task speech supersedes off-task speech (i.e. if 2 group members are talking about the task and another 2 are talking about their weekend, it is the on-task talk that is coded and not the off-task talk). This decision has been taken because, although all members of the community aren’t on-task, at least half the community is and this will later supply the entire community;

- If, hypothetically, two members are engaged in vocal DU and another engaged in vocal AU then it is coded at **Multiple**.

- If, all are silent (perhaps appearing to be waiting) but a single group member is engaged in some activity then the segment is coded with this individual (for the reasons mentioned in the previous paragraph).

In the pages that follow, tables have been provided that more fully describe each of the Community Goals codes. These tables include exclusion/inclusion criteria, and typical and atypical examples of the code. While coding, keep these tables to hand for reference. The final decision rests with your interpretation of the video in light of the meaning/descriptions of the Community Goals codes.
### Community Goals Codes

<table>
<thead>
<tr>
<th>Code</th>
<th>Sharing Metacognitive Judgements and Monitoring (SMJM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>This code refers to instances in which one or more members <em>share the outcome</em> of their metacognitive judgements and monitoring (MJM) with other group members about anything related to chemistry/science learning/teaching. This is the ongoing awareness of: ease of learning, learning and comprehension, feeling of knowing, and confidence judgements.</td>
</tr>
<tr>
<td><strong>Inclusion Criteria</strong></td>
<td>Considering task/learning difficulty, sharing judgements of personal or community understanding/task progress, a feeling of knowing something but being unable to recall it, or their confidence in statements made.</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td>Discussing the actual meaning of concepts.</td>
</tr>
<tr>
<td><strong>Typical Examples</strong></td>
<td>Identifying concepts that one or more of the group doesn’t understand; implying that the learning/task is difficult through gestures; appraising the value of a task product or idea; admitting confusion about a concept; comparing the difficulty/ease of tasks/learning experiences; stating one’s confidence in a concept/topic_statement, etc.</td>
</tr>
<tr>
<td><strong>Atypical Examples</strong></td>
<td>Being sarcastic or humorous about one’s own or the group’s understanding/task progress; facilitator sharing her judgements of the community's learning.</td>
</tr>
<tr>
<td><strong>Close but no</strong></td>
<td>Asking a conceptual question, e.g.”Why do atoms form bonds?” This implies a lack of understanding/confidence but the focus is upon developing understanding and not sharing a judgement or the outcome of monitoring. An example of an SMJM comment on similar lines would be “I don’t understand why atoms form bonds.”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Practical and Pragmatic Matters (PPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Contains instances of group members focusing on practical activities, statements, or decisions, or pragmatic statements or decisions.</td>
</tr>
<tr>
<td><strong>Inclusion Criteria</strong></td>
<td>Focusing on the practical actions/strategies that should result in task completion and considering practical issues surrounding a task product/learning strategy/teaching strategy, etc.</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td>Any practical action (like sharing a resource) that is for the purpose of sharing one’s <em>personal</em> understanding (e.g. sharing a notepad with personal notes in it).</td>
</tr>
<tr>
<td><strong>Typical Examples</strong></td>
<td>Statements to get the group back on task; decision to move on from problematic area to progress the task; describing, sharing or gathering public resources in a non-conceptual way; creating a title for the task product sheet; selecting format or ordering of responses in task product; suggesting terms for a search engine; deciding how to divide the workload; reading instructions from a task sheet, etc.</td>
</tr>
<tr>
<td><strong>Atypical Examples</strong></td>
<td>Selecting a topic area in which to set the task for purpose of progressing task without any conceptual rationale; making a decision to use an existing resource <em>verbatim</em> for task-product-statements without any consideration of the meaning of concepts or statements, etc.</td>
</tr>
<tr>
<td><strong>Close but no</strong></td>
<td>Swapping notepads with own notes written in them – this is communicated one’s own understanding. An example on similar lines that would be PPM is re-positioning a laptop so that others can read or swapping textbooks.</td>
</tr>
<tr>
<td>Code</td>
<td>Developing Understanding (DU)</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>This code refers to activities, statements, discussions, etc. that focus on the development of concepts related to chemistry or teaching. It could be said to loosely correspond to knowledge, comprehension and analysis of Bloom’s taxonomy.</td>
</tr>
<tr>
<td><strong>Inclusion Criteria</strong></td>
<td>Focusing on chemistry or pedagogical concepts with a view to developing personal/group understanding about them.</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td>Focusing on concepts with a view to suggesting exemplars or discussing how the concepts apply to exemplars, the task, or other concrete situations.</td>
</tr>
<tr>
<td><strong>Typical Examples</strong></td>
<td>Searching for information on concepts; writing notes about concepts; calling out definitions (or alternative conceptions) from external sources or from memory; asking/answering conceptual questions; drawing connections between concepts; sharing personal understanding of concepts verbally, through pictures of mental models or through personal notes, etc.</td>
</tr>
<tr>
<td><strong>Atypical Examples</strong></td>
<td>Searching or calling out concrete examples of concepts from an external source; the facilitator asking conceptual questions, explaining the meaning of a concept, or summarising the community understanding.</td>
</tr>
<tr>
<td><strong>Close but no</strong></td>
<td>Considering the explanatory power of a particular definition. This is an application of pedagogical (pedagogical content) knowledge as they determine whether an explanation is suitable for other groups.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Application of Understanding (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>This code refers to activities, statements, discussions, etc. that focus on applying understanding of a concept to an exemplar, task, or another concrete situation. It could be said to loosely correspond to application, synthesis and evaluation of Bloom’s taxonomy.</td>
</tr>
<tr>
<td><strong>Inclusion Criteria</strong></td>
<td>Applying (through discussion, reading or writing) chemistry or pedagogical concepts to a new situation/exemplar/task or using understanding to suggest exemplars.</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td>Making a more general statement about a concept.</td>
</tr>
<tr>
<td><strong>Typical Examples</strong></td>
<td>Using own/group understanding to come up with concrete examples of a concept; discussing/debating whether an exemplar is of one concept or another; writing a collective or individual task product; proposing a context/topic for a task product (e.g. diagnostic item) in relation to how it encompasses the concepts; discussing how a teaching resource/task product could address an alternative conception, reading aloud or recalling any exemplars or other application of exemplars from an external resource, etc.</td>
</tr>
<tr>
<td><strong>Atypical Examples</strong></td>
<td>The facilitator presenting them with an exemplar and asking them what it is an exemplar of and any parts of their responses which refer to this.</td>
</tr>
<tr>
<td><strong>Close but no</strong></td>
<td>Selecting a context/topic for a task product without any prior or current reference to conceptual understanding; approaching the creation of a task product like the creation of a set of notes (e.g. writing definitions down from webpages); in the midst of discussing an exemplar (which is indeed AU), making a more general statement about the conception (this statement would be DU).</td>
</tr>
<tr>
<td>Code</td>
<td>Multiple (Mult)</td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>This code refers to instances of group members being on-task but no two members have a common focus.</td>
</tr>
<tr>
<td><strong>Inclusion Criteria</strong></td>
<td>Each member of the community is concurrently engaged in a different goal (no two are focused on the same goal).</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td>One member is engaged in a goal (PPM, SMJM, DU or AU) while the remaining group members are <em>silently</em> waiting or <em>silently</em> off-task. This is coded at the goal of the on-task group member.</td>
</tr>
<tr>
<td><strong>Typical Examples</strong></td>
<td>One group member writes notes (DU), another group member is <em>silently</em> reading task sheet instructions (PPM), and the remaining group member is <em>silently</em> looking around the room (Off-Task).</td>
</tr>
<tr>
<td><strong>Atypical Examples</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Close but no</strong></td>
<td>One group member reads through the task sheet while the remaining two group members are <em>silently</em> waiting for her (coded at PPM).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Off-Task (OT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>This code refers to instances of group members having a conversation unrelated to the task or issues surrounding the task.</td>
</tr>
<tr>
<td><strong>Inclusion Criteria</strong></td>
<td>Two or more group members having an off-task conversation (while remaining member(s) are <em>silently</em> on-task) or all group members off-task either silently or in a conversation.</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td>One member is engaged in a Community Goal while the remaining group members are <em>silently</em> waiting or <em>silently</em> off-task.</td>
</tr>
<tr>
<td><strong>Typical Examples</strong></td>
<td>Two group members conversing about the weather, while the remaining group member(s) <em>silently</em> read from a webpage, all group members <em>silently</em> gazing around the room or otherwise off-task.</td>
</tr>
<tr>
<td><strong>Atypical Examples</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Close but no</strong></td>
<td>Two group members having an off-task conversation and another two group members having an on-task conversation (on-task conversation is coded). Being humorous within one of the other Community Goals, e.g. while writing a concept map saying, in good humour, “my arrows look ridiculous!” or “John has to write because he was he’s always making excuses to get away with not writing.” Both of these are simply being humorous within the PPM goal.</td>
</tr>
</tbody>
</table>
PART 2: LEVELS OF COMMUNITY

These are to be applied to interactions. This section should be coded separately from the codes in Part 1 as the two do not necessarily correspond to each other. The following steps should be taken when coding.

1. Identify an interaction and keep the full interaction in mind for Step 2,
2. Use the decision tree to decide which Level of Community is present, and
3. Review the interaction to ensure that this accurately reflects the data.

The notes given here are designed to be guidelines only. You, as the coder, must interpret the meanings that are conveyed through the audio-visual data through tone of voice, body language, eye contact and gestures. The richness of this data could be lost through excessive rule following so you are encouraged to use your discretion.

IDENTIFYING AN INTERACTION

An interaction could be a conversation, a statement or a silent activity. In the case of a conversation or statement the interaction begins with the statement. In the case of a silent activity, the interaction begins when two or more engage in this type of activity (type meaning of DU type, AU type or PPM type). It is the end of the interaction that can be more difficult to identify so the following examples are provided. In the case of an ‘interaction’ being a statement (possibly with assenting noises) then the interaction finishes with the statement (or the assenting noises).

Signals for End of a Conversation:

- a statement signalling the end of conversation has been made resulting in a lull or a change of conversation. This end of the conversation may be only temporary (the group may decide to return to the conversation momentarily). Examples of signals include:
  - ending a conceptual conversation by saying ‘we should just Google that’,
  - ending an off-topic conversation by saying ‘okay so we still need to figure out what concept Y means’,
  - ending a conceptual conversation by engaging in unsupportive behaviour such as laughing at someone (context is important here – not every laugh is unsupportive).

Facilitator type interactions are usually controlled by the facilitator. Most often the facilitator will signal an end to the conversation through summarising, or beginning a related but new conversation by asking a probing question.

- when all have finished talking and naturally proceed to engage in a silent activity,
• or when the number of engaged group members changes from whole group to less than whole or vice versa (see Guidelines for Assessing Attentiveness).

Signals for a Silent Activity:
• when fewer than 2 group members continue to be engaged in that activity,
• when a person starts speaking to others (not just talking to themselves absently) regardless of whether others engage or not.

MEANING OF COMMUNICATION

Usually this is very clear because some group member speaks. However, in some cases a person may speak but isn’t communicating (i.e. speaking under one’s breath to oneself) and in other cases there can be communication without speech. For example, laughing is an example of a communication that doesn’t involve the use of language. Also, sharing things with other group members can also be a form of communication – for example, pushing the laptop over so another group member can look in is a case of communicating without language.

The facilitator is not considered an equal member of the community given that other group members often defer to her and are not comfortable to challenge her, disagree with her, etc. This has been accounted for in Levels of Community by not recognising her voice as contributing to a sense of community. As such, it is only the communication of group members that can be used to determine the Level of Community. If there is an interaction consisting solely of the facilitator communicating and the group members simply nodding or making assenting noises, then we are not considering the community to be engaged in communication.

MEANING OF COMMON FOCUS

Common focus is present when two or more are focused on the same thing. This isn’t an issue when there is conversation as two or more are focused on the conversation. We must watch for this in experiences are non-verbal. If two or more are looking at the same thing, then we have common focus but also if two or more are focused on carrying out the same activity even as individuals we also have a common focus. For example, there may be a non-verbal agreement to write down notes on a concept and we will see two or more writing in their personal notepads perhaps while occasionally looking at a book or a web page; this is also an example of a common focus. An example of the lack of common focus occurs when one group member is focused on reading from some source (laptop or book) while another is focused on writing down a previously discussed statement for the task product, while
another is using their mobile phone to text; here we see a total lack of community and lack of a common focus.

MEANING OF PUBLIC AND PRIVATE DOMAINS

The public domain refers to information or perspectives that exist externally to the individual or the group. The statements made do not require the individual to reveal anything of their own perspective to others. Examples of this include:

- reading a definition from a webpage,
- reporting the topic in a resource or in any way discussing the content of a resource (there is no giving of opinion, etc),
- asking impersonal question (e.g. what webpage are you using?, what topic are you searching?),
- repeating task instructions available on handout or PowerPoint,
- asking someone to repeat a sentence for a task that has already been decided upon.

The private domain refers to a sharing of personal understanding, experiences, opinions, thoughts, suggestions, advice, etc. The essential component is that the person is sharing their own personal thoughts or their impressions of community learning, understanding, experiences, the strategy they should use, etc. Examples of this include:

- revealing a knowledge gap,
- stating own understanding of a concept,
- giving own examples of concepts,
- seeking clarification of or reassurance about meaning of concepts,
- sharing a joke, etc.

This domain also includes the expression of supportive behaviours such as:

- giving reassurance,
- giving advice,
- providing information about a concept to someone struggling to understand,
- sharing a joke or empathising by laughing,
- showing sympathy for someone, etc.

GUIDELINES FOR ASSESSING ATTENTIVENESS

The attentiveness of group members to a conversation should be assessed as follows (recalling that these are merely detailed guidelines):

1. Are all group members talking and attentive throughout?
a. yes – then whole group is engaged  
b. no – proceed to next question  

2. Do the group members with questionable attentiveness merely drift out of eye contact/engagement for a few moments each time?  
a. yes – whole group is attentive  
b. no proceed to next question  

3. Do the group members with questionable attentiveness contribute to the discussion?  
a. yes – proceed to question 4  
b. no – the whole group is not attentive  

4. Does the group member’s response give evidence that there were actually listening to the discussion during their period of lack of eye contact?  
a. yes – whole group was attentive  
b. no – whole group was not attentive  

UNSUPPORTIVE BEHAVIOUR  
Examples of this sort of behaviour includes saying something that embarrasses or shames someone else, getting defensive, and so on.  

The decision tree to aid you in coding each segment is overleaf in Figure F.1.
Figure F.1 Decision tree for the Levels of Community
## Appendix G  Assessing Normality between various Groups

Table G.1 Findings from the investigation of data distribution for male and female PSSTs

<table>
<thead>
<tr>
<th></th>
<th>PNM</th>
<th>Stoichiometry</th>
<th>Chemical bonding</th>
<th>Equilibrium</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male (n = 135)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-score skewness</td>
<td>0.69 (ns)</td>
<td>0.04 (ns)</td>
<td>1.28 (ns)</td>
<td>0.86 (p &lt; .01)</td>
<td>2.29 (p &lt; .05)</td>
</tr>
<tr>
<td>(significance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-score kurtosis</td>
<td>1.08 (ns)</td>
<td>1.87 (ns)</td>
<td>0.63 (ns)</td>
<td>0.04 (ns)</td>
<td>0.223 (ns)</td>
</tr>
<tr>
<td>(significance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance of histogram</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Appearance of Q-Q plot</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Normality</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Non-normal</td>
<td>Non-normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Female (n = 331)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-score skewness</td>
<td>0.59 (ns)</td>
<td>0.19 (ns)</td>
<td>0.71 (ns)</td>
<td>8.85 (p &lt; .001)</td>
<td>0.02 (ns)</td>
</tr>
<tr>
<td>(significance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-score kurtosis</td>
<td>2.03 (p &lt; .05)</td>
<td>2.17 (p &lt; .05)</td>
<td>2.52 (p &lt; .05)</td>
<td>3.92 (p &lt; .001)</td>
<td>1.09 (ns)</td>
</tr>
<tr>
<td>(significance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance of histogram</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Appearance of Q-Q plot</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Normality</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Non-normal</td>
<td>Normal</td>
</tr>
</tbody>
</table>
Table G.2 Findings from the investigation of data distribution for PSSTs in their 1st (n = 97), 2nd (n = 100), 3rd (n = 85), and 4th (n = 41) year of study on concurrent STE programmes

<table>
<thead>
<tr>
<th>Year</th>
<th>PNM</th>
<th>Stoichiometry</th>
<th>Chemical bonding</th>
<th>Equilibrium</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Year 1 (n = 97)</strong></td>
<td></td>
<td></td>
<td></td>
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<td>1.98 (p &lt; .05)</td>
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<td>1.43 (ns)</td>
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<td>0.01 (ns)</td>
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<td>✓</td>
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### Table G.3 Findings from the investigation of data distribution for PSSTs that had studied (n = 245) and had not studied (n = 210) chemistry at upper-second-level education

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<td>z-score skewness (significance)</td>
<td>0.89 (ns)</td>
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<td>2.01 (p &lt; .05)</td>
<td>6.42 (p &lt; .001)</td>
<td>0.78 (ns)</td>
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<td>z-score kurtosis (significance)</td>
<td>1.80 (ns)</td>
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<td>1.35 (ns)</td>
<td>0.06 (ns)</td>
<td>0.92 (ns)</td>
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<td>×</td>
<td>✓</td>
<td>✓</td>
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<td>Appearance of Q-Q plot</td>
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<td>✓</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
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<td>Normal</td>
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<td>1.55 (ns)</td>
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<td>0.14 (ns)</td>
<td>5.67 (p &lt; .001)</td>
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<tr>
<td>z-score kurtosis (significance)</td>
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<td>Appearance of Q-Q plot</td>
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<td>✓</td>
<td>×</td>
<td>✓</td>
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### Table G.4 Findings from the investigation of data distribution for PSSTs that had studied lower level mathematics (n = 167) or higher level mathematics (n = 259) at upper-second-level education

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<td>0.35 (ns)</td>
<td>0.32 (ns)</td>
<td>0.39 (ns)</td>
<td>5.57 (p &lt; .001)</td>
<td>0.14 (ns)</td>
</tr>
<tr>
<td>z-score kurtosis (significance)</td>
<td>1.24 (ns)</td>
<td>1.50 (p &lt; .05)</td>
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<td>1.10 (ns)</td>
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<td>✓</td>
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<td><strong>Higher level (n = 259)</strong></td>
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<td>z-score skewness (significance)</td>
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<td>✓</td>
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Table G.5 Findings from the investigation of data distribution for PSSTs that had an awareness of the issue of alternative conceptions (n = 187) and those that did not have an awareness (n = 265)

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<td>0.21 (ns)</td>
<td>6.65 (p &lt; .001)</td>
<td>0.91 (ns)</td>
</tr>
<tr>
<td>z-score kurtosis (significance)</td>
<td>1.57 (ns)</td>
<td>1.25 (ns)</td>
<td>1.23 (ns)</td>
<td>2.15 (p &lt; .05)</td>
<td>0.14 (ns)</td>
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<td>✓</td>
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<td>7.85 (p &lt; .001)</td>
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<td>3.46 (p &lt; .001)</td>
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Table G.6 Findings from the investigation of data distribution for PSSTs that had a chemistry specialism (n = 143) and that did not have a chemistry specialism (n = 199)

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<td>0.14 (ns)</td>
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Table G.7 Findings from the investigation of data distribution for PSSTs that had studied upper-second-level physics (n = 53) and that had not studied physics (n = 81)

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<td>1.95 (ns)</td>
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<td>1.330 (ns)</td>
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<td>1.00 (ns)</td>
<td>0.04 (ns)</td>
<td>0.83 (ns)</td>
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<td>✔</td>
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Table G.8 Findings from the investigation of data distribution for consecutive PSSTs that were awarded a 1.1 (n = 30), 2.1 (n = 75), or 2.2 (n = 15) degree classification.

<table>
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<th>Equilibrium</th>
<th>Total score</th>
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<td>2.05 ($n$)</td>
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<td>2.44 ($p &lt; .05$)</td>
<td>2.03 ($p &lt; .05$)</td>
</tr>
<tr>
<td>z-score kurtosis (significance)</td>
<td>0.99 ($ns$)</td>
<td>0.05 ($ns$)</td>
<td>0.62 ($ns$)</td>
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<td>0.78 ($ns$)</td>
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<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
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<td>×</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
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<td>5.02 ($p &lt; .001$)</td>
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<td>0.69 ($ns$)</td>
<td>2.75 ($p &lt; .01$)</td>
<td>0.58 ($ns$)</td>
</tr>
<tr>
<td>Appearance of histogram</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Appearance of Q-Q plot</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Normality</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Non-normal</td>
<td>Normal</td>
</tr>
<tr>
<td><strong>2.2 Degree Classification (n = 15)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-score skewness (significance)</td>
<td>0.04 ($ns$)</td>
<td>0.91 ($ns$)</td>
<td>0.23 ($ns$)</td>
<td>0.54 ($ns$)</td>
<td>0.17 ($ns$)</td>
</tr>
<tr>
<td>z-score kurtosis (significance)</td>
<td>0.89 ($ns$)</td>
<td>0.13 ($ns$)</td>
<td>1.19 ($ns$)</td>
<td>1.94 ($ns$)</td>
<td>0.59 ($ns$)</td>
</tr>
<tr>
<td>Appearance of histogram</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Appearance of Q-Q plot</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Normality</td>
<td>Normal</td>
<td>Non-normal</td>
<td>Normal</td>
<td>Non-normal</td>
<td>Normal</td>
</tr>
</tbody>
</table>
Appendix H  Regression Models Adherence to Assumptions

The conclusions related to the assumptions related to multiple regression are presented in the tables below.

Table H.1 Assessing assumption of independence of errors for all regression models

<table>
<thead>
<tr>
<th>Model Outcome Variable</th>
<th>Sample</th>
<th>Durbin-Watson</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNM</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>1.98</td>
</tr>
<tr>
<td>Chemical Bonding</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>2.02</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>2.40</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>2.03</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>2.04</td>
</tr>
<tr>
<td>Total Scores</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>2.25</td>
</tr>
</tbody>
</table>

Table H.2 Assessing assumption of normally distributed errors for all regression models

<table>
<thead>
<tr>
<th>Model Outcome Variable</th>
<th>Sample</th>
<th>Histogram</th>
<th>Probability Plot</th>
<th>$W$(df)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNM</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>.99(295)</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✗</td>
<td>.99(182)</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓</td>
<td>✗</td>
<td>.98(113)</td>
</tr>
<tr>
<td>Chemical Bonding</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>.99(294)</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✗</td>
<td>.99(182)</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓</td>
<td>✗</td>
<td>.98(112)</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>.99(291)</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.00(182)</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓</td>
<td>✗</td>
<td>.98(109)</td>
</tr>
<tr>
<td>Total Scores</td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.00(295)</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.00(182)</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓</td>
<td>✗</td>
<td>.98(113)</td>
</tr>
</tbody>
</table>

There were no cases of significant deviation from normal, ✓ appearance is acceptable, ✗ evidence of some deviation from normal, $W$ is the Shapiro-Wilk statistic, df is degrees of freedom.
### Table H.3 Assessing the assumptions of linearity and homoscedasticity for all regression models

<table>
<thead>
<tr>
<th>Model Outcome Variable</th>
<th>Sample</th>
<th>Plot: standardised residual – v-standardised predicted value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PNM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td><strong>Chemical Bonding</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td><strong>Stoichiometry</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td><strong>Total Scores</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
<tr>
<td></td>
<td>Consecutive PSSTs</td>
<td>✓ Random, ✓ No funnelling</td>
</tr>
</tbody>
</table>

### Table H.4 Assessing the assumption of no perfect multicollinearity for all regression models

<table>
<thead>
<tr>
<th>Model Outcome Variable</th>
<th>Sample</th>
<th>All tolerances &gt; .1</th>
<th>All VIF &lt; 10</th>
<th>Average VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PNM</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.20</td>
</tr>
<tr>
<td><strong>Chemical Bonding</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.21</td>
</tr>
<tr>
<td><strong>Stoichiometry</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>1.26</td>
</tr>
<tr>
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<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.23</td>
</tr>
<tr>
<td><strong>Total Scores</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>Consecutive &amp; Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>Concurrent PSSTs</td>
<td>✓</td>
<td>✓</td>
<td>1.20</td>
</tr>
</tbody>
</table>
Appendix I Reports arising from Semi-Structured Interviews

A sample of the reports that were created for each of the items of the α-instrument (i.e. those related to the PNM items) are provided. Each report considers both the intelligibility of the item and the strategies used by PSSTs in responding to the item.

REPORT FOR ITEM 1

The model produced for this item separates Item Response and Item Intelligibility. This is the case as, although there were some intelligibility issues, intelligibility did not have any relationship with the responses selected by PSSTs. The item was well understood by five of the seven PSSTs; however two PSSTs thought that this was a two-tier item rather than a traditional multiple-choice item. This was the result of the list of properties in the stem of the item that were labelled A-D. Although this created some confusion, the two PSSTs still understood that the first section was about the properties of a sample of solid sulfur while the second asked PSSTs to identify which properties applied to an atom of sulfur. Excerpts demonstrating this particular confusion and how it did not impact upon the understanding of the meaning of the item are provided below from Nora and Deirdre.
Excerpt from Nora:
I: Okay. Do you think you understood what that question was asking of you?
Nora: Ah, the second questions? Oh the second part? Or the first part?
I: Question 1 yeah.
Nora: Well I understand the first part anyway. It's just looking through physical properties… and chemical ones. And the second one then, now I'd be a bit…
I: Did you think this was two questions, a Part A and a Part B?
Nora: Yeah.
I: Okay. So ‘following is a list of properties of a sample of solid sulfur’ and then there’s the list A to D. You thought you had to tick one of those did you?
Nora: Yeah. Yeah I did.
I: So what about the second bit? What did you think?
Nora: Um… are they not kind of the same thing? 'cause it’s a single atom but it still has the same… doesn’t it?

Excerpt from Deirdre:
I: So you’d… you’d go for D still is it? As in Option D [points at response option]
Deirdre: Yeah. Oh you’re looking for this one are you? [points at the stem with list of properties]
I: Okay. So did you think that this was a two, two part question?
Deirdre: Oh. I just thought that they were two separate questions...
I: So if you were just to explain what this question was asking you?
Deirdre: They’re asking you to say how the properties of sulfur… you know what’s in it, what kind of… it’s more kind of just facts about it, it’s kind of… true or false for them [Stem list]
I: Okay and-
Deirdre: And for this bit [response options] it’s kind testing your understanding that, we’ll say, that one atom still has, still has everything that’s kind of… built up to a whole thing...

PSSTs took three main approaches to answering this item. A PSST might use more than one of these strategies during the interview. One strategy was to first consider a definition for the atom and then to make an assumption about its properties based on that definition. Brendan, Patricia, and Nora used this strategy at some point during their interview and all came to the conclusion that an atom must have all of the physical and chemical properties of a solid sample of sulfur. Patricia and Nora gave definitions that focused on the concept of sameness. For example, Patricia said that "all atoms are the same of the same element. Am... they'll all be identical when they're of the same thing". Brendan gave a more textbook definition of an atom: "an atom is the simplest part of a substance that contains the properties of a substance". This definition does not distinguish between chemical and physical properties but is commonly seen in lower-second-level textbooks. Based on these definitions, all three immediately made the assumption that an atoms of sulfur must have all the same properties as a macroscopic sample of sulfur.
Another strategy was to examine some or all of the properties and to discern which applied to an atom. Although Brendan had initially used the above strategy, when probed he used this second strategy. Eamon also used this strategy. The excerpts showing this strategy in use are provided below. Using this strategy, both PSSTs came to the correct conclusion - that only the chemical property would apply and not the physical properties.

Excerpt from Brendan

_I_: Why did you think that a single atom like wouldn’t have a density of 2.1 g cm\(^{-3}\)?

_Brendan_: … if you… like if there wasn’t 1 g of it or 1 cm\(^3\) of it then you couldn’t have 2.1 g cm\(^3\).

Excerpt from Eamon

_Eamon_: Only the chemistry of it would kind of apply. The, the bonding situation would apply when you get down to the atom level rather than the things like, say, melting point and… ah, say brittleness or...

The final ‘strategy’ involved focusing on the response options and selecting the option that ‘looked right’. Eileen and Nora both used this strategy. Neither displayed any confidence in their responses and quickly changed their preferred response option without being able to give adequate reasoning. An excerpt from the interview with Nora is provided below.

_Nora_: only D would be the same… I’m not sure why… I don’t know why… Like it would make more sense yeah…

_I_: Mmm

_Nora_: Would it be A no?

_I_: So that it would be a brittle crystalline solid?

_Nora_: Wait no it couldn’t be if it was an atom.

_I_: So what do you think?

_Nora_: Yeah if I was to go again I’d honestly, I’d probably pick A but… I’m not sure.

_I_: Yeah okay.

_Nora_: Yeah I probably thought it was straightforward but… yeah, a single atom of sulphur it’s… I don’t know. It’s confusing.

A number of studies have demonstrated that learners may be of the opinion that all or some of the macroscopic properties of a substance are also properties of a particle of the substance (Ben-Zvi _et al._ 1982; de Vos and Verdonk 1987; Johnson 1998a; Ardac and Akaygun 2005; Othman _et al._ 2008; Franco and Taber 2009). The literature review previously stipulated that this alternative conception may be linked to the alternative conception that matter is continuous or granular - a notion that has also been recorded among learners (Novick and Nussbaum 1978; Nakhleh and Samarapungavan 1999; Boz 2006; Beerenwinkel _et al._ 2011). This report demonstrates that, for those participating PSSTS that were interviewed and that used the first strategy, the definitions focused on the concept of sameness between atoms and macroscopic substance. In fact after...
Brendan gave his textbook definition described above, he went on to say that "no matter how much you break down into atoms it's still going to have the same properties as sulfur". This suggests a granular view of matter within the context of thinking about the properties of matter.

**REPORT FOR ITEM 2A**

This question cannot assess PSSTs’ kinetic views of matter. Therefore, it is limited to assessing a more static view of states of matter. The analysis of PSSTs’ comments about the reasons behind their classification of diagrams as solid, liquid or gas, revealed a consideration of 3 main areas (as shown in Figure I.2): arrangement of atoms, atom freedom, and, distance between atoms. One PSST also invoked the idea of attraction.

![Figure I.2 Thematic Map of themes relevant to states of matter classification](image)

The terminology used by PSSTs’ to describe each of these decision making areas is shown in Table I.1.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Atom Arrangement</th>
<th>Atom Distance</th>
<th>Atom Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sub-Theme</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSSTs’ Terminology</td>
<td>Not straight lines</td>
<td>Block</td>
<td>Bunched</td>
</tr>
<tr>
<td></td>
<td>Not uniform</td>
<td>Uniform</td>
<td>Tightly Packed</td>
</tr>
<tr>
<td></td>
<td>Has Spaces</td>
<td>Stacked</td>
<td>Close Together</td>
</tr>
<tr>
<td></td>
<td>Irregular</td>
<td>Irregular</td>
<td>Sliding</td>
</tr>
</tbody>
</table>

One interesting point to note here, is that PSSTs’ use the term ‘uniform’ to mean regular or with a pattern and the term ‘not uniform’ to mean random, when the opposite is the case. The same
trend is seen throughout discussion in this question. This will lead to problems when discussing pure substance, homogeneous and heterogeneous mixtures.

Solids were chosen due to a regular arrangement of particles, a perception of atoms not being free to move, and, the particles being close to each other. All the PSSTs in this interview process identified A as a solid. A typical example of the decision making process comes from Eileen who stated that she chose A as a solid "because... they're all bunched together... and they're all in a block like... they're not moving around freely".

Gases were chosen due to the perception of the atoms being free to move, and, the particles being far apart from each other. One PSST also made reference to attraction in choosing diagrams that were gases. A typical decision-making process was simply that a diagram was a gas "because they're [the particles] so dispersed over the, the box" (stated by Nora) and because they're "floating around" (stated by Brendan). Nora based her decision on Diagram E as a gas given that there was distance between the atoms and that "there doesn't seem to be anything kind of pulling them together".

Liquids were chosen due to an irregular arrangement of particles, a perception of atoms being free to move, and, the particles being close to each other. All the PSSTs in this interview process identified D as a liquid. A typical example of the decision making process comes from Nora who stated that she chose C and D as liquids because "they're [the particles] kind of close together but they're not packed tight together. So that would kind of remind me of the, am, atoms in a liquid. They're still close together. They're all in the one area but it looks like they'd slide over each other".

Nora also used this rationale to identify Diagram C as a liquid – the only problematic diagram for the PSSTs. The difficulty appeared to be with the arrangement and freedom of the atoms. Some of the PSSTs appear to create a connection between the existence of spaces in the regular arrangement of particles and their concept of the particles being free to move. Nora follows up her above comments with the following comments specifically about Diagram C: “I woulda thought that, am, it would slide over like a gas but... on the other hand that could just be a little air pocket.” This also reveals that Nora has the misconception that air exists between atoms or particles - although this question cannot assess this idea. Eileen also stated that "I thought liquid would be C and D because there's spaces... they're more free of whatever".

Previous research has demonstrated that learners may view liquids as having an intermediate spacing between solids and liquids (Adadan et al. 2009). Ozmen (2011a) and Tatar (2011) also found that learners may believe that there are no spaces between solid particles. Both of these
ideas, and particularly the latter idea, may be responsible for learners identifying Diagram C as a liquid. In addition, Nora revealed the alternative conception that spaces between particles are filled with air; this has also been previously identified in the research literature (Williamson and Abraham 1995; Tsitsipis et al. 2012; Adadan 2013).

The two PSSTs (Eileen and Nora) that identified C as a liquid associated any space between particles with the freedom of particles to move, as evidenced by the comments previously provided. While those that correctly identified it as a solid, relied primarily on the ideas of a tight and regular arrangement of atoms rather than requiring all atoms to form a block with no spaces. The comments from 3 of these PSSTs are given below:

Brendan: Solid because the... the atoms were close together and they were arranged kind of regularly... And they weren’t kind of flowing or floating around or anything like that.

Deirdre: They look kind of in block format and they look, d'you know, tidy enough, pack together and... they seem kind of really rigid and stuff.

Anne: So I said A and C, they were solids because I said they were more tightly packed together.

In using a question such as this to assess PSSTs' conceptual understanding, it is important to acknowledge what the question can and cannot test. In this case, the question tests PSSTs’ decisions based on three main areas of atom/particle arrangement, atom/particle freedom and atom/particle distance. The selection of C as a liquid demonstrates an over-reliance on a spaces-freedom rationale and a lack of consideration of the regularity of the atom arrangement. However, the diagrams cannot assess PSSTs' kinetic views of matter nor their ideas about attraction and repulsion between atoms.

REPORT FOR ITEM 2B

The analysis of PSSTs’ comments about their reasons behind classifying the diagrams as pure substance, heterogeneous mixtures or homogeneous mixtures revealed two major and three minor (or divergent) decision making areas. The two major areas were the randomness of the particles and the sameness of particles or atoms. The three minor areas were purity (as in the common usage of the term), smoothness of the material and the state of matter of the material.
The terminology used by PSSTs to describe each of the two major decision making areas is shown in Table I.2.

<table>
<thead>
<tr>
<th>Themes</th>
<th>Randomness</th>
<th>Sameeness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Theme</td>
<td>Ordered: Random</td>
<td>Different: Same</td>
</tr>
<tr>
<td>PSSTs’ Terminology</td>
<td>Pattern: Shuffled</td>
<td>Different Atoms:Same Atom Type</td>
</tr>
<tr>
<td></td>
<td>Uniform: No Pattern</td>
<td>Different Molecules:Same Molecules</td>
</tr>
<tr>
<td></td>
<td>Ordered: Not Uniform</td>
<td>Different 'Things': Same 'Things'</td>
</tr>
<tr>
<td></td>
<td>Disordered: Random</td>
<td>Different Materials: All Triangles</td>
</tr>
<tr>
<td></td>
<td>Gradient: Concentration</td>
<td>Different Substances: Same Compound</td>
</tr>
<tr>
<td></td>
<td>Dispersed: Gradient</td>
<td>Dispersed: Gradient</td>
</tr>
</tbody>
</table>

Note again the incorrect use of the term ‘uniform’ to mean ordered or not random and the use of the term ‘not uniform’ to mean random, when the opposite is actually the case. Two examples from Eamonn of the use of uniform to mean ordered are given below, along with the diagram being discussed.

**Eamonn**: Homogeneous gives me the idea of uniform but I don’t know… mixtures… A was a solid and it’s ordered, yeah, that it’d be kind of homogeneous.

**Eamonn**: A was homogeneous… because it was ordered and, ah, kind of uniform.
PSSTs’ decided that a diagram represented a homogeneous mixture based on the particles being random and the idea of difference. This could mean that it contains different molecules, different compounds, different atoms or different ‘things’ (which was usually a reference to different atoms). One student also invoked the idea of heterogeneous not being smooth and attributed smoothness or lack of smoothness to the arrangement of the particles in the diagram – they attributed macroscopic properties to a microscopic area and failed to realise that even smooth materials do not have atoms arranged in perfect harmony with each other. Four of the PSSTs’ identified Diagram A as heterogeneous. Examples of the decision making process in relation to difference and heterogeneous mixtures are given below:

Brendan: Yeah I said they (Diagrams A, B and D) were heterogeneous because they… they were mixtures of atoms but they had different types of atoms.
I: How would you define it [a heterogeneous mixture]?
Brendan: It would be… a mixture containing… two or more things that are different.

I: You have A as a heterogeneous mixture. So, why was A heterogeneous?
Eamonn: Because there was two or more different types of substances in it

Eamonn: Heterogeneous means different types

I: you have A, B, D and E as heterogeneous mixtures. So why did you choose those?
Eileen: Because ‘hetero’ is ‘different’ so… in the, in the block they’re all different

Many more comments such as those given above can be located in the data. The source of the ‘different’ rationale was provided by Anne:

Anne: Hetero is like two different, different, you know not the same.
I: Okay. So two different…
Anne: Like I always think male female.

Nora was among the three that identified A as homogeneous:

I: for homogeneous mixture here you have A and E. So why would you have chosen those?
Nora: Am, because with A and E, what I’d see to be one molecule, say, for A is that box, box, diamond, circle diamond, circle... or no box, box, diamond circle. I’d see that to be one molecule... and they’re all the same.
I: So, this let's say these two boxes, the diamond and the circle, that's one molecule is it?
Nora: Yeah that's what it looks like to me so they all look the same. So that's... to me homogeneous is the same.

Deirdre: they both [Diagrams A and E] have got, I would say, the same things but it's kind of in order if you get me.
I: you have, ah, A and E as homogeneous mixtures.
Anne: A and E. Yeah... that's all the same... oh because there's a pattern.
I: Okay. So a homogeneous mixture...
Anne: It's d'you know, it's square, square, diamond, circle... d'you know it's following a pattern almost.
I: Okay.
Anne: And then E is kind of the same as well it's... a pattern.

It can be seen that although four of the PSSTs correctly identified A as heterogeneous, it was for the wrong reasons and simply because A contains either different atoms or molecules. However, in all cases the PSSTs followed through with their faulty reasoning by also identifying Diagrams B and D as heterogeneous mixtures (despite the fact that they are homogeneous). Therefore, the analysis suggests that PSSTs that identify A, B and D as heterogeneous do so as they believe that heterogeneous is a synonym for mixture. In one case, E was also selected as heterogeneous with the rationale that it contains different atoms.

Those relying on this rationale had difficulty when it came to differentiating between a pure substance and a homogeneous mixture. Three of the four reached cognitive dissonance during the interview in which they acknowledged that their conceptions of pure substance and homogeneous mixture were the same and that a single diagram could not be both. These three excerpts are provided below:

I: Okay. Are all these mixtures so? So you have A, B, D and E as heterogeneous mixtures and C as a homogeneous mixture.
Eileen: Yeah… but that wouldn’t be pure then… would it?

I: Am, so why did you choose, ah let’s say, E as a homogeneous mixture? Why did you decide that E was a homogeneous mixture?
Patricia: ‘cause each individual one is the same.
I: Yeah
Patricia: Let’s say… that’s a water molecule, a water molecule and a water molecule.
I: Mmhmm
Patricia: So they’re all the same.
I: Okay. So they’re all the same. So that’s you’re homogeneous mixture?
Patricia: Yeelah.
I: Okay so...
Patricia: It's not really a mixture though... hmmm...

I: Yeah. And… your homogeneous mixture?
Brendan: Homogeneous mixture then I would have said… ah… containing the same types of molecules? Mixture? Well I suppose then it’s not really a mixture then is it? Am…

Those that selected A as homogeneous did so because it was ordered. In all of these cases, the PSSTs’ also identified E as homogeneous – viewing it as having an order because in each molecule
the atoms were bonded together in the same order. Examples of this type of reasoning are included in the excerpts given above. Therefore, the identification of Diagrams A and E as homogeneous is associated with the alternative conception that homogeneous means ordered or non-random (this may the result of the fact that they do not understand what the term ‘uniform’ means and most definitions use this term). Conversely all of these PSSTs identified Diagrams B and D as heterogeneous given that it was random and ‘not uniform’. The three PSSTs that associated homogeneous with ordered and heterogeneous with disordered were able to identify Diagram C as a pure substance (although they considered E homogeneous given the idea that the atoms were in the same order in the molecules).

Five of the seven PSSTs identified C as a pure substance but not E, classifying it as either heterogeneous or homogeneous (though three lingered between it as pure substance and homogeneous mixture as these concepts were identical for them). The concept of pure substance was virtually identical amongst all the PSSTs (apart from one that had the correct conception). Pure Substance relied on ‘sameness’ as the reason why they selected C as a pure substance but not E. One comment from each of these PSSTs is given below (though more than one comment was made by each PSST about this idea):

*Brendan*: C as a pure substance. I chose it cause I thought that’s... it was a pure substance because it contained all the same atoms. All the same types of atoms so... I thought C was the only one that had that.

*Brendan*: No I would have said that a pure substance is just type same type of atom... so it’s... a block of gold of something like that.

*I*: Why is C pure?

*Eileen*: Am… because they were all the same and am… yeah pure substance, presumably they’re all the same…

*I*: And C is pure why?

*Patricia*: Because it’s only triangles (laughs).”

*I*: So if you were to define, or tell me, what is a pure substance how would you do that?

*Nora*: It is, am, so it can contain only one kind of an atom.

*I*: Okay.

*Nora*: An element.

*Deirdre*: Well say just from the pictures it's kind of like... it's all, it's all made up of the same thing like kind of.

*I*: So you've C as pure because...

*Anne*: Yeah. Because there's nothing... let's say it's just say all triangles.
The comment from Anne, above, relied on the idea of sameness but also on an idea of pure substances as substances without impurities. Her definitions of heterogeneous, homogeneous and pure substances are given below. However, when she actually categorises the diagrams, she relies on the idea of order to differentiate between heterogeneous and homogeneous mixtures and not the ideas of sameness and difference she mentions here. This may suggest that, while she believes both alternative conceptions, that the ideas of order and randomness are the dominant ideas.

*Anne:* Hetero is like two different, different, you know not the same.
*I:* Okay. So two different...
*Anne:* Like I always think male female
*I:* Okay yeah so it's just it's made up of different things?
*Anne:* Different things yeah. And then homogeneous is all the same.
*I:* Okay.
*Anne:* And then pure is there's nothing else... in it.

These findings are similar to that of Sanger (2000) from which the question was taken. He found three main strategies. He describes the strategies, C (the strategy leading to the correct response), X1 and X2 as follows:

C: Pure substances contain only one kind of molecule. Pictures 3 and 5 depict pure substances because there are only molecules in picture 3 and only molecules in picture 5. The difference between particulate drawings of heterogeneous and homogeneous mixtures is the extent to which the different types of particles are randomly or thoroughly mixed. Picture 1 represents a heterogeneous mixture because the atoms are not randomly mixed with the molecules, and pictures 2 and 4 represent homogeneous mixtures because the two types of particles in each picture (atoms and molecules in picture 2, and atoms in picture 4) are randomly mixed together.

X1: Students using this method identified picture 3 as a pure substance, pictures 1, 2, and 4 as heterogeneous mixtures, and picture 5 as a homogeneous mixture. The following student quote (which is representative of other student quotes) demonstrates that these students classified elements as pure substances, pure compounds (with two or more elements) as homogeneous mixtures, and all mixtures as heterogeneous mixtures: 1 The majority of these students defined heterogeneous and homogeneous mixtures using macroscopic characteristics. Some students used a simple description based on “visual” cues (e.g., Student B), while others used a “sampling” definition.

X2: Students identified picture 3 as a pure substance, picture 1 as a heterogeneous mixture, and pictures 2, 4, and 5 as homogeneous mixtures. Although these students were able to correctly assign the pictures of heterogeneous and homogeneous mixtures, they classified pure compounds (like picture 5) as homogeneous mixtures. The most striking difference between these students and those using X1 is their definitions of heterogeneous and homogeneous mixtures. Students who
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successfully identified heterogeneous and homogeneous mixtures were more likely to use definitions based on how thoroughly mixed (or randomized) the sample was.

**REPORT FOR ITEM 2C**

![Diagram of reasoning processes in classifying diagrams]

Figure I.4 Reasoning processes in classifying diagrams

The analysis of PSSTs’ comments about their reasons for classifying the diagrams as compound(s), element(s) and mixtures revealed a more step-by-step decision-making process than the previous two sections. Rather than simultaneously considering a few areas, PSSTs first consider the number of atoms types before then considering the bonding (in their terminology combined or uncombined). A thematic map of this analysis may be seen in Figure I.5.
Six out of the seven PSSTs identified E as a compound (with one providing no response for E). Compounds were described by one PSST as two or more atoms (whether the same type or a different type) joined together. In other words, all molecules are compounds. The excerpts from his transcript which indicate this belief are given below.

Brendan: I would have said C and E were compounds because... the way they are kind of arranged in the diagram here... you see they kind of put together here [points at pair of atoms in Diagram C]

Brendan: E... I would’ve said that they were compounds as well because you’ve got the... they’re all kind of joined up together in threes.”

Brendan: Element and compound yeah. I would have said that yeah... because... in A you have the diamonds joined to the circles. The way I kind of looked at was that the squares weren’t combined.

Another PSST selected compounds as being two or more different atoms types joined together as being compounds.

I: E then you’re saying... you would swap that over now to compound.

Eileen: To compound yeah... because it’s two or more isn’t it so... and compounds is... one or more joined to together or whatever so I would have said... what did I say... A... or B.
Eamonn indicated that the structure of the material impacted on whether or not it was a compound: “I had classified A as a compound because it was all so rigid and structured.”

Three PSSTs relied on all the atoms being the same as the rationale for deciding on C as an element. They made no mention of the bonding in elements, however, this does not necessarily mean that they did not note that all the molecules were also the same.

Eamonn: the first one for elements, and I went with C because they were, there was no other, there was only one kind in it. So, one… like one… there only seemed to be one type of thing in it. So there could only be elements in it.

I: So you have C as an element. Why is that?
Nora: Am, 'cause it's all the same.

Deirdre: I understand what the elements are. They're all made up of the same... say, matter like or something,... obviously they're all kind of uniform, so that's C.

There also appeared to be a link between compound and mixture for three PSSTs. In the case of Eamonn and Deirdre, they believed that A could not be described both as being a mixture and as being made up of an element and a compound. Eamonn discussed at length his difficulty with this idea.

Eamonn: I know now why I put A over there. Yeah very good. It was because, it was because I, I thought it was a mixture.

Eamonn: And… I was still confused as to what you were looking for here. Were you looking for mixtures? Because it's a mixture as well.

I: Okay
Eamonn: But you asked specifically for an element and a compound. It was very kind of weird, a weird question. So…

I: So having this one before… so having my stuff about the, the pure substance and mixture, having that [Q2b] maybe before that [Q2c] could have… maybe confused the matter?

Eamonn: Maybe… maybe a small bit. Yeah, maybe that was it. I think in general, am… from teaching it and learning it from Junior Cert. and onwards is that it always goes elements, compounds and mixtures.

I: Did you understand from the question that you were, like that it was every single diagram should have been put somewhere?

Deirdre: Ah... well I probably thought it was a... I thought it was kind of a trick question ‘cause I thought that like, everything wasn't... d'you know...

I: Wasn't going to be an element or a compound or an element and a compound?
Deirdre: Yeah. It could be a mixture you know.

Deirdre conceived of compounds as being the same thing as a mixture and as a result identified A, B and E as compounds. She had previously classified all of these as mixture in the previous section of the question.
Deirdre: then compounds... they're kind of a mixture... so A.
I: So if you were to point out there on the Diagram A what are the compounds in A?
Deirdre: In the middle.
I: Okay. So you have... as in the diamond and the circle is it?
Deirdre: Am yeah. I think.
I: Okay. And what are the squares there? (pause) Is that another compound or...
Deirdre: Am, well no it's all kind of the one compound, d'you know.
I: Okay. Okay yeah. So the whole thing there in A is the compound?
Deirdre: I think so.”

PSSTs that assigned D to a category all correctly selected elements based primarily on the fact that the atoms were not bonded together.

Eileen: Am… I’d say they’re all elements… because… they’re not joined together so…

I: So would you put D here with C?
Nora: Yeah. 'cause it's two separate elements.

Anne: I said element, I dunno why... I said element as well... oh elements (emphasising plural) yeah. I'd still say elements for that one.
I: Because you have...
Anne: Your triangles and your little kind of wheel thing.
Brendan: Okay. I said D was elements because… they’re uncombined. So just a mixture of various types of atoms.

One PSST explicitly made the link between element and pure substance which supported the idea uncovered in the previous section of the question (i.e. that pure substances could be made up of the same type of atom)

Anne: I'd still say C is an element, say like carbon ‘cause it's a pure substance or whatever.”

The alternative conceptions discussed by PSSTs when responding to this item have been previously identified among groups of learners in previous research. For example, the link which was made between mixtures and compounds was identified by a number of other studies (Papageorgious and Sakka 2000; Kahveci 2009; Stains and Talanquer 2007). As shown in the excerpts provided above, some PSSTs revealed an association between molecule and compound as was noted by Stains and Talanquer (2009).
All PSSTs made positive statements about their understanding of the stem of the question. They asserted a belief that they had understood the question and that it wasn’t difficult to understand. An example from Patricia and Eileen is given below:

I: Question 2 there... what did you think of that question?
Patricia: [reading question] I think it’s understandable. It looks... to be okay like, am...
I: Mmmmm
Patricia: I liked that kind of question... just cause of the visual aid. Am... yeah. Seems straightforward enough like.

I: So the next part… what was I asking you to do down here, just to make sure we’re on the same page?
Eileen: Which ones [pointing at diagrams] were element, compound or element and compound.

However, when further probed, three of the PSSTs had not understood that they were to categorise each of the five diagrams (rather than select one that fits in each of three categories).

I: I notice that you put down one answer for solid, one for liquid, one for gas and the same the whole way down. I’m just wondering did you realise that from this part here [the stem of the question] that I was asking you to put each of these [the Diagrams] into a category? So you could have had more than one solid....
Patricia: Oh right
I: You didn’t realise that?
Patricia: No.
I: Even when you went back and read over it there?
Patricia: No.
One of the PSSTs mentioned that they thought it could be a trick question.

*I:* did you understand from the question that you were, like that it was every single diagram should have been put somewhere?

*Deirdre:* Ah... well I probably thought it was a... I thought it was kind of a trick question ‘cause I thought that like, everything wasn’t... d’you know...

*I:* Wasn’t going to be an element or a compound or an element and a compound?

*Deirdre:* Yeah. It could be a mixture you know.

In relation to the interpretation of the diagrams, the PSSTs pointed out the shapes that they thought were combined or uncombined e.g. the circle-square in B was seen as combined and the diamond-circle in A as well as in E was considered to be combined. Similarly they could identify shapes that were presented as uncombined such as the diamonds in B, the squares in A and the wheels and diamonds in D. The only misinterpretation of the diagrams came from a case where a PSST viewed each row of A as a molecule. However, this PSST also identified A as a mixture and stated that compounds were the same as mixture and therefore, this misinterpretation appears to be due to their own alternative conception rather than the actual diagrams.

**REPORT FOR ITEM 3**

Four PSSTs (Brendan, Eamon, Eileen, and Patricia) were asked questions about Item 3 of the diagnostic instrument and all responded correctly. Each PSST took two main factors into account in selecting their response option: the state of matter, and the bonding during evaporation. The type of particle led was considered by the PSSTs and this led to statements about bonding.

Excerpt from Brendan

*I:* So then here [points at Diagram C] then. Would you have thought…
Brendan: No I wouldn’t have picked that at all because am… that wouldn’t be ammonia anymore because the atoms have all separated out to Nitrogen and Hydrogen. So… I wouldn’t have said that no. Like if you vaporised it… it would just turn into ammonia gas. It wouldn’t… it wouldn’t break the bonds really.

Excerpt from Eamonn (also in response to a probe about Diagram C)
Eamonn: Am… definitely not just ammonia anyway because of the white dots.
I: Okay.
Eamonn: Possibly, am, the ammonia split up of something. Who knows?
I: Okay
Eamonn: But it’s not ammonia anymore.

Eileen and Patricia made slightly more implicit bonding statements. For example, in response to a probe about Diagram C Patricia stated that C is the nitrogen and hydrogen separated.

PSSTs also considered the state of matter depicted in the diagrams. Previously in Item 2 PSSTs considered some or all of the factors: proximity, arrangement, and freedom of particles. In this case, only particle freedom and distance were considered by PSSTs (though both were not necessarily considered). However, atom arrangement was only considered by PSSTs in Item 2 in order to distinguish between solids and liquids. An excerpt from Eileen in provided below and typifies the responses from the other PSSTs also.

Excerpt from Eileen
Eileen: I probably, I probably would've said A.
I: You’d go for A okay. And what do you think A is showing?
Eileen: Because it’s a gas and am… they’re far apart and they’re, like, moving around freely so…

Although, the alternative conception that covalent bonds break and may reform is commonly reported in the literature (Valanides 2000; Mulford and Robinson 2002; Kirbulut and Beeth 2013), this particular group of PSSTs did not adhere to this conception. It is possible that this is simply the result of the small size interviewed in this study.

PSSTs understood the meaning of the stem and diagrams well. The excerpts above demonstrate this clarity. However, Eileen stated that she didn’t realise that Response Options C-E were unclear:

I: Okay. Can you see that those are all split up?
Eileen: I never realised that they had little white ones all joined onto them.
I: Okay.
Eileen: Even there I just thought it was a shadow you know.

Therefore, one alteration needed with this item is to ensure that the diagrams are clear and that the particles are clearly visible for respondents.
There were three main strategies identified in PSSTs' responses to Item 4 of the diagnostic instrument. The first strategy consistently led to the selection of the correct response options. These PSSTs considered two factors: that the iodine was evaporated in a closed container, and mass was considered to not alter as the result of a phase change. For example, Brendan responded by saying: “Am… because, like, if you have… you know if you have one hundred grams of water… and you heated it in a closed container… you’d still have a hundred grams of water. It’d just be steam. You know it would change phase but it won’t change its mass.” Patricia provided a similar response. However, her consideration that mass does not change during phase change was more implicit than explicit: “it can’t go anywhere. It’s a sealed chamber.”

Eileen did not consider the sealed nature of the tube. However, she may have implicitly considered this. She explicitly described how mass is reduced on phase change from solid to gas but also indicated that the mass disappears completely: “Because yeah you’d just kinda think that a gas is lighter... And , you know, if it was solid there and it evaporated… it would be less. The gas weighs...
less. So if it evaporated it would be less like, because in the solid it would be a gram and if it evaporated it’s gone, you know, it’s a gas so I would have said less.”

Finally, Eamon felt that the response to Tier 1 of the instrument was self-evident. When asked how he knew the mass would be the same he stated that: “Oh no no I knew straight away... Oh it couldn’t change sure.” Eamon said that he wouldn't have been confident about his response to Tier 2 of the item (in which he selected 'conservation law of mass'). He indicated that the phrase was familiar to him and also pointed out that this response was the only one consistent with his selected response in Tier 1.

Excerpt Demonstrating Eamon’s Position that it was Familiar

_Eamonn:_ yeah B was the only answer but… I dunno…. if you put in something like I dunno… something about the conservation of energy of something I might have gotten confused… like more confused. The rest of them were… it was obvious in that case but, but… I wouldn’t necessarily have ah, have known that mass was always the correct answer if there were slightly more similar answers.

_I:_ Oh I see

_Eamonn:_ Concerning laws anyway… it was definitely a law.

Excerpt Demonstrating Eamon’s Position that it was the only Consistent Response

_Eamonn:_ Or or… I knew that was the answer straight away, 27 grams, that’s fine. And then I came down here and I would’ve, I would’ve looked at all of them but I knew most of them were kind of… were talking about, am, reasons why you would pick any of the other [first tier] ones. Gas lighter… but in any case, am, ‘mass is conserved’ is the only one that would fit with my choice.

_I:_ Yeah yeah. So it was really you chose your answer here [in the first tier] and that [Option B in the second tier] was the only one that… to support it.

_Eamonn:_ to support it yeah.

Learners’ conceptions of mass changing during physical changes has been reported in other studies (Griffiths and Preston 1992; Othman et al. 2008; Aydeniz and Kotowski 2012). It is interesting that only those responding correctly gave explicit consideration to the sealed nature of the tube. This may be a central aspect of the ideal approach to conceptual questions like this and may be worth highlighting in the stem of the item.

In terms of intelligibility, the only PSST to indicate some confusion about the meaning of the item was Eileen. The stem of the item had the following phrase: ‘The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:’. This was followed by the response options. An excerpt from Eileen is given below which shows that she was confused about whether it was the weight of the tube or the contents.

_Eileen:_ [reading question] right the weight after heating… it’s the weight of the tube.. and the iodine is it... or are they…?
I: Okay. So if I had put in ‘will the weight…’. So you have your tube, there’s iodine in it and it’s then evaporated so if I had said ‘will the weight of the tube’… if I had put in ‘the tube’ there would that have made a difference?

Eileen: Yeah… because… yeah I just think that that there, you know like, is it saying… I’ve worked out 26 there. D’you know I was kind of saying… together it’s 27 so it’s asked to know the tube now…

Furthermore, the term weight is incorrect. The item is actually asking about mass. Therefore, this item needs some clarification to the stem in order to ensure that PSSTs are aware that it is sealed tube and contents for which PSSTs are being asked the mass.

**REPORT FOR ITEM 6**

Three main themes were associated with PSSTs’ comments about Question 6 of the instrument. Two main problem-solving processes were used by PSSTs when answering this question. Process X is composed of Process X1 and X2 which are more fully explained in Table I.3. The common factor with both of these processes is PSSTs’ consideration of both the information provided in the chemical equation and in the diagram. Process Y involved only the use of information in the chemical equation in decided upon an answer. Excerpts from each of these processes are given below.

![Figure I.9 Thematic Map for Item 6](image-url)
Table I.3 Processes adopted by PSSTs in responding to Item 6

<table>
<thead>
<tr>
<th>Name of Process</th>
<th>Steps Involved in the Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process X1</td>
<td>(1) attention given to stem diagram,</td>
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<tr>
<td></td>
<td>(2) use of information from chemical equation,</td>
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<td></td>
<td>(3) deciding on answer mentally,</td>
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<td></td>
<td>(4) checking for diagram matching mental answer.</td>
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<tr>
<td>Process X2</td>
<td>(1) Use of information from chemical equation,</td>
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<tr>
<td></td>
<td>(2) selection of possible response diagrams,</td>
</tr>
<tr>
<td></td>
<td>(3) attention given to stem diagram,</td>
</tr>
<tr>
<td></td>
<td>(4) isolation of single response option from those selected during Step (2).</td>
</tr>
<tr>
<td>Process Y</td>
<td>(1) Use of information from equation (and also possibly stem),</td>
</tr>
<tr>
<td></td>
<td>(2) selection of response diagram.</td>
</tr>
</tbody>
</table>

Process X1 Excerpt:

*Brendan*: Okay so I would’ve, I probably would’ve counted the… number of sulphurs first of all anyway and… counted the number of oxygens [in the diagram]. And then… so like we’ll say there, this one… six sulphurs and six molecules of oxygen.

*I*: Yeah

*Brendan*: So… you need three… oxygen atoms for every sulphur. So then you have… okay… so you would’ve ended up with actually… let me get it now again… you would’ve ended up with four molecules of sulphur trioxide… and then two sulphurs left over.

Process X2 Excerpt

*Eamonn*: the first thing is to compare the reaction. You’re going to get SO₃ and compare that with each and look and how many of them have 3 oxygen and sulphur bonded to it and that will eliminate 3 straight away. And then compare your starting amount to your finishing amount and it’ll sort itself out.

Process Y Excerpt

*Nora*: Am… 2SO₃’s so it looks like these are the only molecules here that look like SO₃’s… because it's got the one block and the three O's.

The theme of interpretation is similar to that found in Question 5. The sub-theme co-efficient identifies the meaning which PSSTs attributed to coefficients in chemical equations. All those that had used a 'No. of Molecules' interpretation of coefficients in Question 5 used this interpretation again here. Eileen also carried on from her Tier 2 use of this interpretation in this Question. While Deirdre maintained her 'Multiplier of Subscripts' interpretation. Four of the seven PSSTs (Brendan, Eamonn, Patricia and Nora) interpreted a 'closed container' as meaning that matter within the container had to be conserved. Two excerpts of this reasoning are from Patricia and Nora.

*Patricia*: they can't go anyway. I know they can't go anywhere so I have to have this exact amount of pieces in my answer.

*Nora*: There shouldn't be enough O₂'s to make up... all those in C... so there would be some S atoms left over.
Eileen and Anne stated that the term 'closed container' was an indication either that there would be more particles or that they would be in closer proximity. This suggests some confusion associated with pressure may be influencing their ideas here. Anne then changed her mind after a moment and began counting the number of atoms in the chemical equation indicating that she believed that the term 'closed container' meant that the chemical equation had to be balanced. The excerpt from Anne is as follows.

I: If I were to highlight there 'closed container' would that affect your decision at all?
Anne: I don't think it would to be honest... maybe they'd be more tightly pack together.. maybe that [Diagram E]... oh wait now [counting] maybe that one...
I: When you're counting there what are you doing?
Anne: I'm saying [points at both sides of equation] 2 by 3 is 6 O and then 2 S .
I: So you're making sure it's still balanced?
Anne: Yeah. Like obviously 'closed container'... I didn't really... I just kind of looked at it but never really saw that there.

Deirdre had no understanding of the concept of a closed container.

I: If I brought your attention here to this word 'in a closed container', what would that mean to you?
Deirdre: Not much.
I: Okay. So that wouldn't really make any difference would it?
Deirdre: It probably should but... my chemistry is very bad like.

Deirdre selected Response E, a response consistent with a 'Multiplier of Subscripts' interpretation and a lack of understanding of the concept of a closed container. This response, Response E, shows a molecule that would be correctly be represented by chemical symbols 'S2O6'. Kern et al. (2010) calls this molecular flocking and 13.1% of the upper-second level chemistry learners in that study created drawings consistent with this conception. Eylon et al. (1982) had a similar finding with 11% of upper-second-level chemistry students creating drawings consistent with this conception. Yarrock (1985) also found this conception among upper-second-level students. Using this Item, Mulford and Robinson (2002) and Kruse and Roehrig (2005) also found that 22% of second-level science teachers and 74% of third-level chemistry students select answers also consistent with this alternative conception.

These findings suggest that Anne, Deirdre and Eileen either did not have a concept of conservation of particles or possibly (and more likely) they simply had no connection between this concept and their concepts related to chemical equations. As a result, they did not consider conservation of particles at all when answering the question and the term 'closed container' did not link these concepts for them. Abraham et al., (1994) also found that learners in lower-second-level, upper-
second-level and third-level chemistry education did not understand the concept of conservation of particles when looking at chemical equations. Gabel and Samuel (1987) also found that pre-service elementary teachers, with and without previous chemistry instruction, often ignored the conservation of particles.

The interesting thing to note about the interpretations of a 'closed container' is that Patricia and Nora answered the question incorrectly despite maintaining a conservation of matter interpretation of 'closed container' and a 'No. of Molecules' interpretation of the meaning of coefficient in chemical equation.

This leads to the final theme 'Question Intelligibility'. Within this area, it was found that most PSSTs did not notice the term 'closed container' in the question stem either at all or at first. In fact only Eamonn took this piece of information into account without prompting. As previously mentioned, Patricia and Nora answered the item incorrectly despite maintaining a conservation of matter interpretation of 'closed container' and a 'No. of Molecules' interpretation of the meaning of coefficient in chemical equation. When Patricia and Nora had their attention drawn to this term they both changed their Response C for Response D. Brendan initially selected Response C but almost immediately identified the term 'closed container', realised its importance and began his process again. This suggests that Question Intelligibility in relation to 'closed container' is a confounding variable in this question resulting in false positives for the misconception which the question is attempting to test for. This repeatedly came up as a suggestion for the improvement of the question.

This question has been used in a number of other studies (Mulford and Robinson 2002; Kruse and Roehrig 2005). These studies have previously reported that 46% of teachers and 65% of third-level chemistry students do not conserve particles in chemical equations. The findings of the qualitative portion of this study suggest that these figures are inflated due respondents failing to observe or attribute meaning to the phrase 'closed container'.
Five PSSTs were asked questions about Item 7 during the semi-structured interviews. The reasoning provided by PSSTs and their understanding of the factors which impact on ionisation energy was separated into two main categories: spontaneous reasoning and reasoning on probing questions. This approach has been taken to modelling the data as the reasoning provided by PSSTs was quite different depending on whether they were answering the item, or were responding to more general questions about ionisation and ionisation energies. Often they returned to the item after considering ionisation energy in a more general manner and considered other response options; however, they did not state that they wished to change their own response. The area of the circles in Figure I.10, represents the number of PSSTs attempting to apply that particular concept to their response to the item. The responses to the item provided by each PSST are shown in Table I.4. Some PSSTs wavered between two responses or selected a main response but said they may also consider another response to be accurate or possibly accurate so these are also provided where relevant.

### Table I.4 Responses given by PSSTs to Item 7

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>Main Response (if given)</th>
<th>Other Possible Responses (if any other considered)</th>
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</thead>
<tbody>
<tr>
<td>Brendan</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Eamonn</td>
<td>A</td>
<td>D or E</td>
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<tr>
<td>Patricia</td>
<td>B</td>
<td>A</td>
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<tr>
<td>Nora</td>
<td>--</td>
<td>D or E</td>
</tr>
<tr>
<td>Anne</td>
<td>--</td>
<td>A</td>
</tr>
</tbody>
</table>
Brendan and Eamonn both identified the stability of a fully-filled orbital over a half orbital and/or the stability of a half-filled orbital over an empty orbital. An excerpt from Brendan's spontaneous reasoning for selecting Response Option A (removal of an electron will disrupt the stable completely-filled 3s sub-shell of magnesium).

Brendan: When you remove the electron from this you have a half-filled subshell which is more stable than the Aluminium which will be... d’you know the p-level there isn’t half-filled.
I: Yeah... so once you’ve taken out an electron the p won’t be filled is that it?
Brendan: No like... it is... d’you know like at the moment... when a shell is filled or half-filled it’s more stable
I: Oh right. Okay. As it is... before you...
Brendan: Yeah, yeah. Am... and then I would’ve said that... that’s why I would’ve said it would’ve been... greater
I: So it’s easier is it to take away this electron from Aluminium?
Brendan: Yeah... than it would be to take that one from Magnesium. That’s stable as it is... so d’you know it’s got its maximum fill or whatever.

Eamonn’s spontaneous explanation was less detailed but did express the view that fully-filled orbitals are more stable than half-filled orbitals. Eamonn said that “For me... they’re most stable when they have all their shells filled, and, I would still go with that [Option A]”.

Nora and Anne made reference to the energy level diagrams and/or electronic configurations as necessary for reasoning about ionisation energy. However, neither was able to follow through to an explanation as to how this information could inform their response. In response to being asked about the item, Anne stated that she found the item very hard and that "I just, like, d'you when you're doing the arrows and things, I just don't really get... about that really". While Nora stated that, "It's just I'm going through it in my head... all the... like, I know they're written there, the electronic configuration, but I'm actually trying to remember the pictures... you know the diagrams of the levels". Neither followed up further with how the energy level diagrams could inform their response. Anne also made an oblique reference to distance from the nucleus as a rationale for responding to the item as shown in the excerpt below.

I: Am... so just Question 7 there, if you want to...
Anne: Yeah. I was looking at that a little bit earlier. [Reading question]... it’s because of the, the 3p... it’s another orbital... d’you know what I mean it’s a p-orbital but... [reading question]
I: So... it’s because there’s... a 3p orbital in aluminium and there isn’t one in magnesium?
Anne: Yeah. Yeah.

Two PSSTs were categorised as providing no spontaneous rationale. Patricia had to be asked probing questions to obtain her rationale. Although Nora was classified as providing the energy level diagrams as a spontaneous reasoning to her approach to the item, she was also classified as
providing no rationale. This is because the energy level diagrams were the only concept she relied upon in her spontaneous reasoning (unlike Anne who also relied upon the concept of the distance of the electron from the nucleus) but she also could not explain how having this information could be useful in responding to the item.

All five PSSTs were also asked probing questions such as 'what factors impact on ionisation energy in general?'. Although four of the PSSTs relied upon the idea of the stability of fully-filled orbitals, the same number also relied upon the concept of the distance of the electron from the nucleus. The concepts of nuclear charge and screening were now first introduced by some PSSTs even though none had thought of these concepts during their initial approach to the item. Upon answering the probing question, the PSSTs relied upon each of the concepts shown in Figure I.10 as described in Table I.5.

<table>
<thead>
<tr>
<th>Table I.5 Concepts relied on by PSSTs in responding to Item 7</th>
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<tbody>
<tr>
<td>Stability of fully-filled or half-filled orbitals</td>
</tr>
<tr>
<td>Brendan</td>
</tr>
<tr>
<td>Eamonn</td>
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<tr>
<td>Patricia</td>
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<tr>
<td>Nora</td>
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<tr>
<td>Anne</td>
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</table>

As shown in Table I.5, all PSSTs except Nora referred to the stability of fully-filled or half-filled orbitals as a factor that affects ionisation energy. Their comments were similar to those given above from Brendan and Eamonn. Furthermore electronic configuration was also brought up by Eamonn as of central importance to understanding ionisation energies but, as with Nora and Anne during the spontaneous reasoning, he did not provide a reason as to why this is important. He may have made a link with the concept of the stability of fully-filled orbitals but this isn't clear from the interview. The excerpt from his interview in relation to this is provided below:

_I_: And would you know why… if you were to give me some reason why the ionisation energy of one thing is higher or lower than another.

_Eamonn_: okay it always come down to… it comes down to these things but that's just… that's as far as I went for Leaving Cert.

_I_: Yeah the electronic configuration.

_Eamonn_: The electronic configuration and obviously if… in… and am… am I suppose the other things would have been if, if the shells themselves were full. The, the let's say the ordinary 2,8,8… I probably wasn't thinking about that very much when I was looking at this…

All PSSTs save for Nora referred to the distance of an electron from the nucleus when asked the probing question. Eamonn relied on nothing more than the concept of stability, electronic
configuration and distance from the nucleus. Anne relied on nothing further than the concept of stability and distance from the nucleus. However, Patricia also considered the nuclear charge, while Brendan consider both the nuclear charge and the screening effect. Excerpts from Patricia's and Brendan's interviews are given below. Their comments relating to the distance of the electron from the nucleus were typical of Eamonn and Anne’s views also.

Excerpt from Patricia's Interview

I: Yeah. And what makes it easier for an electron to be removed?
Patricia: If there’s, ah… am, if it’s further away from the positive charge of the nucleus… and… am… it depends on how big the charge of the nucleus is. I think there was another reason but I don’t know what it is.

Excerpt from Brendan's Interview

I: So if I was just to ask you like… what does an ionis… what do ionisation energies depend on? Just in general…
Brendan: Yeah. Am… I suppose.. it’s the distance it is away from the nucleus anyway.
I: Yeah
Brendan: The number of shells… screening…
I: Yeah
Brendan: … like between it and the nucleus. Am… what else? The… the number of electrons… I suppose… altogether… d’you know what I mean.
I: Yeah
Brendan: The more you have the easier it is to take away… or whatever
I: Yeah
Brendan: Am…
I: And why is it easier? Like why… let’s say… so you’ve mentioned the distance from the nucleus. You’ve mentioned the am… the screening. You’ve mentioned… so the number of other electrons. Why do they make it easier?
Brendan: Am… because I suppose, like, obviously, like, the electrons are negative and nucleus is positive so the closer it is the stronger attraction it will have for the nucleus. So then… it’ll want to stay there more let’s say.
I: Yeah
Brendan: It’ll be more difficult to remove.
I: Yeah
Brendan: And then… the screening. I suppose, you know, you’ve got your electrons going around inside… on the shells. Inside the one you’re trying to take it off from I suppose. Am… so therefore, they kind of… knock away some of the attraction that the other electrons would have for the nucleus?
I: Okay. Yeah.
Brendan: So it’s easier to remove that way. Am… then I suppose another one would be if the shell was full.

The correct response to Item 7 required PSSTs to consider: nuclear charge, the screening effect, and the distance of the electron from the nucleus. It is interesting to note that Brendan considered
all of these to be important for ionisation energy yet did not ever consider selecting the correct response - even after providing this explanation. Although Patricia does not consider the effect of screening, she is aware that there are three main factors responsible. Later in the interview Patricia states that "yeah I would consider that [Option A]. Because it’s... the 3s orbital is more stable". Yet she doesn’t indicate that this the third factor which she had previously forgotten. This suggests that Patricia and Brendan are aware of the three factors that impact on ionisation energy (although Patricia may have forgotten about the screening effect) and that either they could not apply their knowledge to a practical scenario or they could not understand the response options in order to realise that two response involved considering these three factors.

Brendan’s response also displays an alternative conception regarding nuclear charge. Brendan’s statement that "they [other electrons] kind of... know away some of the attraction that the other electrons would have for the nucleus”. This indicates a conception of nuclear charge similar to that described as conservation of thinking in Tan et al. (2005) as follows: "the nuclear attraction would be redistributed among the remaining 10 electrons when an atom of sodium loses an electron because the number of protons was the same but there was one less electron to attract". Tan et al. (2005) also discussed upper-second-level students’ used of ‘relation-based reasoning’. The authors describe this as the exclusive reliance on one the factors which affect ionisation energy. Eamon and Anne certainly display this type of reasoning as they focused on nuclear charge and the distance of the electron from the nucleus but did not consider screening. Arguably Patricia also displayed this reasoning as she only mentioned these two concepts but not the concept of screening; however, she had an awareness that there was a concept missing and that there should be three concepts that impact on ionisation energy. Tan et al. (2005) also discuss the use of energy level diagrams within the context of students' ideas about the distance of the electron from the nucleus. The authors found some evidence that students’ use these diagrams to assess which species has an electron furthest away from the nucleus. Therefore, Eamon, Nora and Anne's references to energy level diagrams may be an attempt to assess this factor - the distance of the electron from the nucleus. However, this link cannot be explicitly made in this study based on the PSSTs' comments.

Tan et al. (2005) also noted the stability conception within their study. Learners’ expressed views similar to that expressed by PSSTs within the current study. However, Tan et al. (2005) found that almost half of upper-second-level learners displayed evidence of an Octet rule framework in which the magnitude of ionisation energy is attributed to the stability of a full octet configuration. PSSTs did not make reference to such a framework in the current study. However, neither magnesium nor aluminium has eight electrons in its outer shell and, therefore, this item is likely to be incapable of determining whether or not learners have this alternative conception.
There were no issues identified with the intelligibility of the stem of this item; however, the responses appear to have caused difficulty for PSSTs. The themes associated with the intelligibility of response options are shown in Figure I.11. There were two main ways that the intelligibility of the responses are examined with the interview data: based on simple statements about the clarity of the item or lack therefore, and in relation to the consistency between PSSTs' understanding of ionisation energy and the response they selected for the item. In terms of PSSTs’ simple statements, Eamon and Patricia indicated that there were no issues relating to the ease with which the responses to the item could be understood. An example of a simple statement comes from Patricia who, when asked if the responses were clear, stated that "yeah they're all fine". Four of the PSSTs also indicated that the responses were difficult to comprehend. For example, later in the interview Eamon stated about the responses that "even now it would take me a couple of minutes to really understanding what the rest of the options mean...". When Nora was asked about the intelligibility of the item she states that "am… it's clear in what it's asking [pointing to stem]. I think it's just I'm getting confused in the answers... yeah". These sorts of statements were typical of the other PSSTs also.

The second way that the intelligibility arose from the interview was in the consistency of PSSTs' explanations of the factors that impact on ionisation energy and the actual response they selected to the item. None of the explanations and responses could be said to be consistent. Four PSSTs were found to provide spontaneous reasons that were initially consistent with the response option selected, but the reasoning became inconsistent as PSSTs explained the factors that influence ionisation energy. However, none of the PSSTs, upon returning to consider the item after answering the probing questions, decided to alter their response. However, they did often consider
than another response may be accurate. As shown in Table I.5, Brendan's response was consistent with the stability concept but did not take into account his understanding that the screen effect, nuclear charge and distance of the electron from the nucleus all impact on ionisation energies.
Just prior to this narrative, the group had discussed the meaning of compounds and confirmed that water was an example of a compound. During the search for information about compounds, Katie came across something that she thought might be of interest to the discussion. “Does molecules come into this?” asks Katie. Aishling and Rachel look at her and she continues, “Because I’m after finding this thing that ‘All compounds are molecules, but not all molecules are compounds.’”

Aishling hangs her head slightly, “What does that even mean?” she exclaims, and Rachel has a brief conspiratorial laugh. Aishling points to the screen of the laptop that she and Rachel have been using as she says, “I see molecules here actually.”

Katie provides her own understanding of the statement as Rachel and Aishling give her their attention to her.

“Yeah so, like, a molecule… can be… H-two. That’s a molecule of hydrogen, or a molecule of oxygen is O-two, but then—“

“—so does that mean—“ interrupts Aishling.

“—a compound is a mixture, of like—“ continues Katie.

“—of any of them,” finishes Aishling before she asks a clarifying question, “So does a molecule have to be the same elements coming together? Like two oxygens come together. A hydrogen and an oxygen can’t come together,” says Aishling.

Rachel, looking down at her notepad begins to speak in a quiet voice and Aishling and Katie glance over at her.

“Yeah, it says…” starts Rachel, before Aishling and Katie begin to talk over her.

“No, then that’s a compound,” says Katie, answering Aishling’s previous question.

“Then that’s a compound,” confirms Aishling.

Rachel continues to read aloud quietly from her notepad, “—two or more different elements.” Rachel raises her head to look at Katie as she surmises her own understanding, “So a molecule is just one element.”

“It’s just one of them,” agrees Aishling as she turns over a sheet of her notepad in preparation for writing.

“Consists of one element,” says Rachel.

Katie reads aloud from a web page, “It’s the smallest bit of each…” before her voice trails off into silence.

“Okay. Hang on,” says Aishling, “I’m going to look up the definition of a molecule.”
“Yeah,” agrees Rachel. Aishling begins to type on the keypad.

Katie reads out the definition that she has already found for a molecule, “I have that ‘A molecule is formed when two or more atoms join chemically together.’”

Aishling stops typing and raises a hand to her face in frustration as Rachel and Katie look at her.

“Every single… what does it mean?” she says, shaking her head, and she begins to type again.

“But what’s an atom though?” says Katie with a little nervous laugh, “This is where I get confused.”

“An atom?” says Aishling, looking up from the screen of her laptop.

“Like, what’s the definition of an atom?” says Katie.

At this exact moment, I pass close by the group’s table and am within earshot, although I am not listening but merely returning to the top of the room to retrieve something for another group. When Aishling sees me walk close by, she puts one hand up to shield her face in embarrassment.

“Oh Jesus Christ!” she says with embarrassed laughter before continuing, “This is so confusing.”

“I’m gonna click that link,” says Katie murmurs.

Aishling waits for me to walk by the table again on my return journey to a different group, before she returns to the task at hand.

“Oh, I see!” she says and then reads aloud from a web page, “A molecule is an electrically neutral group of two or more atoms held together by chemical bonds.”

“Are you on Jefferson lab?” asks Katie.

“No. I’m on Wikipedia.”

Rachel, who has been looking at the web page that Aishling found, says, “An atom is supposed to be like, a hydrogen atom, an oxygen atom.”

“Yeah,” agree both Rachel and Aishling.

Aishling raises her two hands to simulate two atoms and says “And then they come together,” as she brings her two hands to meet each other. She follows up with a joke, “We need, like physical means to do this because I’m getting so confused.”

“It’s an actual balls like,” agrees Katie.

Rachel returns to their conceptual issues.

“An element then would be like hydrogen and oxygen,” she says.

“It makes sense,” says Katie.

Aishling begins to summarise what they have learned thus far as the group intermittently writes in their notepads.

“Okay. So… a molecule is two hydrogen’s coming together… to make H-two’”

“Yeah,” agree Rachel and Katie.

“Okay,” says Aishling, “And now we have to think, what’s an atom?”

Katie gives her understanding of the concept, “An atom is, like, the things on The Periodic Table”
“So that means hydrogen is an atom,” concludes Aishling.

“Yeah,” says Rachel with certainty, “Hydrogen *is* an atom.”

“Yeah,” agrees Katie.

“I’m learning more in this than I did all last year,” says Aishling as she writes in her notepad.

Katie reads a definition for an atom that she has found using the internet.

“Atoms are composed of protons, electrons and neutrons… have a nucleus. So it’s just—“

“Oh okay,” says Aishling remembering, “So carbon is an atom… hydrogen, iodine and all them.”

“Yeah,” agree the other group members.

“Oh my God,” whispers Aishling as she writes in her notepad.

“So we know what that means… we’re making progress,” laughs Katie.

“Yeah… if we get this done today,” laughs Aishling. Rachel joins in the laughter.

Aishling completes her writing while Katie looks at a web page and Rachel looks around the room waiting for them before they move on

**NARRATIVE A2**

Aishling proposes a direction for the questions that they could create to accompany their concept cartoon in a teaching context. She looks between Rachel and Katie as she does this.

“Say if we stay with our original idea, right, and in the questions underneath we say, how is H-two formed, or, like, like, the answer would be a molecule but, like, you have to phrase the question in such a way —“

“—that they get to molecules,” contributes Katie as looks between Aishling and the screen of her laptop.

“Yeah,” agrees Rachel.

“D’you know what I mean?” says Aishling before continuing, “And then we’d have to, like… “

“No,” says Katie shaking her head and looking up at Aishling, “but it’s not a molecule. It’s a compound.”

Aishling looks up at Katie and raises her hands to face. Rachel briefly looks down at her notes.

“A molecule is—” says Katie.

“H-two,” say Aishling and Rachel together.

“H-two is a… molecule,” says Aishling looking towards Rachel for confirmation.

“A molecule,” agrees Rachel.

“When two of the same thing come together,” says Aishling gesturing with her hands to demonstrate the coming together.

“And H-two-O is a compound,” says Rachel quietly.

“I thought you said that, ‘If the H-two and the O come together’,” clarifies Katie.
“Then that’s a compound,” say Aishling and Rachel.

“Yeah. Oh! I thought that’s what you said. Sorry.”

“But H and H together is a co—a molecule,” says Aishling, again gesturing the coming together of the hydrogen atoms as Rachel and Katie watch.

“Yeah I thought you said it the other way around,” Katie says apologetically.

“But wait now hang on. I’m confused,” says Aishling, “I thought an element is the same thing as an atom.”

Both Rachel and Katie look down at their notes and laptop screen for a moment.

“No an element is only just one,” explains Rachel as Katie looks first in her direction and then looks over to me as I am leaving another group and making my way towards this group.

Aishling turns to Rachel to confirm that she understands Rachel’s explanation, “Just one, so that’s H… on its own.”

“Yeah. And then a molecule, then is two Hs,” continues Rachel.

At this stage, I have now come adjacent to the table and all the group members are aware of my presence.

“But then how is an atom not the same as an element… because one H is an atom,” says Aishling before she glances over at me and abruptly finishes, “I don’t know.”

Aishling laughs a little while Rachel rests her head in her hand with a sigh.

“I’ll come back to ye,” I say as Aishling laughs, “Ye’re in the middle of a discussion and I’m going to ruin it so I’ll go over there. I’ll come back to ye in a minute.”

Aishling returns to the previous conversation and, looking over at Katie, says, “D’you know what I mean?”

Katie then contributes a definition that she has found online to the discussion.

“An element is a substance that is made entirely from one type of atom.”

“Well that is H,” says Aishling. Rachel begins to carry out her own search for information using the internet while Katie and Aishling continue the conversation.

“So if we put loads of Hs together—“ says Katie.

“—then that’s an element—“ adds Aishling.

“For example, ‘An element hydrogen is made up of atoms containing a single proton and a single electron. If you change the number of protons on the atoms you change the type of element it is.’”

Rachel then contributes the definition she has just found for the concept of an atom.

“Oh, an atom is a basic unit of matter that consists of a dense central nucleus surrounded by a cloud of negatively charged electrons,” she says.

After a moment Katie adds, “Sure that is, like, a kind of an atom.”

“It’s an element though,” says Rachel.
“So atoms and elements—“ starts Katie, before being interrupted by Rachel.
“—So an atom is an element… No?” she says as she looks to Aishling.
“I think an element is made up of atoms,” says Aishling, “I have no, see this, this is where this gets me. I have no idea. That’s being so honest with you.”
Rachel drops her pen with a sign and leans back her seat. Katie returns to looking at the web page she has open.
“I’m confused now,” admits Rachel.
Aishling then begins to summarise what they have decided upon so far and after each statement looks to the others for confirmation. They jot down notes throughout the summary.
“Okay, so, hang on,” she says, “A compound is water.”
“Yeah,” they agree.
“An element is… hydrogen.”
“Yeah.”
“A mixture is sand and water.”
“Yeah.”
“A molecule is… H plus H making H-two.”
“H-two,” agrees Katie. The three community members write this down.
“Okay. And then, we dunno what the difference between an atom and an element is. I assume an element is made up of the atoms,” says Aishling.
“Yeah. This says an element hydrogen is made from atoms so… atoms are used to make an element,” adds Katie.
“Okay,” says Aishling as she adds this to her notepad.
“My head is sore. My back is sore,” says Katie, to laughter from Aishling and a smile from Rachel.
Aishling calls out what she is writing in her notepad and Rachel also begins to write in her notepad while Katie continues to look at the web page.
“Atoms… are used to make an element,” calls out Aishling.
“All I’m looking at is… what is the difference between atom and elements,” says Katie, “I love this page.”
“That’s a good one,” says Aishling before she and Katie have a quick conversation to tell each other which web pages they are using.
Katie then provides another definition of element for the group to consider.
“Okay. ‘An element is a basic substance that can’t be simplified’, so hydrogen, oxygen, gold.”
At this point, I join the group and a new conversation begins.
NARRATIVE A3

I pull my chair up to join the group at the table so that I am beside and slightly behind Katie, with a full view of Aishling and Rachel. I begin with a light-hearted, “Okay. I’m going to annoy ye now.” I laugh and all the group members give me their attention. “So how are ye going?” I say.

Aishling takes the lead by explaining their practical strategy for completing the task. “We were finding all the definitions… first… so we know what they are,” she says laughing with embarrassment. Katie and Rachel join in the embarrassed laughter.

“Oh. That’s important,” I say, joining in the laughter.

As Aishling gives some more detail about their strategy, Katie faces forward in her chair and looks between her laptop screen and Aishling and Rachel. “So we found compound, element, mixture, molecule… and then we have an example of all them.”

Rachel sits slightly forward in her chair with her chin resting lightly on her hand and says, “We don’t know the difference between atom and element.” I ask what they think an element is and Katie looks down at her laptop and Aishling at her notes. Rachel answers for them, occasionally looking down at her own notes. “Well, we know an element is like hydrogen or oxygen. It’s made up of atoms, like, just one atom, like.”

Aishling looks away from her notes and gives her full attention to the conversation. She adds, “But then it’s a pure substance.”

I move to bring the conversation back to an earlier point to ensure I have understood the meaning they attribute to the concept element. “Yeah. Okay so hang on now. Say that again… an element is just made up of one atom?”

Rachel looks at me while Aishling and Katie initially look down at their notes. “Yeah,” she says. “Like, hydrogen is an element.”

Katie and Aishling now return their full attention to the conversation. Aishling adds that an element is “one type of atom.”

“One type of atom,” I repeat as Katie turns to face me. Aishling confirms that this is their understanding. I present them with an example to further clarify their understanding. “So… if I had loads and loads of H-twos, so hydrogen in the air is two hydrogens bonded together. So if I had loads of those, would that be an element?”

“No,” says Rachel, “That’s a molecule… loads of H-twos.”

Aishling seeks to clarify the situation. “Yeah, see, we were saying that hydrogen would be an element.”

“One hydrogen atom is it?” I ask, holding up one finger.

“I,” says Aishling.

“So lots of single hydrogen atoms would be an element?” I ask.

“Yeah,” she says.

“But what if they were bonded together?” I ask.

“If they were bonded together that’s a molecule,” she explains.
“So… you’re saying that an element is different from a molecule,” I surmise.

“This is why we’re confused,” says Aishling and she laughs along with Katie and me,

Rachel then jumps in to say, “No an element is different from a molecule.”

“Yeah,” agrees Katie.

“Yeah their different!” confirms Aishling.

“But then an element is an atom,” adds Rachel.

I then summarise my perspective on the main source of confusion, “Okay so really the crux of the problem is, for you, element and atom pretty much mean the same thing”

“Yeah,” they agree and nod their heads.

“That would be it. Okay,” I say.

We then move on with the conversation to determine their understanding of other concepts and will shortly return to clarify this point.

NARRATIVE A4

I begin by asking the group another conceptual question, “So, am… so, let’s say, a compound. What’s a compound?”

Rachel takes the lead in answering with help from Aishling while Katie looks ahead.

“A compound is… two or more…” starts Rachel.

“different—“ adds Aishling.

“—elements… different elements,” says Rachel.

“Two or more different elements,” I repeat.

Rachel then gives an example, “So, like, water.”

I present the group with a scenario to explore what is meant by this. As I do so, all group members are making eye contact with me. “So if I took the air and I said there’s hydrogen and oxygen and there’s water vapour in the air and there’s nitrogen in the air. Would that mean that air is a compound?”

“Yeah,” says Aishling.

“Am… if it can’t be… separated by… chemical reactions,” says Rachel with a little hesitation.

I facetiously say, “Now do you really believe that or are you just quoting the text book?” I laugh and the group members join me but Rachel feels a little embarrassed at the joke.

Realising my error, I then move swiftly along and shift the conversation to the concept of mixture. All of the group engages with this discussion with Aishling initially taking the lead. At the end of the discussion about a mixture, I then try to summarise the overall thinking in the group about atom, molecule, element and compound but inadvertently misdescribe it, “So, I’d say, maybe the crux of the problem is the element-atom thing and then you’ve a, let’s say, all molecules are compounds? Would that be a fair description of what you think at the moment?”
The group moves to correct me. “But not all molecules are compounds,” says Rachel.

“But no it’s that all compounds are molecules—“ adds Katie.

I ask a follow up question. “But then what else can molecules be other than compounds?”

Katie repeats a phrase that she read earlier on the internet. “Is it not that all compounds are molecules, but not all molecules are compounds?”

“Yeah. That’s true,” I say, though in fact the phrase is incorrect.

“I don’t know why. I just read it there a minute ago,” says Katie.

After this point, I go on to explain the distinction between the various concepts that have been introduced.

**NARRATIVE A5**

This narrative is composed largely of explanation of the meaning of element. “An element is made up of one type of atom,” I say and pause for a moment. Aishling and Rachel nod. I go on then to develop this point. “But they can be bonded together. They can be bonded covalently together. Okay, so you can have molecules that are elements. The point is that it’s only one type of atom.”

I then go on give three examples; the element hydrogen as being made up of H\textsubscript{2} molecules, the element carbon in the form of buckminsterfullerene (C\textsubscript{60}), and the element sulfur in the form of S\textsubscript{8}. Throughout these examples, the group members nod or jot down the occasional note.

At the end of this review of the meaning of element, Rachel says, “Oh right! I think I know the difference now.”

I once more reiterate the main point about elements, “Okay. So it’s just that it’s one type of atom. It doesn’t matter that they’re bonded together and actually, in reality, they will be bonded together.” The group members nod their agreement.

I then go on to describe a compound by saying that it is “two or more…”

“—different” interrupts Aishling.

“-different types of atoms bonded together. And remember, that it’s in a specific ratio.” I say. I then give the compound water as an example of this specific ratio. At this point, each group member begins to take notes in their personal notepads. I also point out that water is a molecule in addition to being a compound. I proceed to give the example of salt as a compound that is not a molecule.

Aishling confirms after this explanation that salt is a compound but it is not a molecule. I respond to her by saying, “It’s not a molecule, no. Because if you think, it’s ionically bonded so you actually have loads of Nas and Cls all sticking to each other by electrostatic attraction – the attraction of plus and minus.”

**NARRATIVE A6**

I have just left the group and they consider what has been said. “So we weren’t clear,” says Aishling of their understanding prior to my joining the group. Rachel agrees. Aishling then begins to summarise their understanding. “Okay. So we’re still right,” she says as Rachel and Katie give her
their attention. She looks between the two of them as she says, “Water is a compound. Loads of different hydrogens are an element. It doesn’t have to be just one of them. A mixture is air… because, like she said, nothing is broken and nothing is gained.”

“Yeah,” agrees Katie.

Aishling continues, “Okay. Then a molecule is water.” She pauses, thinking. “Okay. So a molecule and a compound are kind of the same, except like, like—“

“—No,” says Katie. “It’s that ‘All compounds are molecules, but not all molecules are compounds,’” she says while looking at the screen of laptop.

There is a long pause before Aishling sighs and covers her face with her hands. “Oh my God,” she says quietly.

Katie laughs and then tries to explain further, “So, like, the compound H-two-O—“

“—But then some elements can be molecules too,” points out Rachel.

“But she said salt is a compound but not a molecule,” Aishling remembers. “So that’s wrong,” she says with conviction as she points to Katie’s laptop. “Read that again.”

“All compounds are molecules, but not all molecules are compounds.”

“But she said salt is a compound but not a molecule.”

“That makes sense. Compounds… all…” says Rachel gesturing towards Katie’s laptop.

“All compounds are molecules, but not all molecules are compounds,” repeats Katie. “That’s right,” she says with certainty.

“Okay,” says Aishling uncertainly.

Katie begins to explain further, “Because, say, a molecule, the H-two… that’s a molecule but it’s not a compound because it’s not a mixture of two different atoms. But H-two-O… has the two different types… so it is a compound… and then why is it an element as well?” Aishling starts to laugh in response and Katie quickly corrects herself, “No why is it a molecule? So many words.”

“Too many,” says Aishling with her head in her hands, “My head hurts.”

“Oh it’s because it’s two joining together,” says Katie.

Aishling then takes control of the situation and ends the conversation. “Okay. Okay. We will think about our cartoon, because…” she says with the laughter and the rest join in.

“We could be going around like this all day,” agrees Katie.

The group begin to prepare their materials to begin drawing their concept cartoon.

**CASE STUDY B**

**NARRATIVE B1**

“Non-polar covalent bonds anybody?” asks Luke as the other three group members look at him, “Any of those sites?”
“Ah… okay,” says Orla moving turning her laptop slightly so that others can look at it. “This is one of them.”

All group members look at the laptop screen. Luke asks as he looks down at the task sheet, “Does it mention anything about non-polar covalent and polar covalent? ‘Describe each of these.’”

Luke and Orla look at their laptops, as Caroline tucks a piece of hair behind her ear and suggests, “You’d have to say what polar is first wouldn’t you?” Michelle agrees with her and attempts to explain polarity before she is interrupted by Orla.

“This is the only thing they say… about non-polar and polar,” says Orla. Michelle looks at the laptop screen agreeing that it doesn’t say much on the topic. “We’ll try the next one,” says Orla. She and Luke search and read from their laptops for a moment before she reaches for the task sheet in the centre of the table. Caroline and Michelle stare into space and Luke continues to look at his laptop screen, while Orla flicks through the task sheet. After a few moments she says, “Where do you even start like?” before proceeding to enter in a web address. Caroline and Michelle are waiting for their peers as they gaze in an unfocused way upon the laptop screens or table and Caroline takes out her mobile phone to search for information. Orla asks Luke whether he has looked up a particular webpage and he confirms that he has.

“I’m looking for non-polar covalent bonds,” says Luke, “and I’m getting… jack”. After some time, Luke finds a definition that he thinks may be useful. As he speaks Orla and Caroline continue to look at their devices and Michelle looks at him. “Non-polar covalent bonds form when the electronegativity values are very similar.”

Orla looks up from her laptop having recalled something but is interrupted by Luke, “Isn’t it something to do with, isn’t it—“

“—Okay,” he says, “This is a polar bond definition first I think we should go with yeah?” He looks up at Michelle who agrees that is a good idea. Orla and Caroline continue to look at their devices and Michelle looks at him. “That’s what it says here. chemistry-dot-about-com.” Orla and Caroline continue to look at their devices.

“That doesn’t really explain it though,” says Michelle and Luke agrees. “It just says it’s polar, like.”

“Let’s see if I can open it up a bit more,” says Luke.

Michelle makes a suggestion and Caroline looks up as Luke and Orla look at their respective laptops, “Could you just say that the electrons in the bond are more, are am, attracted to one side of the bond?”

“Yeah,” agrees Caroline, adding that, “They’re unequally distributed.”

“Yeah, like partial negative and partial positive,” says Michelle.

Luke jumps into the conversation cutting off something Caroline was about to say, “Okay so here we go. This is the definition. ‘A polar bond is a covalent bond between two atoms where the electrons forming the bond are unequally distributed.’” Caroline and Michelle agree and Caroline
begins to write in her personal notepad while glancing at her mobile phone. Luke continues, “This causes the molecule to have a slight electrical dipole… moment, where one end is slightly positive and the other is slightly negative. Polar bonds are the dividing line between covalent bonding and pure ionic bonding. Examples: water is a polar bonded molecule.”

After a moment looking at their devices again, Michelle suggests, “Should we draw out water?”

“It’s a bit heavy though isn’t it?” asks Luke as he looks at Caroline.

“Yeah I think it is,” says Orla as she continues to look at her laptop screen.

“It’s very long,” says Michelle, “But at the same time, it’s explaining to us not to students”

“If you had a, like—“ starts Orla as she turns her attention towards Michelle and Luke.

“We can just put it into our own words sure,” says Caroline looking up from her mobile phone and notepad.

“Yeah,” says Orla, “If, even a picture or something would be…”

Caroline, Orla and Luke return their attention to their devices as Michelle adds, “It does make sense. It’s just very long-winded like.”

“Yeah, I totally tuned out,” says Orla with a wave of her hand.

The group member’s return to looking at their respective devices for a moment. Caroline, looking at her phone, says, “See that goes on to talk about dipole moments.” She lifts her head to look at Luke and Michelle and Orla gives her attention to the conversation, “So that means we’d have to explain dipole moments as well.” Luke agrees with her.

“Yeah,” says Michelle, “and then you’d have to go on to, like, electronegativity—“

“It does highlight all those words,” says Luke, “like covalent bond, atoms, electrons, and dipole.” The other three group members all listen. “Maybe just to have a look and see does it give us any images?” Michelle agrees with him. “If I have a look at dipole? I’d say it’ll just be a text definition or something,” he says as Orla and Caroline return their attention to their devices and Caroline jots down notes in her personal notepad. Luke quickly finds a definition and directs his attention towards Michelle. “Dipole is a separation of electric charge. In chemistry, a dipole refers to the separation of charge within a molecule between two covalently bonded atoms”, he says laughing and Michelle joins in while Caroline looks up. “You’re kind of going ‘round in circles here.”

“Yeah,” agree Caroline and Michelle. Michelle goes on to add, “It’s really just long-winded as opposed to being precise.” Luke agrees with her assessment. Caroline returns to writing information down from her mobile phone to her notepad.

Orla begins to read aloud some information from the internet about giant covalent structures before she trails off obviously deciding that the information isn’t that relevant, “Giant covalent structures contain a lot of non-metal atoms each joined to adjacent…” That’s going from what, like, covalent bonding…” After a moment Luke returns his attention to his laptop.

“Is there a chemistry for dummies?” asks Luke, looking up from his laptop. Caroline smiles weakly at him though neither Michelle nor Orla react. “Don’t take it personal,” he says, “I’m talking about
myself here.” Caroline returns to taking notes and Luke looks back to his laptop. Michelle picks up the task sheet, apologising to Orla who must move to give her access, and flicks through it while the other group members continue for some time to look at their devices.

Eventually Caroline looks up and Michelle says, “It’s a good definition if you just kinda break it down and not use all the words, say.” Caroline agrees that it would good if they could break down the definition. After a few moments of looking at their devices, Michelle suggests, “Non-polar covalent, could you just say it’s distributed equally like?” Nobody responds to her as they continue to look at their devices.

Luke looks up from his laptop. “So, so where are we going with this then?” he says, indicating the notes that Caroline has taken. “What’s the next question there Michelle?” he asks.

“The non-polar covalent as well… you have to explain that too,” she says as Luke and Caroline give her their attention. “Well for that you could just say the electrons that are in the bond are distributed equally. There’s no partial charge.”

Luke leans back in his chair and says, “We need something like an image don’t we. I might just put in images of covalent bonds.” After this, Caroline will go on to redirect the conversation towards the next question on the task sheet.

**NARRATIVE B2**

This narrative follows on from Narrative A. Luke and Orla are focused on searching for more information about polarity. Caroline looks over at Michelle and asks her about the next step in the task, “What’s after the non-polar thing?”

“Am… why do atoms form covalent bonds”, says Michelle as reads from the task sheet, “The clue is energy ‘check out relevant website section.’” Michelle looks up from the task sheet to Caroline and back again. “Why do atoms form covalent bonds?” she says and after a moment comes up with a response “cause they want to have a full outer shell.”

“Yeah,” agrees Caroline. Luke and Orla continue looking at their laptops.

As Caroline starts to this down, Luke looks up from his laptop asking, “Should I have a look at images of covalent bonds? Maybe that would spark something would it?”

Caroline stops writing, and Luke and Michelle give her their attention. “Do we have to have this all typed up and printed out like?” she says.

“I don’t know. I, I don’t know,” says Luke before he returns to looking at his laptop.

Orla looks up from her own laptop and turns to Michelle as she scratches her head. “What are looking for a definition of?”

“For the next one now, it’s ‘why do atoms form covalent bonds?’” says Michelle. Orla starts to enter search terms on her laptop and Caroline returns to writing notes in her notepad. Luke continues to look at his laptop.

“Can they just be put in our words or do they have to be proper definitions?” asks Michelle. Caroline looks up from her writing, “I’d say they could be put in our words.”
Orla contributes to the conversation with a definition on the web. She leans back in her chair as she reads aloud and the other community members give her their attention. “Covalent bonding takes place. It’s the easiest way for all the atoms to get a noble gas configuration is by gaining electrons.” She turns towards Michelle as she finishes reading.

“Yeah,” say Michelle and Caroline in unison and Michelle nods her head.

Luke leans forward toward Michelle and brings the palms of his hands up to meet each other. “There has to be a simpler way,” he says. He stays this way looking between the other three group members as they continue talking.

Caroline points at Orla’s laptop as she says, “That’s to become more stable though, like.”

“Yeah,” agree Michelle and Orla.

“Pretty much like… to get a full outer shell,” says Caroline.

“I think I like that one,” says Orla.

Michelle says, “They want to have, like, eight electrons in the outer shell.”

Orla adds to Michelle’s statement. “And they get them by getting them ‘on loan’,” she says, making a quotes gesture. She leans back in chair again and extends a hand to her laptop. “Like I’m taking that right off of that.”

Caroline writes in her personal notepad, while Luke continues to sit with palms together looking around at the other group members.

“How does that sound?” ask Orla, still leaning back in her chair. She has her arms folded across her stomach.

“For what?” asks Luke. “Covalent bond?” Orla confirms that she is talking about a covalent bond and Luke responds, “Yeah. If, if, if, if we’re happy with that. Where did you pick that up?”

“skool.ie,” she says.

Someone shouts over to the group from a group elsewhere in the room asking about an assignment for a module of their peer-service science teacher course. All of the community members give their attention to this conversation.

Luke looks down at his laptop, Orla leans back in her chair stretching, Michelle looks at the task sheet and Caroline look towards the centre of the table. Michelle repeats the question on the task sheet, “So ‘why do atoms form covalent bonds?’

Luke shifts in his seat and leans over to Caroline’s notepad. “Okay,” he says, “Let’s put something down. What have we got so far there?” Orla leans forward and looks at strands of her hair while Caroline speaks.

“I just have the definition of a covalent bond, a polar bond, a dipole, and then I just said ‘atoms form covalent bonds to have a full outer shell’,” says Caroline. She looks up, picks up her pen and says, “And to become more stable.” She begins to add this to her notes. Luke looks at the notes she has and is making, resting his elbow on the table and his head in his hand.
Orla turns her attention to her laptop and adds, “They get them ‘on loan’ from the other, the other, from other ah, am…” Orla begins to snap her fingers and looks at Michelle, “ah, whatever, ah…the things, the….”

“Atoms,” supplies Michelle.

“Atoms!” says Orla and she and Michelle laugh. “I actually could not think of that. I’m hungover.”

NARRATIVE B3

Luke and Caroline have retrieved some books and are looking through them for useful information, while Orla and Michelle are discussing their former enjoyment of rote learning Leaving Certificate chemistry. Luke and Caroline are standing at their places looking at the books they have retrieved. A definition catches Luke’s eye and Caroline joins her voice to his towards the end of the definition, “There’s a very simple… a covalent bond ‘a bond formed between two or more atoms by a sharing of electrons.’” Caroline takes her seat while Luke remains standing, looking at Orla and Michelle who return the look.

“Yeah,” says Michelle smiling, “That’s like what we have.”

“That’s very straightforward, isn’t it?” says Luke. Michelle and Orla agree with him that it is a good definition. They look down at their devices and books for a moment.

“Sharing of electrons,” repeats Orla.

Luke considers how this definition fits in with their previous conversation, while Orla and Caroline give their attention to their laptop/book, “Am… if I look up… do we need to go down the route of dipole and that with that definition? That explanation?”

“With that explanation that you called out there?” asks Orla, as she looks up and then shakes her head to say ‘no.’

Caroline looks up from her book at Luke. “But you see we have to explain polar then and dip—, with polar then you kind of have to explain dipole.”

“Yeah,” agrees Michelle nodding her head. Orla and Caroline returning to look at their laptop/book.

“Well let’s see what it says about polar,” decides Luke. He realises that it may take him some time to find that definition in the book as he says, “But then… I guess polar could be anywhere.”

Each group member looks at their respective devices or books. Michelle offers her own thoughts on the meaning of polarity, “Like, polarity just happens when the electrons that are being shared aren’t shared equally.” Caroline murmurs some agreement but neither she nor Orla look up from their laptop/book.

“Okay. This is a polar covalent bond,” says Luke who, still standing in place, has found a definition. Orla momentarily interrupts as she has also found a definition, “It’s a covalent—.” She realises that Luke is speaking and gives her attention to him.
“The ease with which an electron… cloud of an atom or a molecule is distorted by an outside influence…”

“No,” says Orla, quickly dismissing the definition, and turns back to her laptop.

“…thereby introducing a dipole moment,” finishes Luke.

Orla introduces a definition that she has found on the internet and Luke gives her his attention, “I have one here. I have one that it’s ‘a covalent bond in which the shared pair of electrons is attracted more to one of the joined atoms than to the other.’”

“Yeah,” says Michelle, “H-Cl is a good example of that actually.” Luke looks between Michelle and Orla, appearing somewhat lost, as they continue to talk. “In that case, Cl is one type, is partially negative ‘cause the electrons are—“

“So it’s attracted to… depending on the polarity,” says Orla, leaning back and dismissively waving her hand.

“Yeah.”

“It’s attracted to one.”

Michelle then raises another point, “Do you have to go into electronegativity values then though?”

“You do,” says Orla, “cause it’s kind of like well how would you know if they’re attracted to it.”

“Yeah, they’re all linked, like,” agrees Michelle. Luke takes his seat and returns his attention to his book.

“So then you go to the electronegativity,” says Orla with a smile, as she types in search terms to locate information on the concept.

Caroline looks up from her book and, as she speaks, Luke and Michelle give her their attention, while Orla continues to search for information on electronegativity. “This is really broad,” she says, somewhat exasperated. Michelle agrees and Luke asks her to repeat herself. “When you go into it in detail, it goes really broad,” she says again and Luke agrees leaning back in his chair. He seems somewhat dejected.

“And that’s a measure of attraction,” says Orla, having found the definition for electronegativity. Caroline and Michelle agree.

Narrative B4

Michelle and Orla are leaning back in their chairs while Luke looks at a book. Caroline, who has been looking through a different chemistry book, says, “There’s the octet rule anyway.” The other group members give Caroline their attention as she goes on, “It says when bonding occurs, the atoms tend to reach an electron arrangement of eight electrons in the outer shell.” Caroline starts writing this down in her notepad and Luke leans over to look at Caroline’s book. Michelle and Orla continue to sit back in their chairs and Orla takes out her mobile phone to text.

Luke, who has been looking at Caroline as writes, asks, “That’s the… octet rule is it?” Caroline confirms that it is.
Michelle lets out a yawn and then sits forward in her chair. “Is it just definitions we’re giving or are we supposed to go into more detail after then?” she asks as she and Luke look at each other. She clarifies, “Like not extreme detail but brief kind of like explaining.” Orla puts away her phone and leans forward in her chair, while Caroline continues to write.


He then responds to Michelle’s previous contribution. “Am… so do we need to get the definitions first and then… present it, or teach it, then?” Caroline has stopped writing and is listening to Luke. Michelle and Orla are also giving him their attention.

“Yeah. I think we should,” says Michelle. Caroline also agrees with her, before returning her attention to her book. “Like you can’t… if you’re in a group of students you can’t just tell them, you have to say, like, why this happens.” Orla nods her head in agreement with Michelle.

“Cause you’re bringing this to the next group, right,” says Luke. You’re the expert in covalent bonding. So we should have… some kind of structure or some kind of…” Michelle and Orla agree with him.

“Covalent bonding goes on to…” says Orla gesturing a sequence with her hand.

Luke takes up her train of thought. “Covalent bonding goes on to this, goes on to this, goes on to this. So each question should lead into the next one shouldn’t it?”

“Yeah,” agrees Michelle. Orla returns her attention to her laptop.


Orla turns to Michelle, “Are they leading into the next…?”

“They’re all linked though, like,” says Michelle in response. Orla returns her attention to her laptop.

“So… we should be all in agreement of what a covalent bond is,” says Luke. “We should all be taking that definition to the next table.” Caroline looks up from her book, using her finger to hold her place.

“Yeah cause we’re all going to be saying the same,” agrees Michelle.

“So should we all be taking down the stuff?” wonders Michelle.

Caroline jumps into the conversation to read aloud a definition she has found, as Luke and Michelle give her their attention. “It says here, it’s just really simple as well. The chemical bond formed by sharing a pair of electrons is known as a covalent bond.”

Michelle and Luke nod their approval. Luke adds, “I would go with simplicity more than…”

“If we start off saying that and then build it up,” suggests Michelle and Caroline agrees.

“I think then we should explain the octet rule,” says Caroline, looking between her notes and Michelle and Luke, “because then you have to say why they bond. To form eight d’you know.” Luke turns around in his chair to retrieve his notepad from his bag, while Caroline returns her attention to her book.
“Okay. So covalent bond is first then,” confirms Michelle.

Orla shifts in her seat and ask, “Will I type this up?”

Caroline looks up and turns over to a new page of her notepad as she says, “We need to ask her does she want it typed up?”

“But it would be handy for her as well so…” says Orla. Caroline returns her attention to her book.

Luke holds his notepad in his hand as he asks, “Are we all writing down the same thing?” Michelle agrees and he adds, “Just we’ll all make our own personal notes about what it is. Okay.”

“Yeah,” says Michelle as she writes in her notepad, “Cause we’re gonna have to teach it to all the other groups anyway”.

“But I think we need to be in agreement what we’re teaching everybody,” says Luke. He then turns to Caroline who looks up from her book. “So… what definition are we gonna take? Are we gonna take this one?” he says pointing at her book. Orla starts to type on her laptop.

“Do you want to? It’s easy,” says Caroline.

Michelle looks up and agrees that they should use that definition. “Yeah it’s easy it’s just, basically the sharing of electrons, like to give a full outer shell. And then you’re right yeah, then we go onto the octet rule.” Michelle starts to write in her notepad.

“Okay,” says Luke, as he starts to write in his notepad “So the definition is…?”

The entire group writes or types for a few moments, Orla stops typing and leans back saying, “Sharing electrons to give a full outer shell.”

Luke stops writing and leans into Caroline’s book. He reads aloud, “A chemical bond formed by the sharing of a pair of electrons.” Michelle doesn’t look up from her notepad but confirms that this is the definition. Caroline and Luke begin to write and Orla returns to typing.

After a period of time in which the group has been writing and typing, Caroline asks, “So then will we say why do they...”

“Why do they want a full outer shell,” says Orla without looking up from her laptop. Michelle stops writing to look at Caroline and nods her agreement. They return to writing. “Cause that’s when they’re at their most stable,” adds Orla.

“We don’t have to… yeah these are just guiding questions we don’t have to stay with them,” says Michelle, referring to the questions on the task sheet for the session. Caroline confirms this is the case. All group members write or type for a moment.

Luke looks up and leans over to ask Caroline, “Okay so what’s the next thing we’re saying?”

“Why, am…”

“Why does that need to happen or…?” adds Luke.
“Yeah,” Caroline says and stops writing. Orla stops typing and looks at her and listens. “Why do covalent bonds occur. And we say, to become more stable and to have a full outer shell.” Orla starts to type again.

“Is that the next question?” asks Luke and he leans over towards Michelle and points at the task sheet. “Or is that what we’re just asking?”

“That’s what we’re just saying,” says Orla, looking up from her laptop at Luke and Michelle.

“These are just the guiding questions so we need to try to make the links ourselves,” explains Michelle. Caroline and Orla return to writing and typing. Michelle goes on, directing the conversation to Luke. “If we do say about needing a full outer shell in the definition, like, the next question will be ‘why do they need a full outer shell?’ So would it not be better to talk about the octet rule after that?” I walk up to the table and crouch down as I wait for them to continue.

“Yeah. Yeah… to take it to the octet rule then,” agrees Luke and all conversation stops.

**NARRATIVE B5**

Prior to this narrative, Luke speaks for the community and focuses upon their strategy and their broad ideas about explanatory strategy but without reference to any specific concepts save for repeating their definition for covalent bonding. I begin to ask for information about why bonding occurs but don’t receive a conceptual response. I then go on to explain why covalent bonding occurs.

“Why do two ions form a bond?” I ask, looking around at the group who are giving me their attention. After a moment, I answer my own question. “So one is plus and one is minus, so it’s a force of attraction between the two.” I then take an oxygen molecule as an example of a covalent bond and I holding each hand out in front of me to represent each oxygen atom. “So what you have is that each one has a nucleus which is positive and electrons which are negative. So, what’s happening really is that the electrons from this atom,” I say, as I gesture to one hand, “while they are attracted for their own positive nucleus, also become attracted to this, ah, nucleus of the other atom. So that’s why they actually end up sharing. Okay?” I pause for a moment and the group members nod their heads.

I continue, “I just hear you mentioning the octet rule as well. I have some questions about that and things to look up… like exceptions to the octet rule.” Orla turns her attention away from me and back to her laptop. I continue, “Because that’s one of the big problems and it ‘causes problems for people once they reach college because everything… if an atom bonds you have to think ‘oh well what would the octet rule say?’ The octet rule is only a rule of thumb. There are more exceptions than there are things that actually follow it. You know, so, that’s just something to think about you know.

**NARRATIVE B6**

I am crouched down at the end of the table between Luke and Michelle. All of the group members are giving their attention to the conversation. Caroline asks a question and the other group members look towards either her or me. “How far should we go… in depth of knowledge, like?
Do we have to go talk about polar, non-polar, dipoles, then into electronegativity, like?” she says as Luke echoes her on the word dipoles.

As I respond, all group members are leaning forward and giving me their attention. I look at each of them in turn as I speak. I initially make the point that they could reasonably go further if they can still ask the question “but why?” I take the example of electronegativity, “Electronegativity is really important cause it’s why some things are polar covalent.” I begin to use hydrogen-fluoride as an example to explain why electronegativity is an important and relevant concept, but stop to ask Luke if I can draw on his notepad; he gives me his permission and leans back in his chair but turns his head so that he see into the notepad I have placed in the centre of the table. “So this atom here,” I say point to what I have just drawn, “so F, is very electronegative. Okay. So what electronegative means is that it just has a stronger attraction for electrons. Alright? So hydrogen then is not as electronegative.” I go on to remind the community members about the atoms I am speaking about, “So remember hydrogen is a nucleus surrounded by an electron. Fluorine is another type of a nucleus surrounded by electrons. So, that’s what we’re really talking about.” I explain the polar bond between hydrogen and fluorine, “So, they’re sharing, but the electrons actually spend more time around fluorine. So, they are sharing, but the electrons would spend more time around fluorine than they will around hydrogen.”

Luke asks, “Would you think it would be better to do that via an illustration… rather than doing it with words?” I agree and suggest that some words would be needed to explain the illustrations. “And is that what you’re trying to get us to do here?” he says.

“Yeah,” I reply. “I’m trying to get you to think like that. To think—so that you’re thinking ‘how could I explain this to somebody else?’ You know how would be best for you to explain this, to that group over there?” Luke then asks whether I can give them a website with animations. I recall an animation on H-F on YouTube and suggest that they search for it. Luke takes out his mobile phone and give his attention to that while other group members continue to focus on me and the notepad. I then reiterate the point about the polar bond between hydrogen and fluorine and introduce the notation delta-plus on hydrogen and delta-minus on fluorine. “Delta-minus… so it’s slightly negative, or partial negative, and this [pointing to hydrogen] is partial positive. So all that means is, in general, it’s kind of electrically neutral but, in reality, the electrons spend more time around the more electronegative element.”

NARRATIVE B7
I have just left the group. Luke continues to lean back in his chair and look at his mobile phone. Orla looks at her laptop. Michelle and Caroline look generally towards each other. “Back to the drawing board lads,” says Michelle wryly and rubs her eyes.

Luke looks up momentarily as Orla begins to speak, “I think we should just kind of get an example, two examples, one of polar…”

“One of non-polar, yeah,” says Caroline.

“And then just work with those two for the whole thing,” says Orla as she looks towards the other group members.
Michelle nods her head in agreement and, as she gestures towards the notepad I was previously writing on, says, “So we could just use that one for the polar example.” Orla and Caroline agree with this and Caroline begins to write in her notepad. “We could just, like, take O-two or something,” she says and after a moment adds, “cause a diatomic molecule is non-polar.” Caroline looks up at Michelle and then writes down a few notes.

**NARRATIVE B8**

This narrative follows Narrative B7 in which Luke had begun texting on his mobile phone. He continues to look at his phone over the course of the following experiences.

Caroline looks between Michelle and Orla, who are sitting forward in their chairs and listening to her. She says, “You know the way she was saying about how there’s, ah… exceptions to the octet rule?” Michelle nods and Caroline continues, “But we didn’t really do it for Leaving Cert.” She pauses for a few moments and then asks, “Did we?”

“Well it was just that there’s an octet like,” says Orla.

“Yeah, hydrogen and lithium. They’re… ‘cause they only have two,” says Michelle.

“We didn’t go into detail though,” says Caroline.

“No,” confirms Orla and Michelle shrugs. Orla says, “It was just ‘oh there’s an exception to the rule.’”

“How are we supposed to know that though?” asks Caroline, “d’you know… since we didn’t do it?”

Michelle responds to her, “The octet rule only applies up to, like, s, p and d or something.”

“Yeah. Yeah,” says Orla with certainty and then turns her attention away from the conversation to her laptop.

Michelle continues, “No, s and p, and after p it doesn’t apply, because d can have ten electrons or something… ‘cause there’s five orbitals. So the octet rule doesn’t apply to one’s with d orbitals.”

“Oh,” says Caroline in surprise.

**CASE STUDY C**

**NARRATIVE C1**

Aishling, Lorraine and Eileen have just listened to an explanation of the task and now have their first opportunity to begin their work. Lorraine shares a few words with Aishling, while Eileen is looking at the task sheet.

“So… what is it? Covalent bonds just?” asks Lorraine, as she plays with her scarf.

“Yeah,” Aishling agrees.

“So, sharing of electrons.”

“Sharing electrons, yeah,” echoes Aishling, before she goes on to call out what the next part of the task will be. “And then you break them down into non-polar and polar.”
Lorraine, apparently satisfied by this understanding, begins to write in her notepad about the meaning of the covalent bond type.

Eileen looks up at her laptop screen and says with some confusion, “But where is… the Check Your Understanding for…”

Aishling echoes her frustration. “Bonding isn’t on this site though… so I dunno,” before she picks up her pen and begins, like Lorraine, to write in her notepad.

Eileen seeks clarification from me about where they are to find the information they need to complete their task and I explain that all the information they require is on the task sheet.

“This is completely confusing,” says Aishling, after I have left the group. She then returns to writing.

Aishling and Lorraine finish writing their interpretation of the meaning of covalent bonding and begin silently reading the next part of the task sheet. Meanwhile, Eileen searches the internet for a definition of covalent bonding. Aishling moves the task sheet such that both she and Lorraine have better view of it.

“I don’t know how you can read upside down,” says Aishling with a laugh and they share a smile.

Eileen finds a definition of covalent bonding on the internet and reads it aloud to the whole group.

“A covalent bond is the sharing of electron pairs between atoms.”

“I never said between atoms,” says Aishling, with a nervous chuckle.

Aishling and Lorraine begin to write again. Eileen continues to look at the laptop screen and, by the time Aishling has finished writing and is looking at the task sheet again, Eileen is still shuffling her notepad and arranging things on the desk. She appears to be stalling and uncertain.

I am standing close to the group and have observed the previous few minutes, so I ask the whole class to ensure that each individual person in their respective groups understands what has been written. This appeal does not have the desired effect on the observation group and they continue as before.

After a few moments, Lorraine and Aishling begin looking at the task sheet for some time, as they quietly read the next question. The question asks the group to categorise covalent bonds into polar and non-polar types. Both begin to write without any discussion.

Once Eileen has finished writing her definition of the meaning of covalent bonding, she sits there awkwardly, unsure what to do next. She reaches for the task sheet. She flicks through the pages, though she doesn’t seem to really be reading it, and repeatedly tucks her hair behind her ear in a nervous gesture. When Lorraine and Aishling eventually finish writing, they wait for Eileen to return the task sheet to the centre of the desk, which she does after a few moments.

After a moment, Aishling looks up at Lorraine, “Do you have any idea about the polar and non-polar?”

“I don’t remember about polar and non-polar,” responds Lorraine.
The group spend another few moments gazing at the task sheet, before Lorraine nods in the direction of the laptop and suggests, “Will we Google the non-polar and polar?”

NARRATIVE C2

The group have completed the previous portion of their task and Aishling and Lorraine look into the task sheet, while Eileen looks at her laptop screen. Aishling and Lorraine read the next question for the task which asks the group to write about why atoms form covalent bonds.

“To become more stable isn’t it?” says Lorraine.

“Hmm” says Aishling.

“It’s to become more stable is it?” she says more clearly.

Aishling looks up from the task sheet, “Sorry, say that again.”

“To become more stable is it?” she says with certainty.

“Yeah,” Aishling responds briskly before reading aloud from the task sheet, “‘Clue: Energy’…”

Lorraine leans over to continue reading where Aishling left off, “‘Check out relevant website section.’”

Lorraine and Eileen look on as Aishling turns the task sheet over to the page with the list of websites. The group looks at the task sheet for some time.

“What’s the question?” asks Eileen.

Aishling turns back to the page of questions saying “Why do atoms form covalent bonds?” and follows it up with “It is to become more stable because then she goes ‘Energy’”.

Both Lorraine and Aishling pick up their pens and begin to write, while Eileen starts to search for information on the internet using her laptop. After some time, Aishling and Lorraine finish writing and Aishling looks at the task sheet, while Lorraine flicks through her reflective journal. Aishling begins to help Eileen by suggesting which website from the task sheet should be used.

“It’s that website that she wants you to use,” says Aishling, as Eileen and Lorraine listen. “Cause if you read through it she goes ‘so why do they form bonds?’ and then she goes, ‘If I were doing housework I would prefer to do it with less energy rather than more.’”

As Eileen types in her laptop, Lorraine quickly draws a conclusion based on what she has just heard.

“So does it take less energy to form a covalent bond rather than forming a—”

“—yeah because they’re only sharing,” Aishling says with certainty.

Lorraine begins to write in her notepad, while Eileen asks Aishling which web address she should be entering from the task sheet. Aishling then joins Lorraine in writing, while Eileen types out the web address. Lorraine completes her writing and looks around the room or at her mobile phone until Aishling also completes her writing and they have a long and friendly conversation about their weekend plans.
Once they finish their conversation, Aishling looks at the laptop screen with Eileen. Eileen, who has been searching for a webpage, then moves her laptop over so that Aishling has the best view of it and begins to write. Aishling reads from the page while Lorraine colours in the front of her reflective journal. After some time, Eileen also completes her writing and both she and Lorraine fidget or look around the room, while Aishling continues to read silently. Aishling then finds something on the webpage she thinks is of relevance and she and Lorraine have a conversation, while Eileen flicks absently through the task sheet.

“So it says they want to share them… they want to share them rather than transfer them,” says Aishling, as Lorraine leans forward to see what part of the webpage she is looking at.

“Yeah. So it’s just kind of—” says Lorraine leaning back, before Aishling interrupts her.

“It says that if they have the same electronegativity… roughly the same.”

“Mmm.”

“That’s why they say that they share.”

“Yeah,” says Lorraine with some disinterest.

“Yeah. This is complicating it isn’t it?” says Aishling, tucking her hair behind her ear.

“Yeah,” agrees Lorraine.

Aishling and Lorraine sit back and wait for Eileen to return the task sheet so that they can move on with the task.

NARRATIVE C3
Following on from the previous narrative, Eileen leans over with the task sheet so that Aishling can see into it while Lorraine looks on.

“What is the Octet Rule?” Eileen reads aloud from the task sheet.

“What’s that one?” asks Lorraine.

“What is the Octet Rule?” repeats Eileen, handing the task sheet over to her.

“So they want to have… eight electrons in the outer shell isn’t it?” says Lorraine and Eileen echoes her words with the slightest of delays such that it almost appears they are speaking at the same time.

Eileen and Lorraine pick up their pens to write. As I begin to approach the table, Aishling asks if they are writing down what has just been said and all three begin to write. On seeing that the group are in the midst of writing, I move off to another group as I do not want to disturb them in writing down their ideas.

Eileen on completing her writing picks up the task sheet and again absently looks at it. After some time, Aishling also completes her writing and starts looking at the webpage on the laptop screen. When Lorraine completes her writing, Aishling speaks aloud to confirm the meaning of the octet rule. Eileen continues to look at the task sheet.
“So it’s that they want to have the same number of electrons as the noble gas,” she says before she begins to imply that is essentially what has been written already, “but the noble gases are usually eight so yeah.”

“Yeah, so they are stable,” adds Lorraine.

As Lorraine begins to write, Eileen reads an alternative conception from the task sheet, “There’s a misconception there that ‘Atoms bond to satisfy the octet rule.’”

Eileen’s contribution is met with silence. Lorraine completes her writing and sits back in her chair, shifting in her seat and looking around the room. Aishling and Eileen gaze at the alternative conceptions listed in the task sheet. Eventually, Aishling turns away from the task sheet also and gazes down at the table for some time.

“I guess that explains it,” says Eileen, turning over the task sheet to the list of questions.

“Like I don’t even get what she’s saying,” says Aishling.

“Yeah,” agrees Lorraine, “The octet rule is easy enough, like.”

Aishling returns an emphatic, “Yeah.”

The group moves on to the next question on the task sheet.

NARRATIVE C4

Carrying on from the last narrative, Eileen calls out the next question on the task as Lorraine and Aishling listen.

“Does the octet rule apply to all atoms that bond covalently?”

The other group members look to Aishling who says, “No, ‘cause you’re not guaranteed to achieve—“

“—the oct, eight,” says Lorraine.

“the full outer shell, like,” continues Aishling.

“Yeah,” agrees Lorraine.

“It’s like a trick question though,” says Aishling, as Lorraine and Eileen begin to write.

Aishling joins them in writing. Eileen completes her answer and looks around the room or gazes at the task sheet in the centre of the table.

“That question is stupid,” says Eileen once the other group members have stopped writing, before quickly continuing with the next question. “Are there exceptions to the octet rule? Are there many of them compared to atoms that follow the rule?”

Both Lorraine and Eileen again look towards Aishling who begins to repeat the question briskly.

“So, are there exceptions to the octet rule?”

After some silence Eileen continues with an uncertain tone in the repetition of the question, “and… ‘Are there many of them compared to atoms that follow the rule?’”
“What does that even mean?” says Aishling with a laugh and continues with a critical tone, “The phrasing, like”.

“Yeah,” agrees Lorraine absently, before making a suggestion, “I’d say, just type in ‘Are there exceptions to the octet rule?’ or something like that… and see what comes up, like.”

Eileen sets about this and begins typing, while Aishling turns pages of the task sheet, and Lorraine waits, gazing ahead of her. Aishling finds a web page address on the task sheet that she thinks will be useful and points it out to Eileen. She then looks at the screen of the laptop as she waits for Eileen to bring up the web page.

“The octet rule has more atoms breaking the rule than following it,” reads Aishling aloud from the web page.

Lorraine begins to write as Eileen and Aishling continue to read the web page.

Aishling again reads aloud from the web page, “So, ‘there’s three classes of exception to the octet rule’, ‘Too few electrons’, so hydrogen, lithium and boron break it ‘cause they’ve too few electrons to form an octet’.”

Lorraine continues to write, and Aishling and Eileen also prepare to start writing as they pick up pens and move the task sheet to free up space to write in their notepads. Eileen then shares her opinion of SuBATOMIC with Lorraine and Aishling who both look up as she speaks.

“I hate this thing.”

“Hmm?” says Aishling.

“I hate this thing,” repeats Eileen.

“Yeah so do I,” laughs Lorraine, as Aishling nods her agreement and adds further comments in agreement.

The three group members all return to writing, when Eileen remembers their answer to the previous question.

“We already said that all atoms don’t follow the rule.”

“Yeah,” says Lorraine stretching, “You’re just kind of repeating yourself.”

Lorraine yawns, sitting back in her chair, while Eileen and Aishling continue to write notes and occasionally look up at the laptop screen. After a period of time, Aishling leans forward to more intently read the information on the screen on the laptop, while Eileen continues to write. Aishling sees some contradiction in what they have previously read.

“It says that there’s three classes of exceptions. Oh there’s only three things that can’t… make an octet, like, break the octet rule. It says that there’s three classes of exceptions to the octet rule.”

“But did it not say that there was more elements break the rule,” says Eileen.

Aishling gives an emphatic, “Yeah,” and goes on to conclude, “so those are just examples, there’s—“
“—I’d say so,” interrupts Lorraine who continues to sit back in her chair.

“—more than that,” continues Aishling.

Eileen and Aishling return to writing, as Lorraine yawns and looks around the room. Eventually, Eileen reaches over to the mouse of the laptop and scrolls down to reveal more information. As Eileen speaks, Lorraine now returns her attention to the group.

“There’s too many electrons, expanded octets, and lonely electrons, free radicals,” says Eileen and looks up at Aishling.

“So, they’re the other two,” realises Aishling. “There is three. So there’s too few electrons, too many electrons, and lonely electrons.”

All three group members begin to write again.

“What was the last one again?” says Lorraine looking up at Aishling, “too many electrons…”

“Lonely electrons,” she responds and Lorraine returns to her writing.

NARRATIVE C5

I approach the head of the group’s table such that I am between Lorraine and Aishling with a view of Eileen.

“Okay,” I say. “How are ye going?”

“Grand,” whispers Lorraine looking down at the desk, while Eileen busies herself on her laptop, and Aishling looks up at me.

“So, what question are ye on?” I ask, looking at Lorraine.

“Are all covalent… things molecules?” says Lorraine quietly, leaning over to look into the task sheet.

Aishling and I also look at the task sheet and Eileen continues to busy herself at the laptop.

“Okay,” I say. “Are all covalently bonded atoms molecules?”

“So,” I say as Lorraine looks down at her notepad and starts to write, “have you found an answer yet or… what’s your feeling about it?”

I look towards Eileen who continues to look at the laptop. She makes no eye contact but responds.

“Umm, we’re looking for an answer,” she says quietly.

There are a few moments of silence as Lorraine writes, Eileen looks in her laptop, and Aishling gazes in front of herself. I am under the impression that I will get no further response than this.

“Okay, do you want a hint?” I say.

“If we get the definition for a covalent bond, or a molecule first and then…” says Aishling and as she speaks Lorraine and Eileen look up at her.
I decide that the direction of the conversation is going to lead to my having to leave without any real discussion so I give them the answer to their question. “Yeah. Well, all molecules are covalently bonded. So, you know that. So, it’s ‘do all covalent bonds form molecules?’” I say, looking mainly at Aishling and Eileen before continuing, “So, for a hint, diamond is covalently bonded.”

After a moment, Aishling responds, “But diamond is just made up of carbon.”

“Oh yeah,” says Eileen in a tone that suggests some memory is returning to her. “Just on its own.”

“Yeah, and is it made up of molecules?” I ask.

Some silence follows as the group think and I sense that they do not currently know how to answer the question. “So, that’s something to look up,” I say. “That’s something that could help you to answer that question.”

I then go on to direct Aishling, who has the task sheet, towards a web address on the sheet that may help them to decide whether or not diamond is made up of molecules. I then make to leave the table but remember that I have forgotten to look at the reflective journals which they have placed on the table. I use this opportunity to attempt to have a further conversation with them.

NARRATIVE C6

Aishling reads the next question aloud from the task sheet, while Lorraine and Eileen listen to her. The next part of the task requires the group to determine the physical properties of covalent lattices and reminds them that physical properties apply to a relatively large sample of a substance but only chemical properties apply to a single covalent molecule.

“So…” says Aishling as Lorraine and Eileen begin to write, “but we’re only talking about the physical properties of… covalent bonds. We don’t talk about the chemical properties.”

Lorraine absently murmurs, “Mmhmm.”

As Aishling organises her notepad to prepare for writing, a beep goes off on Eileen’s phone and she takes it out and begins to text.

“Focus on the lattices is it?” says Lorraine.

“Yeah,” says Aishling, before looking up to the webpage they have open about diamond. “Sure, we have the lattice here.”

Lorraine leans forward to join Aishling in looking at the webpage, while Eileen continues to text. Aishling reads from the webpage under her breath and begins to write again. Lorraine continues to read for some time, occasionally scrolling down the webpage. She then starts to write in her notepad. Both Lorraine and Aishling write for some time, though Eileen continues to text on her phone. Aishling puts her pen down with bang and leans back in her chair before she reads aloud from the web page.

“So, high melting point and variable conductivity,” and she picks up her pen to join Lorraine in writing again.

Eileen now decides to join the group again and puts down her phone. “Sorry, what are we doing?” she says looking at Aishling.
“We’re on the physical properties,” says Aishling.

“What are you saying about that?”

“Sorry, am… we’re saying…” says Aishling. She points at the laptop screen, “It’s there. Very high melting point and variable conductivity.”

“Oh yeah,” says Eileen, as she leans forward to look into the web page.

Eileen joins the other two group members in writing down her response to this part of the task. After some time, Lorraine takes out her phone and then sits back in her chair waiting for the others. Eileen seems to have finished writing but continues to lean in to her notepad with pen in hand to give the impression of writing. However, she spends most of her time turning her head to gaze around the room. Aishling then speaks up about an idea she has had and Lorraine and Eileen listen.

“See the way she said focus on the lattice and the lattice is the grid-like structure?” she says putting down her pen.

“Mmhmm,” says Lorraine.

“Do you know the way it says variable conductivity or whatever? The way diamond doesn’t conduct. Does that mean it has, like, a… strict structure?”

“Yeah.”

“Whereas, say, graphite has free electrons so that’s why it does… because it doesn’t have a—”.

“—rigid kind of structure,” finishes Lorraine.

“Yeah,” says Aishling.

The group returns to writing in their notepads with Lorraine the first to finish, and then Eileen.

CASE STUDY D

NARRATIVE D1

Ger has just finished explaining the meaning of ionic bonding to the other community members. Dylan now begins his explanation of intermolecular bonding. All four of the community members lean in towards each other. Jenny, Ger and Dylan lean their forearms on the table. Caroline rests an elbow on the table with her head in her hand.

“This is a quick one then,” says Dylan. He looks between the other group members and his notes from the previous week as he speaks. The other community members look at him as he speaks.

“What are intermolecular bonds?” he says, repeating one of the questions that was asked of his group last week. “It's basically, am just, bonds in between molecules. It's the question that's asked.” He tracks his notes with his finger and continues, “Am… ‘What is a hydrogen bond?’ Am, we had it down as, ah, ‘It is the bonding by attraction of a hydrogen molecule and a molecule of higher electronegativity.” He continues as he reads aloud the notes that I have written on the sheet, “But actually it’s ‘A hydrogen bond is between, am, a hydrogen of one molecule and an electronegative atom of a different molecule.’ So… ‘Hydrogen must be covalently bonded to an electronegative
atom for this to happen.’ Dylan pauses and the other community members continue to give him
their attention. He whispers in a low voice to them, “I’ve no idea what that means. Am…” and
the group members quietly laugh together.

I am not visible to the community but they are close to my position at the top of the room. I then
let them know that I have heard them. “Sorry I can’t help but overhear,” I say with a laugh and
the other community members laugh with me. Caroline and Ger shift in their seats so that they
can see me. I begin to start moving my wheeled chair over toward the table as we all continue to
giggle at the awkwardness of my overhearing them. All of the community member’s then direct
their attention toward Dylan’s notes. “So you’re okay with the first part?” I ask, as I reach the top
of the group’s table. Jenny turns her attention towards me.

“Yeah,” says Dylan confidently as he continues to look down at his notes.

“That it’s the hydrogen of one and the electronegative atom of another?” I ask for clarification.
The community members gaze at Dylan’s notes as I speak and do not respond. I lean forward
towards Dylan’s notes and I ask, “Did I do a little picture?”

“It’s right there,” says Dylan as passes his notes towards. The other community members maintain
their gaze upon the notes as he moves them.

“Yeah. So, if I just draw it here,” I say as I lean forward such that I can access the notes but keep
them in the centre of the table. I begin to draw and as I draw I explain. “So let’s say we have water,
H-two-O, and I have another H-two-O here. Okay.” I pause from drawing and look toward Dylan
and Jenny as I say, “So you know the oxygen there has a lone pair on it?”

“Yeah,” confirms Dylan with confidence.

I then shift my attention towards Ger and Caroline. “What that really means is that this here is
more electronegative.” I shift my attention towards the drawing I have just made and point out
the relevant parts of the diagram as I say, “So these oxygens are more electronegative than those
hydrogens.”

“Okay,” says Dylan.

I continue to point out the relevant parts of the diagram and move my attention between the notes
and various community members. “So the intermolecular or the hydrogen bond here is in between
those molecules. Okay. So that’s my hydrogen bond.”

“Oh okay,” says Dylan as he leans forward to point towards a covalent bond in the diagram. “So
it’s not actually from hydrogen to oxygen.”

“No,” I say, looking up at him.

“Oh okay! Now I get it,” says Dylan.

I return to moving my attention between the diagram and different community members. I gesture
to respective parts of the diagram as I say, “But in order for a hydrogen bond to happen, I need
the hydrogen to be covalently bonded to an electronegative atom as well. The purpose of that is
because this is more electronegative so again we have a permanent dipole here. But this is actually
the hydrogen bond here.”
“Okay,” says Dylan as I lean back from the centre of the table. “You’re very good at diagram drawing. It’s very clear like. It makes a big difference like,” he says as he retrieves his notes.

“Thanks,” I say, laughing. Dylan and the other community members return their gaze to the set of notes and I leave the community. Caroline leans back in her chair and crosses her arms. She remains in this position for the remainder of Dylan’s explanation.

Dylan continues with his explanation of intermolecular bonding. “Am… then, ah, the Van der Waals then she explained on the board,” he says, referring to a clarification I gave about the terminology and meaning of types of intermolecular bonds earlier in this session. “Am, we’d gotten that… some point about that. We hadn’t gotten as much as what she did. But, ah… did ye understand that as well do ye? What she said?”

“No,” says Ger.

“No?” asks Dylan, directing his gaze at him.

“No I did,” says Ger, laughing nervously. “I’m messing,” he says, and Dylan laughs with him.

“Yeah, am, so you’ve the weakest then is the induced dipole,” says Dylan and gestures towards the board where my writing remains. Ger, Jenny and Caroline turn to examine the writing on the board. “Then it’s the dipole-dipole. Then it is… then it is what?” he says, as he focuses upon his notes. The other three community members turn away from the board to look at Dylan. “Then it is… am… Where the hell is this gone? Oh yeah the hydrogen bonds! An example of hydrogen bonds is water. Am… an example if dipole-dipole is carbon dioxide. Oh, ah, no it’s not actually,” he says. He begins to read the comments that I added beside the example which was given. “C-O-two does not have a dipole. The two polar bonds give overall…” Okay,” he says, feeling he has understood my comment. “So you said that earlier on,” he says looking up at and gesturing towards Caroline. He is referring to Caroline’s earlier explanation of how some non-polar molecules can have polar bonds. Dylan summarises what he took from Caroline’s earlier explanation, “That the positive and negative cancel out… so there’s no overall actually polarity.” Dylan flicks the sheet over and say, “Am… I think I’m done.”

**NARRATIVE D2**

The community have just called out the question on the task sheet, ‘Why is an alcohol like n-propanol much less viscous than glucose?’ Initially Caroline mispronounced ‘viscous’ as ‘vicious’ and all the group members laughed together at this. All four community members lean forward on the table towards each other and the task sheet in the centre of the table. Caroline has her laptop placed in front of her on the table.

“Okay. What causes viscosity there Milly?” says Dylan, indicating that she should search this in her internet browser. Caroline begins to enter search terms on her laptop and Ger makes a reference to her earlier mispronunciation and they laugh together. Jenny writes the task question in her notepad.

Dylan leans back slightly in his chair and Ger gives him his attention as Dylan begins to speak. “Yeah that, that means like when, say, you have a test tube. It sticks to the sides more than being flat like?”
“Oh… okay,” says Ger hesitantly.

“Isn’t it?” asks Dylan. “Or am I getting that mixed up, like?”

“I’ve no ideas,” says Ger.

Caroline looks up from her typing and says, “That’s the meniscus.”

“That’s the meniscus,” agrees Dylan as he gestures towards Caroline with his pen.

“Yeah,” says Caroline. Jenny stops writing and is distracted by a pre-service teacher at a different group as Caroline makes another suggestion for the meaning of viscosity. “Isn’t that in biology when things transfer from higher concentration to lower concentration. I could be completely wrong.”

“That’s diffusion and osmosis,” says Dylan.

Caroline pauses for a moment and Ger looks between her and Dylan. “Yeah but is… didn’t we put them in like a viscous tube or something like that?” she says.

“Oh! Yeah!” say Ger and Dylan.

Caroline laughs saying, “I could be completely wrong.”

Caroline returns to entering search terms on her laptop and Ger quietly helps her by holding the task sheet for her so she can see the question more easily. However, Dylan joins Jenny in her distraction with the pre-service teacher from a different group. They laugh together over joke known only to themselves. The three appear to be communicating with each other using their mobile phones. Jenny and Dylan then both begin to look at their phones quietly. Ger puts down the task sheet and gazes at the table, leaving Caroline reading information she has located on the web.

Caroline moves her laptop such that other members of the community can read it, should they wish. Ger looks at the screen while Jenny looks at her phone and Dylan takes a picture of the pre-service teacher from a different group. Caroline begins to read aloud the information she has found about the causes of viscosity. “Causes of viscosity in a fluid are possibly attributed to two factors; one) intermolecular force of cohesion, and two) molecular momentum exchange” Caroline turns her head as she hears Jenny and Dylan giggling. “Is anyone listening, no?”

“I am,” says Ger.

Dylan turns to face Caroline and Jenny returns to writing down the questions from the task sheet. “Right I’m listening Milly. Sorry,” says Dylan. “It’s just that Dave is being a jackass!” he adds with a laugh.

“Am… that makes no sense to me,” says Caroline as she leans back in her chair, crosses her arms, and looks towards Ger.

“I don’t understand it,” concurs Ger.

Dylan leans forward to the laptop and, as he does so, Caroline also leans in and turns the laptop slightly to give him a better view. “Intermolecular force –” reads Dylan before he says a little
dejectedly, “Aw this is my job. Ah no.” Dylan’s tone become more serious and business-like as he says, “‘Intermolecular force of cohesion and molecular momentum exchange.’ Okay. Let’s go with the first one. ‘Intermolecular force of cohesion.’ Can you Google that please?” he asks Caroline. Jenny stops writing, and she and Ger lean forward to get a view of the laptop screen.


“The first bit,” says Dylan, pointing at the laptop screen as he reads, “‘intermolecular force of cohesion.’”

Caroline types on her laptop as Ger and Jenny look on. Dylan picks up his phone and starts to use it again, laughing to himself at something on his phone.

“What one will I go into?” asks Caroline, referring to the search results.

Jenny then makes a suggestion for the meaning cohesion. “Cohesion, is that like the molecules sticking together and stuff?” No one responds to her and after a moment Caroline begins to read aloud a definition for cohesion.

“The action or property of like molecules sticking together,” says Caroline. She, Ger and Jenny begin to laugh at the accuracy of Jenny’s earlier comment. Caroline continues to read, “‘being mutually attractive. This is an intrinsic property of a substance that is caused by the shape and structure of its molecules, which makes the distribution of orbiting electrons irregular when the molecules get close to one another, creating electrical attraction that can maintain a microscopic structure such as a water drop.’” Dylan looks up from his phone. Caroline leans back saying, “That’s a really long sentence.”

“That is a really long sentence,” agrees Dylan and he leans in towards the task sheet in the centre of the table. “The question again is what causes… that. They say that this causes that,” says Dylan as he points between the task sheet and the laptop screen. Caroline and Dylan both lean forward to look at the laptop screen.

Jenny, who has also leaned towards the task sheet, says, “Dylan, what are you reading?”

“Yeah what are you reading?” agrees Ger. Caroline and Dylan give their attention to Jenny and Ger.

“Why is it much less viscous?,” reads Jenny from the task sheet.

“That’s what I said no?” asks Dylan.

“You said what causes it,” say Ger and Jenny together.

“Apologies,” says Dylan as he drops his forehead to the table in embarrassment. Dylan, Ger and Jenny begin to giggle.

Dylan lifts his head from the table as Caroline points out, “Yeah but we kind of need to find what, what causes it first to figure out that. No?”

As Jenny leans in to read the task sheet again, Dylan points to it and says, “So, oh yeah there it is there. ‘What causes viscosity?’ What causes viciousness is how Milly would pronounce it.” He and Caroline laugh for a moment. Dylan points to the laptop before he continues the joke, “Okay.
What causes… viciousness, okay. Cohesion causes viciousness!” Ger and Jenny join in the laughter. “Okay,” says Dylan getting serious again, “So that means then, obviously, I’m gonna guess anyway, that alcohol has a stronger, am… cohesion force.”

After a pause in which Jenny, Ger and Caroline lean over to look at the task sheet, Jenny looks at Dylan and asks with some incredulity, “What?”

Ger also makes a suggestion, “This has a got a higher molecular weight than that. Has that got anything to do with it? It does, doesn’t it?”

“Hang on now”, says Jenny, calling the community to a momentary pause.

NARRATIVE D3

“If you Google, can we Google ‘what is viscosity?’ first maybe?” asks Dylan, before returning his attention to his phone. Caroline begins to enter search terms to her web browser, and Ger and Jenny watch the laptop screen.

After Caroline has located information on viscosity, she begins to read it aloud. “‘The state of being thick –’

“due to internal friction,’” interrupts Jenny who is also reading from the laptop screen.

Caroline continues to read aloud, “‘sticky, and semi-fluid in consistency, due to internal friction.’”

“Internal friction,” repeats Jenny.

Dylan returns his attention to the laptop and leans forward to get a better view of the screen. “Okay,” he says, “So it’s like, okay, not watery, say.” He turns towards the other group members and speaks for a moment as though talking to himself, “So, like, concentrated. Okay, so… what causes it? Yeah.” Jenny and Caroline give him their attention, though Ger largely focuses on the laptop screen. Dylan addresses them with his idea, “So that means the bonds in these, say, alcohol… I dunno whether the right word is closer together but they’re stronger so that means they’re less likely to flow, which is like shampoo.”

There is a pause for a few moments before Caroline says with laughter, “Let’s go with that.” Ger removes his attention from the laptop. He sighs and agrees with Caroline. Caroline and Ger orient themselves at an angle to each other and gaze at the task sheet.

“Glucose has a viscosity –,” says Dylan before he is interrupted by Jenny.

“I don’t, I don’t understand what makes this more viscous than this,” she says, looking directly at Dylan and pointing between the words glucose and alcohol on the task sheet. “Like what is it that causes this to be more so than that?”

“Weaker bonds,” says Dylan definitively. He also addresses Jenny directly. They continue to speak only to each other.

“What?” she says.

“Weaker bonds.”

“Weaker bonds. Is that what it is?”
“Cohesion like. The bonds of cohesion,” he says definitively again. Dylan then leans back in his chair. He appears a little frustrated as he gestures with his pen and animatedly says, “What you just asked is the question!” Caroline now looks between Jenny and Dylan as they continue their conversation, though Ger gazes down at the table in front of him.

“Hmm?” she says.

“What you just asked is the question,” he repeats.

“Yeah. But you know, like, we were looking at what causes viscosity but – ,”

“Yeah but we find that first and then – “

“Yeah that’s fine but… ,” she says, as Dylan starts to use his mobile phone. “I just don’t understand why glucose is more viscous than alcohol.”

“That’s what we’re trying to figure out, sure,” says Dylan dismissively, and puts his phone down on the table.

NARRATIVE D4

“Okay. So. Refresh again,” says Dylan, as he leans both forearms on the table and looks at Jenny. Caroline leans back in chair with arms folded and Ger leans his head in his hand and gazes at the laptop screen.

“What the page, or…?” says Jenny with a smile.

Jenny starts laughing as Dylan drops his shaking head to the table. “It’s still gonna be the same page when it comes back!” says Dylan, also laughing. He lifts himself up to rest on his forearms again. “Okay. So. ‘Why is alcohol much less viscous than glucose?’” he says, reading the question aloud.

Ger looks at Caroline as she, continuing to lean back with arms crossed, says dejectedly, “We don’t even have the, like… it’s so much effort to think about this.” Dylan starts to laugh quietly.

“Mmm. You really have to think like,” agrees Jenny. Dylan continues to laugh quietly.

“It’s hard to explain,” agrees Ger as he leans back in his chair and stretches.

Dylan stops laughing and says with a tone of collegial banter, “Okay lads. I’ll carry the team, as, as per usual!” The other group members laugh at this, and Caroline and Ger lean forward again resting their arms against the table. “Fuck sake!” Dylan adds in the same tone.

Dylan then begins to read the question aloud again but he is interrupted by Ger who wryly observes, “We’ve read the question so many times.” The others giggle at this.

“I still don’t understand,” agrees Dylan.

With laughter Ger says, “We’ve read the question so many times, like. It’s just not going in, like.”

Dylan gets down to business again, “Okay so it means alcohol is more viscous than glucose.” After a pause, he corrects himself. “No. It’s less.”
Jenny jumps in and, speaking to Dylan, she says, “What we want to find out is, is why this is more viscous than this, right?” Caroline turns to her laptop. “So what, what makes it really viscous and what makes it not so viscous.” Caroline begins to giggle as she types search terms into her web browser. Ger and Jenny laugh with her.

“Did we not just Google it?” wonders Dylan.

“Third time into Google,” laughs Jenny.

Caroline asks someone to call out the exact question and Dylan helps her. As she enters the search terms, the group begins to joke and laugh about some of the automatic search suggestions that are supplied by the browser.

Once Caroline has found some information, she reads it aloud. The other group members look on at the laptop screen. “Ethanol has a dipole moment in the C-O bond and the carbon part of it has London disperse force.”

Dylan jumps in and points at the intermolecular bond categories that I had written on the whiteboard earlier. “Which is… Van der Waals, which is… dipole-dipole? I think.” Ger and Jenny look at the whiteboard and back to Dylan as he speaks. “Right. Keep going,” he says to Caroline, as he takes out his set of notes from the previous week.

“Whereas water has only hydrogen bonds. So ethanol has more intermolecular force than water,” reads Caroline.


Caroline continues, “– making it more viscous than water. Meanwhile ethanol has less boiling point than water because – “

Dylan interrupts with more banter, “Because London… go on. Keep saying it. Keep going.” Ger laughs at him. Dylan finishes reading the remainder of the information aloud. “This type of force is easily disrupted by heat. That’s ‘cause it has weaker bonds.” Dylan slaps his hand on the desk with satisfaction as he jokes, “It’s all in the bonds lads, come on!”

NARRATIVE D5

“But this is ‘why is alcohol more viscous than water?’ not glucose,” points out Caroline.

“Yeah but it’s probably the same answer,” Dylan.

“It’s the opposite then for… what we’re doing. I’d be thinking,” says Ger. The four group members then look at the task sheet for a moment, and then refocus on the laptop screen.

Jenny begins to refocus on their question, “Okay so then what makes glucose more viscous… than a supposedly – “. Dylan leans back in his chair and lets out an exasperated sigh and turns to Jenny. “Hang on!” says Jenny as she puts out her hand to Dylan in a restraining motion.

“That’s not the question. The question is – ,” says Dylan, before Ger interrupts him.
“No go on… Yeah?” says Ger, encouraging Jenny to finishing her thoughts. He repositions himself so that he is facing Jenny and Dylan. Caroline also turns away from the laptop screen to look at them.

“Go on! Finish your sentence,” says Dylan with a tone of impatience but in good humour.

“It is! I was right yeah!” says Jenny, also with good humour. Jenny and Dylan address each other only and continue this banter for a moment before Jenny continues. She points at the laptop screen as she says, “So we’re talking about, in this one we’re obviously saying that alcohol is stronger.”

“Yeah,” agrees Caroline, also turning to look at the laptop screen. Dylan gives his attention to his mobile phone.

Jenny points down at the task sheet. “So then this obviously is a lot stronger… than alcohol. So what makes it stronger than alcohol?” she says looking at Caroline. Caroline asks Jenny to repeat what she has just said. Jenny smiles, and Ger and Caroline laugh. Jenny again points at the laptop screen to indicate that she is referring to the water and alcohol comparison as she says, “In this question, alcohol is, is the stronger, has the stronger bonds or whatever right.”

“Yeah, than water yeah,” says Caroline.

Jenny drops the phone and joins the others in giving her attention to Jenny. The whole group is silent for a few moments. Jenny then clarifies, “Which is a supposedly strong bond. What makes it even stronger?”

Caroline turns to her laptop and calls out search terms as she enters them, laughing as she does so. “what’… ‘makes’…” The group begins to laugh and they have fun reading the automatic search suggestions of the web browser.

“Is it not the same answer as the water no?” asks Dylan. Jenny looks at him and he repeats, “How come it’s not the same answer for water?”

“Because alcohol is more viscous than water,” says Ger.

Jenny jumps into the conversation and looking directly at Dylan says, “Okay because in that example, in that example alcohol was more viscous than water. Whereas in this one, glucose is more viscous than alcohol.”

“Yeah. So is it not glucose, then alcohol, then water,” says Dylan to Jenny. After a moment of consideration, she and Ger agree with him. “So what are we trying, what are we…” says Dylan with some confusion.

Jenny and Dylan direct themselves towards each other. Jenny explains, “We’re trying to find out what makes glucose a stronger bond than alcohol.”

“But sure, hydrogen bonds,” Dylan says with certainty. Ger directs his attention away from Dylan and Jenny towards the laptop, with which Caroline continues to search for and read information.
“We already know why alcohol is stronger than water,” says Jenny and Dylan agrees with her. “And we have an example of how that is a strong bond,” continues Jenny, pointing at the laptop. Dylan again agrees. “What makes the other one more stronger?” says Jenny.

“Sure is it… does glucose not have, like, hydrogen bonds?”

“Hydrogen bonds are not weak bonds are they?”

“No. That’s what I’m saying. That’s why it’s stronger.”

“Stronger because it has weaker bonds?” she says, with a furrowed brow.

“No. Stronger because it has stronger bonds,” he says, with laughter.

“I just, you just said that it has hydrogen bonds. And I said but hydrogen bonds are weak bonds. Aren’t they?”

No. This has van de waals bonds. This is the London yoke,” says Dylan. He looks up at the whiteboard behind Jenny for a moment. “So it goes induced dipole, dipole-dipole, then hydrogen bonds… and that’s in order of increasing strength,” he says counting out the bond types with his fingers as he speaks. Gesturing to each of the fingers he then says, “So that’s the weakest, that’s the second weakest… That’s the weakest, that’s stronger and stronger again.”

“So then what one does this have then?” says Jenny as she taps the task sheet.

“The strongest one,” interjects Ger, as he turns to face Jenny and Dylan.

“That’s what I’m asking though,” says Dylan. “Does it have hydrogen bonds like?”

“Surely not like,” says Jenny.

“Why surely not,” says Dylan.

“Because they’d be weaker,” she says, looking at Dylan as though this is obvious. Caroline joins Ger in giving her attention to Jenny and Dylan’s conversation.

“No. No,” says Dylan. He leans back in his chair and puts his hands to his face for a moment.

Jenny laughs and says, “D’you know what. D’you know what. I think we should just refer to Google. Google is always right.”

Dylan takes up her suggestion and says to Caroline, “Google ‘does glucose have hydrogen bonds?’”

Caroline returns her attention to the laptop.

NARRATIVE D6

All the group members look at the laptop screen. Ger turns from it and with a sigh says, “So much effort.”

“Back to thinking again like,” says Dylan. After a few moments, Dylan leans back from the laptop picks up his pen. “Okay. Hang on now.” He puts pen to paper.

Caroline’s search has found some information. As she turns her attention towards Dylan, Jenny reads portions of the information aloud. “‘Can strongly hydrogen bond’… ‘O-H groups’.”
Caroline looks down at her notepad and Ger and Jenny continue to look at the laptop screen. The group is silent as Dylan continues to write in his notepad. After a few moments, Jenny also begins to write in her own notepad, occasionally looking up at the laptop screen. Meanwhile Ger and Caroline gaze at the table or task sheet.

Dylan finishes writing in his notepad and leans back in his chair. “Okay. I think I have it,” he says. Ger and Caroline give him their attention. “Glucose is …” He pauses and quietly reads the question from the task sheet again before continuing. “So glucose is more viscous than alcohol, yeah?” Jenny and Ger agree, though Jenny continues to write in her notepad. “And alcohol is more viscous than water,” he says and receives agreement from the others. “We’ve established that alcohol has the… London things.” Jenny stops writing and gives him her full attention. He continues, “Which is the weaker of the weak bonds. Hydrogen bonds are stronger than those bonds. So that’s why glucose is the strongest.” Dylan lifts his head from his notepad and looks at Jenny.

“Keep, keeping in mind that water isn’t part of the question yeah?” she says to him, as Ger and Caroline look on.

“No. I’m using that as a reference point as such,” he says. “So we know… we know alcohol is more viscous than water,” he says, pointing out relevant parts of notepad to her as he speaks. Jenny gives her agreement as he speaks, letting him know that she is following his train of thought. “But we know glucose is more viscous than alcohol. And we found, through Googling that yoke, that alcohol has this bond here. Okay?” Jenny again agrees. Caroline turns her head away from Dylan and Jenny’s conversation to look at something else in the room. Ger directs his gaze in the same direction. Dylan continues his conversation with Jenny, “And we know glucose has this bond here. So… because alcohol has this bond and glucose has this bond. Hydrogen bonds are stronger than these two bonds. So that’s why it’s more viscous. Or less viscous or whatever the question is.”

Ger and Caroline turn their attention back to the group for a moment. Caroline then leans back in her chair and stretches and the two begin a quiet conversation between themselves about their timetables. They continue this quiet conversation as Jenny and Dylan carry on their conversation about the task.

“So that’s more viscous because it has more hydrogen bonds?” asks Jenny.

“No. It has hydrogen bonds,” clarifies Dylan.

“It has stronger hydrogen bonds?” she asks.

“It has hydrogen bonds.”

“So this doesn’t have hydrogen bonds?” she says pointing at the alcohol formula on Dylan’s notepad.

“Yeah. That’s what it said in the yoke isn’t it?” he says, pointing at the laptop.

“I’ve no idea.”
“That’s what I got from it anyway.” Dylan points at his notepad as he continues, “It said it had the London, whatever, yoke.”

“I was pretty sure that had a hydrogen bond though,” she says.

“But… in that yoke,” he says, gesturing again at the laptop screen, “it said… that, that’s what I’m going on like. Because it said that it had the London yoke, the London yoke is another code word for fucking van de waals, like.”.

“Code word!” says Jenny, laughing.

“Whatever, like. It’s another, it’s another heading for it, like,” he says. “So that means then that it’s either induced dipole or dipole-dipole. It doesn’t matter which one it is though because glucose has hydrogen bonds, hydrogen bonds are stronger. Hydrogen bonds are stronger than these two so, therefore, glucose is stronger than these two which is why it’s…”

“more viscous,” says Jenny.

“More viscous which is why alcohol is less viscous,” says Dylan.

Ger and Caroline finish their own quiet off-topic conversation and look in Dylan and Jenny’s direction again. “I believe you then,” says Ger, slapping his hand off the table and leaning back in his chair.

“I’m gonna go with that. I don’t really care,” says Jenny. She and Ger laugh.
Appendix K  Semi-Structured Interviews with PSSTs

SEMI-STRUCTURED INTERVIEW WITH BRENDAN

I: So some of the concepts that were included in the test were, like… the mole, properties of atoms, compounds, elements, mixtures… am… and the meaning of chemical equations. So like… would you… how confident would you feel about teaching those or… on your teaching placement when you were on it or into the future?

Brendan: Into the future… am… I think I'd be fairly confident (cough)… sorry… I'd be fairly confident with moles… and… equations, cause you know… mathsy stuff.

I: Yeah

Brendan: I'd be quite confident with that.

I: Yeah

Brendan: Things then like… am… what were the other ones?

I: Oh I have a list there [shows the list to PST]. There are just some of them there.

Brendan: Okay… ah… things like properties of atoms, now I was teaching that on… my TP… and I found it a bit hard to get across like you know… generally understand it because it’s a bit abstract and stuff like that you know…

I: Yeah yeah

Brendan: … with the electron and the nucleus and all that kind of thing. Am… elements and mixtures and all that kind of stuff I was teaching that too on TP. That was grand. They kind of got that pretty easily enough. I did a few demonstrations and that kind of stuff.

I: Yeah

Brendan: In general, the one I'd say I'd be most confident with… would probably be the moles.

I: The mole?

Brendan: Yeah yeah

I: Okay. And, ah… what about… so I've ionisation energies on there as well.

Brendan: Yeah

I: Would you be confident enough with that one or…

Brendan: A bit sketchy

I: Yeah

Brendan: Like I'd have to… right now if you asked me to teach it I couldn't. I'd have to go away and look it you do you know what I mean.

I: Yeah but would you be confident enough that if you looked it up though that you could…
Brendan: Oh yeah yeah. I think so yeah.
I: Am... so what did you kind of think overall of that... the whole test?
Brendan: Am... I think it was okay. I mean, like... most of the questions were grand. The only ones I really... like that I really have trouble with... always... are these kind of ones [points at Question 2]. You know the... what would you call them... the atoms and molecules... d'you know is it mixtures or... pure substance. That kind of stuff.
I: Ok so that particular question, Question 2, is it?
Brendan: Yeah... or that style of question do you know where you're given like...
I: So it is the pictures?
Brendan: Yeah. It would be yeah yeah.
I: Okay so you would have found... let's say the... the questions with pictures, they're more difficult than the questions with just language?
Brendan: Yay a definitely. In general I would yeah.
I: And do you... do you know why you feel like that or...
Brendan: Am... I don't know. It's just I suppose... looking at Question 2 there again like. Am... trying to kind of... assign something to each of the symbols.
I: Yeah
Brendan: And then trying to figure out... just trying to actually get it right in my head.
I: Yeah. So you had to decipher the... visual thing before you can even think about answering the question.
Brendan: Exactly... and that's where I had trouble... kind of deciphering the visual part of it.
I: Okay. Yeah. So like just... I'm just wondering now is it specifically Question 2, or like say for those questions [points at Questions 3, 5 & 6], here you know where you have the labels. You know, you have oxygen labelled... on Question 5 you have oxygen labelled, you've hydrogen labelled. Were they... equally as difficult to...
Brendan: No. I don't think so no. It's just when I don't have... let's say in Question 2 there was no specific thing assigned to it [points at decomposition of hydrogen peroxide equation].
I: Yay a
Brendan: But I know... we'll say that oxygen is... and hydrogen is there... I can picture that as in... do you know... water
I: Yeah
Brendan: or whatever it is... d'you know what I mean?
I: Yeah. Okay so it's kind of... and what about here... Question 3. I mean there are no labels there but is... would that...
Brendan: Well... no that wouldn't really throw me either... cause d'you cause... I know what a gas looks like, d'you know that kind of way.

I: Yeah yeah. You knew... so Question 2 was really really the one?

Brendan: Yeah definitely yeah.

I: Am... oh yeah... did you think the instrument... that it kind of exposed any areas that... you actually found that you didn't understand?

Brendan: Am... I think there was one or two yeah. Oh yeah... Question 11 there. Am... obviously when I was answering I thought that was the right answer.

I: Yeah

Brendan: But... I still actually... don't know why that's incorrect. D'you know what I mean?

I: Yeah

Brendan: So that's kind of a thing that kind of...

I: And did you realise... do you know when you... do you realise that now seeing it or did you realise that when you were writing it that you just weren't too sure about that or...

Brendan: Yeah I'd say... when I was writing it I was kind of... confident when I had it in my head but then when I started writing it down I was kind of like 'ugh I'm not sure if that's right or not' d'you know what I mean.

I: Yeah

Brendan: Am... other ones then... yeah I suppose that kind of stuff would be the main thing you know... like I know I said I was confident to teach moles and stuff like that. But d'you know when I can't... I can't actually work it out on a page in front of me d'you know what I mean... when it's just kind of in my head.

I: Ya

Brendan: I have a bit of difficulty with that kind of stuff I'd say.

I: Ok am... so if I just kind of go through a few of the questions there. So. We'll say Question 1 there. Did you... you felt you understood what that question was asking you?

Brendan: Am... [reading question]. Am... yes. I did yeah. It was kind of like just asking am... if you break down let's say a block of sulphur...

I: yeah

Brendan: Do its atoms have the same properties?

I: Yeah. And why did you choose option c there?

PSST: Am... because... like... an atom is the simplest part of a substance that contains the properties of a substance.

I: Yeah
PSST: So I thought... no matter how much you break down into atoms it's still going to have the same properties as sulphur d'you know what I mean. So... yeah that's kinda why I said that I suppose.

I: Okay. Well the option you selected was that only D would be the same so it combines with oxygen to form sulphur dioxide.

PSST: Oh yeah. I didn't see that actually.

I: So... you didn't actually say that all the properties would be the same.

PSST: Oh. There you go. [laughs] Oops.

I: So... would you... if you were answering that question again. If I just sat you down now and you didn't know what was right or wrong there.

Brendan: Oh no. I don't think I would actually. Sorry. I'm not sure actually [laughs].

I: So why do you think one single atom of sulphur. Let's say your answer there was option c. You felt that it would only combine with oxygen to form sulphur dioxide. Why did you think that a single atom like wouldn't have a density of 2.1 g cm\(^{-3}\)?

Brendan: Am... I'm not sure actually. I thought... I suppose... well looking at it now I would say d... to be honest. But I suppose maybe I thought that... am... if you... like if there wasn't 1 g of it or 1 cm\(^{-3}\) of it then you couldn't have 2.1 g cm\(^{-3}\). I don't know if that's right or wrong now [laughs].

I: Yeah yeah

Brendan: Am... I suppose, yeah, that's what I probably would have said... d'you know what I mean... because there's only one atom.

I: And do you think... could that have been... do you think that could have been a guess or was your mind just a bit clearer about the whole thing at the time?

Brendan: Am...

I: Or could it be the fact that D is a longer answer?

Brendan: Yeah... I suppose yeah like... I could have just picked that one straight away yeah... when I was doing it d'you know what I mean. Am... I suppose like... when I was doing the test actually initially I suppose I would have had more time... more kind of you know... to focus on the questions.

I: Yeah well you would have... that's true yeah.

Brendan: Am... yeah... so.

I: Okay so... if you have a look there at your Question 2.

Brendan: Yeah
I: So… this one was the difficult one. So did you… did you feel you understood what I was asking you there [point to stem of question]?

Brendan: Am… yeah I definitely understood what you were asking me yeah.

I: Yeah

Brendan: Am… then again I remember actually answering this question when you gave it to me. And… I really kind of tried to do the first one. Then I kind of realised that I wasn't sure… so for the other two I was just kind of like 'ugh'.

I: You mean you weren't sure which diagram was…

Brendan: Which diagram was… well the first one was grand because I kind of got that straight off.

I: So why did you… did you say A and C were a solid?

Brendan: Solid because the… the atoms were close together and they were arranged kind of regularly.

I: Yeah

Brendan: And they weren't kind of flowing or floating around or anything like that.

I: Yeah

Brendan: For D the liquid… because it's kind of… you know they're not arranged regularly. They're still close together but they're not regular.

I: Yeah. Okay.

Brendan: And then the gases they're kind of floating around and stuff so…

I: Yeah. And so why then would you have chosen C as a pure substance?

Brendan: C as a pure substance. I chose it cause I thought that… it was a pure substance because it contained all the same atoms. All the same types of atoms so… I thought C was the only one that had that.

I: And ah… like say for am… B and A. You chose those as being heterogeneous mixtures.

Brendan: Yeah

I: So why did you…

Brendan: Yeah I said they were heterogeneous because they… they were mixtures of atoms but they had different types of atoms.

I: Okay. And then your D and E.

Brendan: Homogeneous mixtures

I: Yeah homogeneous mixtures.

Brendan: Yeah. Am… I said E was a homogeneous mixture because it contained different atoms but… well sorry it contained different atoms but they're all the same molecules.

I: Yeah
Brendan: So like I said.. the same molecules mixed together… homogeneous, d'you know what I mean? D then, am… yeah because they were different, different atoms… mixed together.
I: So does it have
I: we'll say for A and for D

Brendan: Yeah they should be probably be… they should probably be heterogeneous I suppose cause D contains different types of atoms… but…
I: SO if you were to define a heterogeneous mixture

Brendan: Yeah
I: How would you define it?

Brendan: It would be… a mixture containing… two or more things that are different.
I: Okay. And if you were to define… a pure substance how would you define that?
Brendan: Am… something that contains all of the same atoms… [mutters] or is it molecules maybe?
I: Yeah. And… your homogeneous mixture?
Brendan: Homogeneous mixture then I would have said… ah… containing the same types of molecules? Mixture? Well I suppose then it's not really a mixture then is it? Am…
I: So if you go back to your pure substance there. You're saying that it's the same type of atom… or the same type of molecules?
Brendan: Oh okay
I: Is that what you're saying?
Brendan: No I would have said that a pure substance is just type same type of atom… so it's… a block of gold of something like that.
I: Yeah.

Brendan: Whereas a homogeneous mixture then would be like… say water like. D'you know where two atoms of oxygen combine to a hydrogen. Sorry I mean two hydrogen's and an oxygen… and then… you'd have two types of atoms but they'd be the same type of molecules.
I: Okay yeah.
I: Okay. Am… and ah… then for the third part there [Question 2c]
Brendan: Yeah
I: So we'll say to identify your elements… so you chose… why did you select D as an element and… let's say am… E and C as being only composed of compounds?
Brendan: Okay. I said D was elements because… they're uncombined. So just a mixture of various types of atoms from the same element d'you know what I mean.
I: Yeah.
Brendan: I would have said C and E were compounds because... the way they are kind of arranged in the diagram here... you see they kind of put together here [points at pair of atoms in Diagram C]
I: Put together in pairs?
Brendan: Yeah exactly and then... E... I would've said that they were compounds as well because you've got the... they're all kind of joined up together in threes.
I: Yeah
Brendan: Yeah
I: Okay and the you have... so B and A are element and compound.
Brendan: Element and compound yeah. I would have said that yeah... because... in A you have the diamonds joined to the circles. The way I kind of looked at was that the squares weren't combined.
I: Yeah
Brendan: They were just separate elements. So I would have said the diamond and circle combination were compounds... and then B I would have said that the squares and circles were joined together as compounds and then the diamonds, and the bracket there if that's one, was ah... an element.
I: Yeah. That was a typo [laughs]. My fault, my fault.
Brendan: No worries.
I: Okay so just Question 3 there.
Brendan: Yeah.
I: That... you were okay with that or...
Brendan: I was grand with that yeah... cause I would have... even on second year TP I would have taught that. So I would have used diagrams like that to explain what a gas looks like... and a liquid looked like and a solid.
I: Okay and what would you have interpreted B there to mean?
Brendan: I would have said it would have been ah... maybe like two liquids mixed together or a solid dissolved in a liquid maybe.
I: Okay so... a sample of liquid ammonia is completely evaporated in a closed container as shown. Okay so which of these diagrams would explain what you would see in the same area?
Brendan: The magnified view of the vapour... Am...
I: So if you compared that [Diagram B] to this [Diagram A] why did you choose this?
Brendan: I chose that because am... the molecules... the molecules of ammonia were more spaced apart. They seem to be like floating around freely like a gas would.
I: Yeah. Okay and B then... you didn't choose that because...
Brendan: No I would have said it's a liquid as well because they're closer together.
I: So essentially it's the same

Brendan: It's the same thing yeah [points at liquid ammonia picture in stem].
I: So then here [points at Diagram C] then. Would you have thought…

Brendan: No I wouldn't have picked that at all because am… that wouldn't be ammonia anymore because the atoms have all separated out to Nitrogen and Hydrogen. So… I wouldn't have said that no. Like if you vaporised it… it would just turn into ammonia gas. It wouldn't… it wouldn't break the bonds really.
I: Exactly okay. Am… so then ah… for your Question 4 there okay.

Brendan: Yeah

I: Okay so… we have one gram of solid iodine in a tube. All the air is removed and together they weigh twenty-seven grams.

Brendan: Yeah

I: Okay so then we heat it until the iodine solid is totally evaporated.
Brendan: Yeah.
I: Okay. So… what… why did you chose your answers there?

Brendan: Am… because, like, if you have… you know if you have one hundred grams of water… and you heated it in a closed container… you’d still have a hundred grams of water. It'd just be steam. You know it would change phase but it won't change its mass.
I: Okay.

Brendan: So that's why I said mass there because…

I: Okay. Am… so for Question 5 there. We kind of talked about that a little bit earlier okay.

Brendan: Yeah

I: So… am… were you confident let's say… you selected B and A there. When you selected those were you confident that those… were the right answer?

Brendan: Am… yeah. I think so, yeah. Because… I mean I used a kind of process of elimination I suppose to pick it [Tier 1 Diagram B] because am… before it decomposes it is molecules of hydrogen peroxide obviously.

I: Yeah.

Brendan: Am…

I: And did you use the equation to help you?

Brendan: Yeah I would have.. because you know you have the ratio there the two H two O two [2H2O2]… so I just picked that [Tier 1 Response B] straight away.
I: Yeah. Okay.
Brendan: Am… you know two molecules of… basically break it down that way… two molecules of hydrogen peroxide.
I: Okay. So then down here [Tier 2 Response A] was your 2H2O plus O2 from the equation.
Brendan: Exactly yeah yeah.
I: Okay. So… for Question 6 there.
Brendan: Yeah.
I: Have a look at the just for a second.
Brendan: Perfect. No worries. [Reading question]. Yeah… okay.
I: Okay. So… would you… well first of all what's… what am I asking you here?
Brendan: Well you're, you're saying the… all the sulphur reacted with all the oxygen as much as they possibly could. Am… what would you be left with? What kind of… I suppose ratios of molecules would you have left over. That kind of thing.
I: Okay. So and what… would you say that this is a very different question from the previous one?
Brendan: Am…
I: Or is different? You know… what's different about it?
Brendan: There's yeah… it's slightly different cause I suppose you're… you're going from one… reactible… reactant we'll say to two products [in Question 5].
I: Yeah
Brendan: And here [Question 6] you're going the opposite direction. D'you going from…
I: Am
Brendan: D'you know you're going from… you're sort of reacting two together to come up with a…
I: Oh yeah. Okay so you're saying there are two reactants and one product and on the other one…
Brendan: Yeah. So it's kind of the reverse I suppose really.
I: Okay.
Brendan: Am… I'd say you know there is similarities cause you know you have am… well in my mind there would be anyway because I would have used the numbers here [points at equation] to, to kind of figure it out. D'you know what I mean.
I: Yeah… you used the ratio again.
Brendan: Yeah exactly yeah. Yeah.
I: Okay so can you explain to me how… if you just think aloud about, about how you would have used that ratio.
Brendan: Yeah. Okay so I would've, I probably would've counted the… number of sulphurs first of all anyway and… counted the number of oxygens [in the stem diagram]. And then… so like we'll say there, this one… six sulphurs and six molecules of oxygen.

I: Yeah

Brendan: So… you need three… oxygen atoms for every sulphur. So then you have… okay… so you would've ended up with actually… let me get it now again… you would've ended up with four molecules of sulphur trioxide… and then two sulphurs left over.

I: Yeah. Okay… so that was… not the option that you chose here.

Brendan: Yeah exactly

I: But am… do you know why you chose that option?

Brendan: I suppose I wouldn't have gone through it like that in my head when I was doing it.

I: Okay

Brendan: D'you know what I mean. I would've just looked at that diagram [Diagram C] and said ‘oh right, they all react completely together'.

I: Yeah.

Brendan: ‘Oh yeah so it must be that one’

I; And ah… let's say if you.. I'm just wondering here if you had more attention drawn to the fact that this was a closed container

Brendan: Yeah I think so yeah

I Would that have… tipped you off let's say to the fact that… this is to do with the number of atoms that are actually inside in this diagram?

Brendan: Yeah. I think so cause… I could've actually skipped past that when I… like I wouldn't have thought, I wouldn't have read it. I suppose it would've clicked with me you know

I: Yeah

Brendan: Am… yeah. So there.

I: And… okay. Question 7

Brendan: Yeah.

I: Did you understand what I… what this question was asking here?

Brendan: Am… [reading question]. I think so yeah.

I: And… let's say for your options there. Did you think they were clear?

Brendan: Am… [reading question] sorry now a few seconds… Yeah I did yeah. Yeah. I would've went through them like, yeah.

I: Yeah. Okay so why am… why would you… let's say choose A there?
Brendan: Am... I said that... because if you move an electron from the... the, ah, magnesium then... you'd make it unstable so the... ionisation energy would be am... umm... oh wait. Okay sorry [laughs]. Yeah I suppose my logic behind it would've been... if you knock, ah... an electron off the magnesium
I: Yeah
Brendan: Then... you have a half-filled subshell that's less stable...
I: Yeah
Brendan: So... yeah if I'd read it properly I would've...
I: Is it compared to Aluminium there that you would have done... is it?
Brendan: Oh wait I'm wrong. Sorry, sorry. When you remove the electron from this [Magnesium] you have a half-filled subshell which is more stable than the Aluminium which will be... d'you know the p-level there isn't half-filled.
I: Yeah... so once you've taken out an electron the p won't be filled is that it?
Brendan: No like... it is... d'you know like at the moment... when a shell is filled or half-filled it's more stable
I: Oh right. Okay. As it is... before you...
Brendan: Yeah, yeah. Am... and then I would've said that... that's why I would've said it would've been... greater
I: So it's easier is it to take away this electron from Aluminium
Brendan: Yeah... than it would be to take that one from Magnesium. That's stable as it is... so d'you know it's got its maximum fill or whatever.
I: Yeah.
Brendan: Am...
I: So if I was just to ask you like... what does an ionis... what do ionisation energies depend on? Just in general...
Brendan: Yeah. Am... I suppose.. it's the distance it is away from the nucleus anyway.
I: Yeah
Brendan: The number of shells... screening...
I: Yeah
Brendan: ... like between it and the nucleus. Am... what else? The... the number of electrons... I suppose... altogether... d'you know what I mean.
I: Yeah
Brendan: The more you have the easier it is to take away... or whatever
I: Yeah
Brendan: Am…
I: And why is it easier? Like why… let’s say… so you’ve mentioned the distance from the nucleus. You've mentioned the am… the screening. You've mentioned… so the number of other electrons. Why do they make it easier?
Brendan: Am… because I suppose, like, obviously, like, the electrons are negative and nucleus is positive so the closer it is the stronger attraction it will have for the nucleus. So then… it'll want to stay there more let’s say.
I: Yeah
Brendan: It'll be more difficult to remove.
I: Yeah
Brendan: And then… the screening. I suppose, you know, you've got your electrons going around inside… on the shells. Inside the one you're trying to take it off from I suppose. Am… so therefore, they kind of… knock away some of the attraction that the other electrons would have for the nucleus.
I: Okay. Yeah.
Brendan: So it's easier to remove that way. Am… then I suppose another one would be if the shell was full.
I: I'm wondering why then… okay so… why then let's say didn't you choose B? That the 3p electron of Aluminium is further from the nucleus than the 3s electron of Magnesium.
Brendan: Yeah… I'm wondering that myself [laughs and reads question again]. I suppose I… I might not have actually… d'you when I saw this one ‘removal of an electron will destroy the stable completely-filled 3s’… so straight away I thought ‘oh that must be it'.
I: Yeah, yeah
Brendan: D'you know what I mean?
I: And let's say here these options here that have nuclear charge and that… what would nuclear charge be? Can you explain that?
Brendan: Am… am… I suppose, yeah, if you remove an electron from… Aluminium… then you've got more, ah, protons in the nucleus than electrons in the… in the shells.
I: Yeah
Brendan: So… the kind of positive charge is being more distributed… like, more to each electron.
I: Yeah.
Brendan: So the nuclear charge is increased.
I: Yeah. Okay. Okay… so I'll go on then to Question 8.
Brendan: Okay
I: So… were you tempted to… so ‘which of the following particles affects the number of particles in a mole of the substance?’

Brendan: Yeah

I: Were you tempted by any of these other options?

Brendan: No. Because the number of moles, or the number of particles in a mole is constant.

I: Yeah

Brendan: It's Avogadro's number

I: Yeah

Brendan: So that's…

I: So you were totally confident?

Brendan: Very confident of that yeah.

I: Okay so… Question 9. Okay. So… our Carbon atoms each contain six electrons. What mass of carbon contains a mole of electrons? Okay?

Brendan: Yeah.

I: So you chose your twelve grams for that.

Brendan: Yeah yeah.

I: So… could you…

Brendan: Explain why I chose it?

I: Yeah.

Brendan: Yeah. Because, like, from the Periodic Table the molar mass of Carbon is twelve grams.

I: Yeah

Brendan: So, therefore, one mole of Carbon is gonna weigh twelve grams. Am… so then a mole, a mole of electrons… would be… the number of electrons in… Avogadro's number of atoms.

I: Of Carbon atoms?

Brendan: Of Carbon atoms yeah.

I: Okay.

Brendan: Because… you know…

I: So, what, let's say… if you were to explain what the mole is or give examples of… you know ‘a mole of…’

Brendan: Yeah

I: Let's say you'd said there carbon atoms. Could you give other examples of a mole of something?

Brendan: Yeah.

I: When you were.. let's say when you were teaching.

Brendan: Yeah
I: What kind of examples would you give. Like a mole of...

Brendan: What type of elements like and stuff or...

I: Is it just a mole of elements? Let's say is it just a mole of atoms?

Brendan: No no no. Like you can have a mole of... Sorry I don't... sorry now.

I: So I was wondering there... so you've said that in... that you'll have a mole of electrons in one mole of carbon atoms.

Brendan: Yeah. Yeah.

I: Okay so... I'm just wondering... okay so what... just describe for me so what a mole is?

Brendan: It's the... weight of a substance that contains six by ten to the twenty-three atoms of it.

I: Okay. So a mole is the weight of a substance that has number of particles?

Brendan: Of particles yeah

I: So is a mole... does a mole have the units then of grams?

Brendan: No it's moles like

I: Okay. So what it is is that it's a weight of...

Brendan: Yeah it's kind of like... you know if you say one mole of... I dunno... iron. You know you'll have sixty-five grams of iron, or fifty-five grams.

I: Yeah

Brendan: So am... yeah you'll have fifty-five grams of iron.

I: Okay. That's let's say... and how do you know that?

Brendan: Because... ah... like fifty-five grams of Iron will have Avogadro's number of atoms?

I: Okay yeah. So just what I'm getting at is it's just from the Periodic Table.


I: Okay so ah yeah I'll go on to Question 10.

Brendan: Cool

I: So am... any trouble here with this one?

Brendan: [reading question] No not really I don't think cause like it was just... a ratio so you have three moles of A and you just... use maths to figure it out I guess.

I: Yeah. Okay am... so I'm just going down here to Question 11. You mentioned it earlier.

Brendan: Yeah

I: So... molecular formula of vinegar and you've the molecular formula of sugar so... one gram of vinegar and one gram of sugar. Would you have the same number of atoms in each?

Brendan: Same number of atoms in each...

I: Okay. So...
Brendan: [Reading question] Am… well I suppose if I was doing it now again… I would've figured out… [reading question and laughs] I suppose I would have gotten the MR of vinegar and sugar.
I: Mmm
Brendan: Figured out how many… moles one gram of vinegar and one gram of sugar are kind of respectively.
I: Okay
Brendan: And then multiplied that by Avogadro's number to work out the number of atoms. I would have had.
I: Okay
Brendan: Am… and then…
I: So, when you, when you looked at this and ah… you didn’t… I see you've no kind of calculations. I'm assuming that you didn't, that you didn't do that.
Brendan: Yeah. No I didn't no.
I: Am.. d'you know… so could you explain why you thought…
Brendan: Yeah… I'm trying to remember
I: So you said 'No' and… why let's say did you decide that ‘they don't have the same number of moles’?
Brendan: Yeah. Well I… I suppose I would've looked at it straight away and said that… am… d'you know you've got two carbon atoms here and four hydrogen atoms and two oxygen atoms for vinegar… then six, twelve and six for the sugar… am… and because you've different numbers of atoms of each element in both of the substances then they could have the same number of… am… atoms, like, per mole say.
I: Well, we'll say…
Brendan: Sorry in one gram is what I mean there.
I: In one gram?
Brendan: Yeah
I: Okay
Brendan: Am…
I: So will I have the same… I'll have the same… let's say in one gram I've the same number of vinegar molecules, will I? As I'll fit…
Brendan: Am… no
I: So if I have one gram of vinegar let's say will I have the same number of molecules of vinegar in there as there would be in let's say in one gram of sugar
Brendan: Of sugar? Am... no I wouldn't think so no. Because am... the molecules of sugar are much bigger.

I: Okay

Brendan: So... they're like three times bigger so... I would say that... no I say you wouldn't.

I: Okay so you wouldn't. Would you think that you'd have three times less vinegar is it?

Brendan: Am...

I: Or three times more sugar?

Brendan: Mm... I dunno if... looking at them say, I don't know if they'd have three times the volume or three times the weight or whatever but... like I Wouldn't say that you'd have am... the same number of molecules in a gram of each of them.

I: Okay and so... why? You wouldn't have the same number of molecules?

Brendan: Yeah

I: Okay yeah. Okay and you're saying this is effectively because it's three times bigger than that.

Brendan: Bigger than that yeah. Well it's got a bigger M.R. so... a gram of that would be heavier than a gram of that [vinegar].

I: Okay

Brendan: D'you understand? Do you get what I mean?

I: Yes I see what you're saying. That because that is heavier in one gram is it?

Brendan: Am... [laughs] yeah... because it's got a bigger like... molecular weight let's say. So if I've a gram of each of them then to find the number of...

I: atoms?

Brendan: Atoms then I'd have to find the number of moles. So because that has a bigger MR there'd be ah... less moles of that I suppose. Sorry of the sugar... and because of that then there'd have to be less atoms of sugar in the...

I: Less atoms of sugar?

Brendan: Less molecules of sugar sorry

I: Well I'm looking for the number of atoms.

Brendan: Oh okay. Sorry. Oh yeah okay but that's sort of the reasoning I would've done to... I see, I see what it is now I think.

I: Yeah.

Brendan: D'you know you have like... [laughs] sorry. Yeah so I've said that like... yeah that the number of atoms, you'd have less moles of vinegar.

I: Yeah.
Brendan: But if you're looking for the number of atoms… then you'd have to divide that a bigger number, the number of moles of sugar a bigger number than you would have to divide the number of moles of sugar.

I: Yeah

Brendan: And they might work out the same.

I: Okay. They might… they might be the same.

Brendan: Yeah. They could be. I can see why they might be d'you know what I mean.

I: Yeah

Brendan: Whereas I wouldn't have when I was doing it I suppose.

I: Okay.

Brendan: Yeah.

I: Okay so am… I'm just going to just see were you confident about these answers for Question 12,13 and 14.

Brendan: Yeah. Grand. Am… [reading Question 12]. Yeah I would've been confident about that because molarity is moles per litre so if it was one mole it would be one mole in one litre.

I: Yeah

Brendan: So I probably would've went away and figured out the… maths in that.

I: Okay and let's say… why, why wouldn't it be a litre of water. Why would it be a litre of solution?

Brendan: Am… because it's like… you put in you 46.07 grams or whatever and then you… I suppose I picture it in my head. You wouldn't put in a litre of water on top of that, you'd fill it up to a litre d'you know what I mean?

I: Yeah. Okay. Am… so down here which of the following best represents the ionic compound sodium chloride.

Brendan: Yeah. Well I knew that if it was ionic it would be a crystal structure sort of thing so… ah… I picked B because there was.. kind of alternate charges and am… I knew it would be a crystalline solid so…

I: Yeah

Brendan: I just picked that straight away d'you know what I mean?

I: Yeah. Okay. Am… so Question 14 'which of the following best represents the position of the shared electron pair in a HF molecule'.

Brendan: Yeah.

I: Okay so you selected the one where they were closer to Fluorine

Brendan: Yeah… because I knew fluorine was more electronegative then hydrogen so it would attract the electrons more strongly to itself.
I: Yeah. Okay.

Brendan: So the bond would kind of… pulled towards the… the bond would be pulled towards fluorine more so than hydrogen.


Brendan: Yeah

I: So heat is given off when hydrogen burns in air according to… this equation.

Brendan: Yeah

I: Am… so what's responsible for the heat? Okay so we have ‘breaking hydrogen-hydrogen bonds gives off energy’, ‘breaking oxygen-oxygen bonds gives off energy’, ‘forming oxygen-hydrogen bonds gives off energy’…

Brendan: Yeah

I: So you selected both A and B. So breaking hydrogen-hydrogen and breaking oxygen-oxygen bonds gives off energy yeah?

Brendan: Okay. I suppose I… again… looking at it now I probably would have picked C.

I: Okay

Brendan: Am… yeah I just would've.

I: Why?

Brendan: Because I kind of know now that forming bonds gives off energy… you know what I mean.

I: Yeah

Brendan: Breaking bonds would take in energy as opposed to giving it off.

I: Okay. And is it something that you've done maybe? Can you think of anything that could have been done… been done let's say over… Did you teach about this or…

Brendan: I wouldn't have taught about it no but… I suppose… oh I would've read about it when I was preparing for teaching practice actually.

I: Mmm

Brendan: Am.. d'you when I had just general topics. I would've been just flicking through just to make sure that I understood what I was going to be teaching obviously.

I: Mmm

Brendan: Am… and I probably would have come across it there I'd say

I: Yeah

Brendan: Whereas before that… straight away I would have thought… ‘you're breaking the bond so energy has to be realised'.

I: Yeah
Brendan: D'you know what I mean
I: Yeah. So you've kind of sorted that one out anyway.
Brendan: Yeah I have yeah.
I: Am… okay. Question 16 there?
Brendan: Yeah
I: So… we have water. It has a boiling point of one hundred degrees Celsius. We have sodium hydroxide. It's a white solid and it has a boiling point of thirteen hundred and eighty-eight degrees Celsius. So what's the difference… in boiling points?
Brendan: Am…
I: Were you happy that you understood that question?
Brendan: Yeah. I was yeah because… [reading question]. I think I was yeah because… you've sodium hydroxide is ionic so… you have to kind of break the ionic attraction between the two.
I: Yeah
Brendan: So… and I knew that, like, the… ionic attraction would be stronger than covalent kind of thing.
I: Okay. So… if am… so you're saying the ionic…
Brendan: Oh not covalent… the ionic bonds between sodium ah… sodium atoms and the hydroxide ions would ah… be stronger than like the Van de Waal's forces between the molecules of water. D'you know what I mean?
Brendan: Okay.
I: Okay so this is kind of about equilibrium.
Brendan: Yeah.
I: So you have ah… hydrogen and iodine… mixed together… and they come to equilibrium okay?
Brendan: Yeah.
I: Okay so you have your 2HI there. So… what would the graph of the concentration of H2 look like over time?
Brendan: Yeah. I picked… C. Am… H2. I don't know why I picked C there to be honest. I probably would… if I was to pick it again I probably would have picked… B I think. Because as the hydrogen gets used up obviously the concentration would go down.
I: Okay.
Brendan: And then would come to… at the bottom of B there it kind of come to a level point.
I: Yeah
Brendan: Which would be the equilibrium. Am…
I: And let's say C there. Could you…
Brendan: Yeah. Maybe I thought… maybe I was kind of going along the lines that it was kind of a… it could've been a reversible reaction.
I: Okay.
Brendan: So like… initially the concentration would go down until the… say the backwards reaction starts to kick in… and then went back up and down to equilibrium.
I: Okay
Brendan: Does that make sense?
I: Okay. So if somebody is… or like if you mix something and we say it comes to equilibrium
Brendan: Yeah
I: What does that kind of mean… to say that something is at equilibrium?
Brendan: That the… forward reaction and the reverse reaction are proceeding at the same rate.
I: Okay.
Brendan: It's like… dynamic. They're both moving but there is no change in concentration anymore.
I: Okay.
Brendan: D'you know what I mean?
I: Okay so it's level?
Brendan: Yes exactly. There'd be no up or down in height or say the hydrogen there.
I: Okay
Brendan: It's be flat kind of.
I: [Turns page on instrument] We're nearly there. Okay. So… this is our Question 18 there.
Brendan: Yeah
I: So…
Brendan: Okay yeah. {Reads Question} Am… okay… so yeah.
I: So do you… would you have… understood that question?
Brendan: I think I would have when I was reading it but I've kind of forgotten it now.
I: So let's say… what would K be there?
Brendan: Yeah I think I'd stall say it was less than one… because when K is less than one than the… hmm…
I: So what is K? As in…
Brendan: It's the equilibrium constant isn't it?
I: Yeah
Brendan: Am…
I: So if you were trying to find an equilibrium constant how would you go about it?
Brendan: The concentration of the products over the concentration of the reactants?
I: Okay.
Brendan: I think [laughs]. Am… okay… yeah. So I probably would have done it kind of in my head, kind of, mathsy… in a maths kind of way maybe. But I would've counted the number of atoms of… A we'll say there… and the number of atoms of B and used that as a concentration.
I: Okay.
Brendan: And then put one over the other. So if that was at equilibrium then… it'd have to be less than one.
I: Yeah. Okay.
Brendan: Am… it's probably how I would have gone about it I'd say.
I: Am… okay so… Question 19?
Brendan: Yeah
I: So… given the structural formulas of… the following three compounds, you have to decide which ones are isomers.
Brendan: Oh yeah. Okay. Yeah… I said A and B. Yeah I… I don't think any of them are isomers really.
I: Okay. SO why… or what is an isomer?
Brendan: Am… it's like the same block of, of ah… atoms repeated kind of.
I: Okay.
Brendan: You know kind of joined up to form the… chain of them say.
I: Okay
Brendan: Am… I suppose the reason I would have said… I dunno why I said B… I would have looked at that and seen the CH CH CH repeated maybe
I: Mmm
Brendan: And just automatically went ‘oh an isomer’ d'you know what I mean like
I: Okay so… you're saying that let's say A is an isomer?
Brendan: Yeah
I: Because it's a repeated pattern within…
Brendan: Within the thing yeah yeah
I: … the compound itself?
Brendan: Am… yeah we'll say looking at it now though if I was doing it… again we'll say… I suppose like that wouldn't be an isomer because it's not… repeated. You know… consistently it, it changes like d'you know what I mean.
I: Okay
Brendan: It's got of like it's got other bits inside and stuff. Am… yeah. I'd probably say that none of them are isomers… looking at it now.

I: Okay

Brendan: But… for that reason because there's no, like, repetition in there like.


Brendan: Yeah.

I: So you have ah… Lewis structures for N2H4

Brendan: Yeah

I: Okay so this is one student's answer and this is another.

Brendan: Yeah. Am… what it's… okay [reading question]

I: So you would've chosen…

Brendan: X and yeah definitely as being am… the correct one.

I: Yeah.

Brendan: Because… there's… if you look at structure Y there, there's five bonds in each nitrogen atom and… it can't, like, the maximum it can have is whatever… three I think

I: Okay

Brendan: Am… well no sorry four.

I: Why can you only have three or four?

Brendan: Because… I think it's four because, am, you've only got… ah, you've only got like enough electrons in the outer shell to form four bonds.

I: Okay

Brendan: I think now. Sorry… [laughs] off the top of my head. And… yeah here like the hydrogens are fine because they've only got one bond which… yeah I don't think nitrogen can take five bonds so I would have said that would be wrong.

I: Okay

Brendan: Am…

I: So and is it anything to do with the number of electrons that Nitrogen has?

Brendan: Ah… yeah well like the valence of it. The number it can share or, kind of, you know take from… well no it's not ionic so yeah the number it can share. It can only share, say four pairs of electrons maybe?

I: Okay.

Brendan: T form four bonds

I: Yeah.

Brendan: So then it can't like… the X one there wouldn't work because it has like five.
I: Okay

Brendan: I think now. I'm sorry

I: And… down here then now. Last question.

Brendan: Yeah [reading question]. Yeah I would've said, yeah, I'd still say A yeah. It depends on the slow step 'cause… it's the rule I have somewhere in head I think that…

I: Okay

Brendan: D'you know … Hess's Law I think, or something, that, you know… the slow step will always, kind of, mediate the speed cause… sorry now I'm a bit vague.

I: Okay. Well it's a while since you did it in fairness.

Brendan: Yeah [laughs].

I: Am… so yeah I was just going to ask you have you heard about chemistry misconceptions let's say… and if you did where have you heard of them?

Brendan: Am… well it would… I suppose it wouldn't specifically be chemistry now but for my FYP I was doing a thing… for a science course so I would've had to look up a couple of misconceptions there.

I: Yeah

Brendan: So it was included in a booklet.

I: Yeah

Brendan: So am… I suppose the ones I would know most about would be physics because a lot of them… experiments that I was using in the book, were… booklet sorry, were physics related.

I: Yeah

Brendan: I would've looked up a lot of physics misconceptions. Not so much chemistry though.

I: yeah. Yeah

Brendan: I wouldn't have, I wouldn't have read too much about them either to be honest.

I: Okay and so… would you, am… let's say would you think about, let's say, if you're going teaching would you consider let's say students' misconceptions or are you may be not… not at that… do you think it's maybe something that you would do is to…

Brendan: I think it's something that I definitely should do. D'you know what I mean, it's obviously something that has to be… you have to address with them d'you know as part of the… teaching or whatever. Am… I don't think I've done it as much as I should have yet though. D'you know what I mean?

I: Yeah. Yeah.

Brendan: Like on Teaching Practice and stuff now am… obviously time constraints as well make it… and that kind of thing
I: yeah.
Brendan: Now if I was… d’you when I’m out teaching… properly, am… yeah I think it’s something I’d have to look at yeah yeah yeah.
I: Okay. And is there… is there any other comments you want to make, or… anything like that?
Brendan: Am… not really no no I think that’s it.
I: Okay.

SEMI-STRUCTURED INTERVIEW WITH EAMONN

I: Have a look over the test instrument there for a few minutes.
Eamonn: [Scanning instrument]. I think I understood them fairly well.
I: Okay.
Eamonn: Like that’s a really good question in fairness because, am… usually I’ve been following, I’ve been kind of… you know [mumbling]
I: So, what do you mean?
Eamonn: Am… okay, am… am, okay…
I: You know the way you were saying…
Eamonn: about the questions?
I: Yeah. You were saying that they were pretty good questions but that you were…
Eamonn: They were good questions, am… good multiple choice questions, which was grand, and, and ah they didn’t require you to add a lot to them. You know, to explain yourself too much.
I: Okay
Eamonn: And in the context of us getting at the end of a chemistry lecture inside in the [name of venue], there is always a temptation to do the first two pages really well and then the last two pages, just gone.
I: Mmm
Eamonn: ah, or ah, you wouldn’t pay as much attention. Am, I think for one or two of the questions definitely, I didn’t pay enough attention. Some questions, I still don’t know what’s wrong.
I: Yeah
Eamonn: And am… some of them, like the mole questions I, I always had a weakness for, for mole questions. In particular, things to do with particles like ah… Avogadro’s constant and stuff and how it all relates to the mole.
I: Yeah
Eamonn: I had a weakness for that in Leaving Cert. and it’s still there so…
I: Yeah. And, am, you were saying that there were some questions that you didn’t pay enough attention to.
Eamonn: I’d say there were some questions, like there was one question I looked at there about classifying ah… whether they are elements are not… question…
I: Question 2?
Eamonn: It was Question 2, yeah, and I was just looking over it there and I, ah, I nearly made the same mistake when I looked at it again but, ah, this one [Diagram A]… is a compound because it has two or more different elements… from what I can tell.
I: So, A here is a compound?
Eamonn: Well, oh wait a minute… is it a compound or is it a mixture? Oh a mixture. It’s a mixture.
I: Okay.
Eamonn: Yeah, that’s a mixture. That’s [pointing to E] a compound.
I: So E is a compound?
Eamonn: Yeah that’s a compound.
I: So…
Eamonn: And, ah, A was a mixture. I think I had classified A as a compound because it was all so rigid and structured.
I: Well if I… so if we just go through the questions from here [question 2].
Eamonn: Okay
I: So your first part [Q2a] is fine here. Then, the second part [Q2b] you got right as well.
Eamonn: Yeah.
I: So this is your pure substance, mixtures, okay?
Eamonn: Yeah.
I: So why did you choose C and E as pure substances?
Eamonn: Hmm… C and E pure substances. Well C because there is only one type of thing in it, and E because there’s only one compound in it.
I: Okay.
Eamonn: There aren’t any other compounds. Yeah, that’s why I did that.
I: Okay so that’s why that was a pure substance?
Eamonn: Yeah, that was a pure substance.
I: And then you have A as a heterogeneous mixture. So, why was A heterogeneous?
Eamonn: Because there was two or more different types of substances in it.
I: Okay.
Eamonn: I didn’t pay enough attention here.
I: Then let’s say B is and D there you have as homogeneous. Why are they homogeneous mixtures?
Eamonn: Oh crap did I get them mixed up?
I: And why is that [A] heterogeneous?

Eamonn: Am… I dunno did I mix up what heterogeneous and homogeneous means.

I: Well what do you think heterogeneous means?

Eamonn: I can’t remember what I thought it meant. Am… heterogeneous… homogeneous is smooth… and heterogeneous means different types. Homogeneous should have… I would think, oh wait, no no it’s a mixture so a heterogeneous mixture would have… different types of materials. Homogeneous… I don’t know what I thought it meant, to be perfectly honest. Am… it’s a mixture. Heterogeneous gave me the impression that it’s, it’s a mixture, it's not smooth, it's not… it’s not uniform, uniform. Homogeneous gives me the idea of uniform but I don’t know… mixtures… oh, oh, so maybe what I meant to think was because… A was a solid and it’s ordered, yeah, that it'd be kind of homogeneous.

I: Homogeneous so. A is homogeneous.

Eamonn: Maybe I, I think I know what… what they [the terms] mean but I might not get them [the diagrams] in the right order. I have it right. But if I was to look at it again and do it today I think that… A was homogeneous… because it was ordered and, ah, kind of uniform… but B and D are more… random or more, ah, disordered so I would have said that they were heterogeneous but, am, I must have known at that what they meant for some reason. Possibly we were doing a module on it at the time. I knew what heterogeneous meant but I certainly don’t now.

I: Okay. We'll just go down then to the third part there so, where you had to decide was, which ones were elements, compounds and which is an element and a compound.

Eamonn: Yeah. I think I went over it too quick. So we have… the first one for elements, and I went with C because they were, there was no other, there was only one kind in it. So, one… like one… there only seemed to be one type of thing in it. So there could only be elements in it.

I: Yeah.

Eamonn: Yeah. Elements, or maybe it’s molecules in it. Am, and then you’ve compounds. Now for that did E and A. E is definitely a compound. I can see that. It's fine. But A is clearly, it’s clearly am… oh yeah. Oh I know now why I put A over there. Yeah very good. It was because, it was because I, I thought it was a mixture. And… oh yeah, I think I got confused because I wrote down A as element and compound first.

I: Mmm

Eamonn: But then I thought… it’s actually… I kind of think it was… why did I change that? I got, I got, I think I thought that element and compound meant, am… something else. I thought it didn’t mean mixture anyway… or maybe, or maybe I thought…

I: So what did you think it was looking for you to say?
Eamonn: I just misread it. Yeah, just when I was going through it too quickly I just misread it… that… oh I don’t know. I must have know you were looking for mixture really, basically… because when I look at… wait a minute I put down… I put down C? Why did I put down C? Ah right so I had this totally wrong altogether. So am… so what, so what…

I: So let’s say D there. You never classified D.

Eamonn: Well, obviously that was a mixture.

I: Yeah

Eamonn: It had to be a mixture. And so did… B.

I: Mmm

Eamonn: That had to be a mixture as well, so… am, the reason, the reason why I put down B for element and compound and not D was because, I thought B looked like it was… an element and a compound.

I: Yeah

Eamonn: And that, that was exactly what I was looking for, an element and a compound.

I: Yeah

Eamonn: And I dunno maybe I thought that this was two compounds or something

I: Okay. SO would you show me where those two compounds would be in A?

Eamonn: Well I can now see that it’s an element and a compound.

I: Okay and is it… can I just ask is it these squares here that you thought were

Eamonn: The black squares. Well the black squares are an element and the, ah, whatever you call it, the diamond and circle would be a compound.

I: Yeah. Okay so might you have thought that the two black squares beside each other was actually a compound?

Eamonn: Yeah… possibly, but am…

I: And if you were to classify D now where would you classify that? Because you never put that in.

Eamonn: It’s, it’s… ah… you see that’s why I didn’t put D in anywhere. It’s ‘cause it’s made up of elements.

I: Yeah

Eamonn: And… I was still confused as to what you were looking for here. Were you looking for mixtures? Because it’s a mixture as well.

I: Okay

Eamonn: But you asked specifically for an element and a compound. It was very kind of weird, a weird question. So…
I: So having this one before... so having my stuff about the, the pure substance and mixture, having that [Q2b] maybe before that [Q2c] could have... maybe confused the matter?

Eamonn: Maybe... maybe a small bit. Yeah, maybe that was it. I think in general, am... from teaching it and learning it from Junior Cert. and onwards is that it always goes elements, compounds and mixtures.

I: Yeah

Eamonn: I've never ever seen someone write down... element and compound

I: Yeah I understand

Eamonn: And it kind of.. it just... it just changes it a bit and so I went and I put down what I thought was right first, which was... something like B and A or something and I thought 'no wait' what, what do you mean by element and compound. What the hell are you asking that question for?

I: Yeah, Yeah it wasn't... you didn't feel you understood...

Eamonn: I didn't feel I understood... I didn't feel I understood what you were looking for, or what exactly you were getting at, am... so am... and as always I wasn't spending too much time thinking about it but...

I: Yeah

Eamonn: But, that... I think it was as much the phrasing of it that I wondered about.

I: Mmm... Okay. So that was one of the ones that you felt that you didn't... you know that maybe the question wasn't that clear.

Eamonn: Yeah.

I: Are there any other questions that you would pick out and say that you didn't understand what was being asked?

Eamonn: I saw this question here and I still don't know what's wrong with it... and, ah Question 5.

I: Question 5.

Eamonn: And ah... if I had to say what was wrong with it I would say... am... the only thing I can... figure out, unless there's something really stupidly... that I'm missing is that I should have... should be H two O two [H2O2] goes to H two O [H2O] plus half O two [1/2 O2]. I just don't why it should make any difference.

I: Am I don't, I don't follow.

Eamonn: Am... oh wait sorry. Oh no sorry sorry sorry sorry. No I'm wrong. Misread the question again. No it's okay. I got that... no I still got it wrong. No that was just stuff down here. So I got that right. No... [mumbling], No... no no no that's okay. Never mind that.
I: So what do you understand the question to mean?

Eamonn: No no no that’s fine.

I: What...

Eamonn: No I misread it [laughs]. I see it this time. I thought that when there was an ‘x’ beside it I was supposed to ah, to ah… when you marked it wrong I thought that something here was wrong.

I: Oh no. That’s just my mark for the overall question.

Eamonn: For the overall question. Yeah… mmm… I’m actually curious now what I did wrong here.

I: Did you understand what this question was asking of you?

Eamonn: Yeah.

I: Yeah?

Eamonn: [Reads question aloud]. You have two waters and an oxygen… why did I pick this one? Oh… no. Geez I’ve no idea why I went for B there. I would have gone for A now I’d say if I was doing it now but I don’t know why I went for B.

I: Mmm

Eamonn: Am… I was possibly wondering about having H two O two [H2O2] left over or something like that. But am… if I, if I looked at it now I’d have gone for A.

I: Mmm

Eamonn: I was going through it too quickly or something… I don’t know.

I: Yeah

Eamonn: It seems very weird that I picked B… a very weird choice altogether. Am… am… can I go through it.

I: So just, let’s say in terms of the questions that you thought were difficult to understand.

Eamonn: Okay.

I: As in… now that you got wrong as such.

Eamonn: Okay.

I: But where you felt like ‘Gosh what’s she asking of me here?’ So Question 2 was one of those.

Eamonn: Yeah.

I: Could you… is there any other one that you’d…?

Eamonn: Yeah I’ll have a flick through it now. Ah… I think Question 9. There’s something I still don’t understand. Am… it’s rather tricky to imagine. I don’t… [reads question aloud]. I don’t think I ever really came across an idea of talking about moles of electrons.

I: Yeah.
Eamonn: Or… it seems very unfamiliar anyway to me that you’re talking about… you talk about moles of a substance… but moles of electrons like? I dunno, I always thought about the substance as a whole anyway… I think…
I: As in you, you mean a mole of carbon or a mole of iron or…
Eamonn: Yeah as in a mole of carbon or a mole of a, a compound of whatever, but a mole of electrons? I don’t recall ever having any need to talk about how many moles of electrons.
I: Yes.
Eamonn: If I had to… if I had a look at it now I would… I think the ‘6’ distracted me. If I look at it now I would have gone for ‘12’ but, but am… but I’m still not sure I understand the question. Like I, I didn’t think there was such a thing as a mole of electrons and perhaps that is the question.
I: Yeah.
Eamonn: But am…
I: Okay
Eamonn: Ah…
I: So maybe including that it was a mole of electrons… that could, that could throw you?
Eamonn: It threw me… yeah it definitely threw me because I definitely didn’t know… or at least I didn’t pay enough attention… I definitely don’t know anyway if… what… if that’s such a thing or… but am… yeah. I probably would have gone for ‘12’ because 12 grams of carbon but am… yeah. Definitely the mole of electrons was just weird.
I: Mmm
Eamonn: But if you think about it I suppose it’s easy to overcome.
I: Just to ask you there… do you know the way some of the questions were like am… with let’s say… pictorial kind of questions like, for example Question 3 there…
Eamonn: Yeah
I: And were… you know… Question 5, Question 6, others then were only just in words like, you know, 9, 10, 11.
Eamonn: Yeah
I: How did you find those questions? You know… did you find one more difficult than the other?
Eamonn: I didn’t find them more difficult, but… having a look at them… it is rather easy to make mistakes without the pictures. Just am… just seeing it represented in front of you, you can really… clear things up or it can help you… help remind you of the actual… ah, meaning of the question I suppose.
I: Mmm
Eamonn: It just, it just helps to clear it up a small bit.
I: Mmm. So you’d have a preference for those kind of pictorial questions?

Eamonn: I think, I think the pictorial questions… yeah, yeah yeah.

I: Amm… oh yeah, I was going to ask you… so do you think the, the test that it exposed, maybe, areas in chemistry that, ah, you thought maybe you understood and then… you know that actually there might be a problem there?

Eamonn: Ah… yeah… am. Well… well… there’s definitely the bit with… mole calculations overall are grand but understanding the more nuts and bolts of… of moles and their relation to particles and their relation to mass… the mass of ah… of an element and stuff. It’s something I thought I’d more or less overcome, or at least had a good grasp of but I think… these kind of questions will always show up my… ah, shortcomings I suppose.

I: Well it’s the same for everyone. It’s the same for everybody.

Eamonn: Yeah. I don’t think there’s anything…

I: And, like, let’s say if I wrote down there, some of the… just a few of the concepts that were included in the instrument so like the mole, properties of atoms, elements, compounds, mixtures, the meaning of chemical equations… like, how confident are you about teaching those?

Eamonn: I’m very confident about teaching them I think. Am… I think a definite reflection of how well I did… like some parts I might have done better… say Question 3 and Question 2… I’d say I probably taught that in teaching practice the previous year and that does enormous things for, for ah… not only learning, reminding me of how all the simple things work but am… also really it makes, I remember it an awful lot better then like. So there’s… I think there might be a correlation there between something I might have taught on Teaching Practice and the stuff that I didn’t teach on Teaching Practice and what, how I’d do on the test.

I: So like your elements, mixtures… etc.

Eamonn: Yeah, elements, mixtures, yeah… and… sorry what was the question again?

I: Am… I was just asking do you feel confident in teaching

Eamonn: I do I feel quite confident in teaching am… a lot of the chemistry concepts… am… we had a very good teacher for Leaving Cert. and I a lot of the concepts I understand them quite well. Am… it only takes a certain amount of am… it only takes a certain amount of revision just to get a hold of them again like. Am…

I: So you, you feel that really… you know that you could go ‘way and just refresh yourself…

Eamonn: Yeah

I:… and go in and teach it?

Eamonn: Yeah.
I: Okay. Am… what I might just do now is just… if I just kind of go through the questions… you know, just to make sure… like…. Say with Question 1 there. So did you feel that you understood what this question was asking you?

Eamonn: [Reading over the question]. Yeah… yeah I understand what the question asks.

I: And why did you choose Option C there?

Eamonn: Sure am… possibly because it was only one atom. Am… the other properties are properties of am… a solid sample of am… I, I think I thought that only the chemistry of it would kind of apply. The, the bonding situation would apply when you get down to the atom level rather than the things like say… melting point and… ah, say brittleness or...

I: Okay. Am… so we already had a talk about Question 2. So… Question 3 there? Do you think you understood?

Eamonn: [reading question] Yeah. Yeah that was perfect.

I: Okay so this (pointing to option A) is the one that you chose.

Eamonn: Yeah

I: So what did you understand let’s say the next one B to mean?

Eamonn: Well the next one looks like a liquid. C looks like a mixture of some kind. Am… definitely not just ammonia anyway because of the white dots.

I: Okay.

Eamonn: Possibly, am, the ammonia split up of something. Who knows?

I: Okay

Eamonn: But it’s not ammonia anymore.

I: Okay. And then D and E.

Eamonn: It’s the same problem with D and E.

I: Okay. Am… so your Question 4 then.

Eamonn: [reads question] Yeah. That was a grand question as well. Am… a very good question I must say. It causes serious problems because of the mass changes. There is a maths background to it. But I’m… I couldn’t have been certain that I’d get this part of it [pointing at Tier 2]. But ah…

I: The second tier.

Eamonn: yeah B was the only answer but… I dunno…. if you put in something like I dunno… something about the conservation of energy of something I might have gotten confused… like more confused. The rest of them were… it was obvious in that case but, but… I wouldn’t necessarily have ah, have known that mass was always the correct answer if there were slightly more similar answers.
I: Oh I see
Eamonn: Concerning laws anyway… it was definitely a law.
I: So when you were up here at the first tier, did you immediately know ’27 g’ or did you look down here (at the second tier) first?
Eamonn: Oh no no I knew straight away.
I: So you knew.
Eamonn: Oh it couldn’t change sure.
I: And you knew then it was a conservation law is what you’re saying?
Eamonn: Yeah yeah.
I: So if there was maybe another option that
Eamonn: Or or… I knew that was the answer straight away, 27 grams, that’s fine. And then I came down here and I would’ve, I would’ve looked at all of them but I knew most of them were kind of… were talking about, am, reasons why you would pick any of the other [first tier] ones. Gas lighter… but in any case, am, ‘mass is conserved’ is the only one that would fit with my choice.
I: Yeah yeah. So it was really you chose your answer here [in the first tier] and that [Option B in the second tier] was the only one that… to support it.
Eamonn: to support it yeah.
I: Okay, am… Question 5 we had a bit of a chat about already.
Eamonn: Yeah
I: Okay. So if you look down then at Question 6?
Eamonn: [reading question] Oh this was tricky! [reading question]
I: What did you find tricky about it?
Eamonn: Am… these diagrams are particularly confusing. They all look exactly the same.
I: Really?
Eamonn: Well not exactly the same but particularly C and D would be particularly confusing if you didn’t spend some time to look at it I think. But right now I’m trying to figure out why I even picked… Oh! Oh no… I don’t even know why I picked D. This is really confusing.
I: Well how… how are you trying to figure out the answer.
Eamonn: I’m just trying to figure out why I picked D mostly.
I: But what are you doing in your head to try to figure out why?
Eamonn: Well for the most part I’m, what I’m looking for is… I’m looking for S O three [SO3] molecules.
I: Yeah.
**Eamonn:** And I know what they look like cause they’re S O three [SO₃]... and ah... I’m looking for S O three [SO₃] molecules... [reading question]... “when it reacts as completely as possible” so if you have .... why do I have two S [2S] left over?

**I:** So are you only looking at the equation here to try and figure out the answer?

**Eamonn:** Am... what else could I possibly look at? Oh! Oh I could look up there too. Oh right that’s probably what I did.

**I:** Which?

**Eamonn:** I probably looked at the, the diagram compared with this one because... to be honest the first thing I would have done is look at the equation.

**I:** Yeah.

**Eamonn:** But if I look at the equation even now I’m wondering how on earth I could have gotten it [Response D]?

**I:** Yeah.

**Eamonn:** It doesn’t make sense to me. So... then I would have gone to the diagram. I would have compared this diagram [stem diagram] to each of these [response diagrams]. Am... and that one [Diagram E] clearly doesn’t work. I think that [Diagram C] probably has too many oxygens. I’m not sure but that probably wouldn’t work. That [Diagram B] doesn’t work. It’s really between A and D.

**I:** Why is A an option whereas it wasn’t before when you were looking at the equation.

**Eamonn:** Oh well A is only an option now because I’m not finished looking at it.

**I:** Okay.

**Eamonn:** Am... [counting atoms]... it’s because there’s 12 oxygens [stem diagram] and there’s only 9 here [Diagram A].

**I:** Okay. And supposing that I added in another 3 oxygens there [Diagram A]. Then what would you do?

**Eamonn:** Depending on how they were arranged but am...

**I:** If you were to write out a chemical formula for this [Diagram A], how would you write it?

**Eamonn:** Oh wait wait a minute. Sorry. No, A doesn’t work either because it’s got two, am, it’s got 2 sulphurs. That’s why I disregarded it. It’s possibly this one so then [Diagram D] I was thinking about it for a bit longer because it has S O three [SO₃]. I dunno, there was probably too many oxygens in that one [Diagram C].

**I:** So do you think it’s not clear enough... let’s say. You know is there any way that you would make this question clearer?
Eamonn: More clear? Am… not really. The only possibly thing I could say is just possibly spreading out the boxes more.

I: Okay.

Eamonn: It’s a simple thing… it’s the only possible thing I could say about it because for the most part it’s a diagram… it just requires to stop, think, compare this with this. The first thing is to compare the reaction. You’re going to get S O three [SO₃] and compare that with each and look and how many of them have three oxygen and sulphur bonded to it and that will eliminate three straight away. And then compare your starting amount to your finishing amount and it’ll sort itself out.

I: Do you think that maybe if I had bolded there ‘a closed container’.

Eamonn: it wouldn’t have made any difference to me to be perfectly honest. I just wouldn’t… I wouldn’t have thought about that too much. Ah I would’ve just, I would’ve just assumed it was a closed container… but that’s just me. Am…

I: Okay. Am… okay Question 7 here.

Eamonn: [reading question]…

I: Do you understand this part[the stem]? You understand what’s being asked at the top?

Eamonn: I understand that. Am… and that’s just a diagram giving a representation of ionisation energy. That’s fine. Ah, my first thought was ‘A’ is right but ah… I must read D and E again. Am… [reading D and E]… Am, in the questions, or in the options, you’re looking for more detail than I was used to doing when I last covered this in detail for Leaving Cert. and that’s why I went straight for A. For me… they’re most stable when they have all their shells filled, and, I would still go with that. Am… it’s probably still partially right but obviously one of these is probably… in a fuller way right, but am…

I: And did you have any difficulty understanding them [the options]? Were they a bit wordy?

Eamonn: Yeah. They’re a bit hard for me to understand. Am… like I’m not even that sure… [reading options again]. I can, I can understand it but I can’t actually form a picture in my head of what that actually means. Or what…

I: So if I was to just ask you, yourself, what does ionisation energy depend on? What reason or reasons might you have?

Eamonn: For me… ionisation energy is… ionisation energy is the amount of energy required to remove the most… loosely bound electron in a… in a…. in a … molecule?

I: Okay.

Eamonn: That would have been approximately what I… as far as I would go with that.
I: And would you know why… if you were to give me some reason why the ionisation energy of one thing is higher or lower than another.

Eamonn: okay it always come down to… it comes down to these things [pointing at item stem] but that’s just… that’s as far as I went for Leaving Cert.

I: Yeah the electronic configuration?

Eamonn: The electronic configuration and obviously if… in… and am… am I suppose the other things would have been if, if the shells themselves were full. The, the let’s say the ordinary 2,8,8… I probably wasn’t thinking about that very much when I was looking at this… and am, am… and… whether or not it was probably a noble gas. That would probably be important as well. Oh and then there’s the other things like obviously the further, the further away from the nucleus they are the easier it is to take off. Yeah, so, yeah, so… as you go down the Periodic Table the easier it is… the ionisation energies go down and, go down. Yeah I didn’t think of all those things when I was doing this question. I just focused on the energy levels.

I: Yeah. You just saw something that just made sense to you and you just went with it?

Eamonn: yeah yeah it just made sense to me. To be honest I really did not… and even now it would take me a couple of minutes to really understand what the rest of the options mean…. and why they’re either wrong or right.

I: Would you say it was time consuming?

Eamonn: Am… at the time it was time consuming yeah.

I: Yeah and you’re under pressure I suppose?

Eamonn: It was the end of a lecture yeah [laughs].

I: Yeah. Am… okay so Question 8 there.

Eamonn: {reading question}

I: Did you understand the question?

Eamonn: yeah.

I: Why would you have chosen the mass?

Eamonn: [reading question]… am that’s just wrong. As far as I know there is nothing that can affect the number of particles in a mole of a substance. I would have gone with mass because moles equals mass over relative molecular mass… so that’s what put it into my head. Am… [reading question]. Well there is nothing that affects the number of particles that are in a mole of a substance. One mole equals, whatever, $6 \times 10^{23}$ … Avogadro’s constant. If I think about it now that’s what I would say but…

I: And why do you think… have you been on Teaching Placement between now and the last test have you?
Eamonn: Yeah yeah.
I: And do you think that that’s clear in your head now because of that?
Eamonn: No no I didn’t teach it during TP. Am I think ah…. I don’t think it’s clearer in my head exactly. I definitely…. there’s some things in that… like when it comes to some small definitions or when it comes to the difference between atoms and molecules and stuff that are definitely still sketchy. I would need to, like,… as opposed to anything else in chemistry that I might just need to revise or refresh. When it comes to atoms and molecules and teaching, and teaching the different definitions and stuff I would need to go away and learn it and really, ah, hammer away at it. I can see what… and it makes perfect sense… and I can see why I said mass because it probably made the most sense… at the time. Yeah.
I: Okay. Am… okay so we kind of spoke briefly about Question 9. So you were saying it’s just the idea of a mole of electrons just didn’t…
Eamonn: Yeah.
I: You were saying that you would choose 12 grams now.
Eamonn: Yeah.
I: I’m wondering why would you choose 12 now where you chose 6 before?
Eamonn: I chose 6 before. I think I chose it because it said 6 electrons… and… possibly I though there were 12 electrons in a…. in Carbon and then I thought you were asking 6 and… I dunno. If I had, if had to choose it now I would say,… I would still assume that you’re talking about a mole of Carbon.
I: Okay so even though I’ve said a mole of electrons you would think about a mole of Carbon.
Eamonn: I would think of a mole of Carbon because I don’t think there’s any such thing as a mole of electrons. Anyway so I would go with 12 grams because 12 grams would be the approximate relative mass of am… of Carbon, and that would have one mole of carbon and that’s why I would go with it.
I: Okay and so what does it mean to say that it’s a mole of carbon?
Eamonn: It contains 6×10²³… a certain number of particles and am… and yeah… so yeah… it contains a certain number of… particles. This is exposing exactly how little I know about what they, what… one mole actually means. I’ve been using it for years but it doesn’t mean that I understand exactly… what a mole means.
I: Okay so…. just to be clear. One mole of carbon atoms is… what?
Eamonn: It contains a certain number of particles.
I: Okay and what are the particles?
Eamonn: They are the particles of carbon.
I: Okay. Are they atoms?
I: Okay.
Eamonn: And there is Avogadro’s constant to tell us exactly how many atoms are in a mole of one thing and… so… am.
I: Does a mole always have to be Avogadro’s number of atoms?
Eamonn: Yeah.
I: Is a mole always referring to atoms? Is that what a mole is? Is that what the particles are?
Eamonn: Am… I dunno. Am… one thing I’m not sure of is are particles and atoms the same thing… which they probably aren’t but I dunno. We will assume for now that they are and ah… so one mole of a substance always has the same number of particles but it doesn’t necessarily have the same mass and… I dunno… the mole is trying to… one mole is the correlation between the two… I’m not sure how to explain.
I: Okay. Okay. Am… have a look here at Question 10.
Eamonn: [reading question]…
I: Okay so do you understand what the question is asking?
Eamonn: Yeah I think so… [reading question].
I: So what are you…
Eamonn: Yeah I’d need a calculator. I understand though.
I: Do you know why you chose 5.
Eamonn: 5 is a bad choice. Am… I probably guessed it to be perfectly honest.
I: Okay. So if you were to do it now, and let’s imagine that you had a calculator, what would you do?
Eamonn: What I would do is I’d… it’s a ratio kind of business so… at the moment you have, ah… you’ve 2 moles of B… is needed… yeah, so, yeah you need… if you want to react 3 moles of A you need 2 moles of B. It’s a ratio kind of business so, ah… am… so I find out what I multiply… what I need to multiply 3 by to give me 5… and I multiply that by 2… and that should give me the answer of how many moles of B I need.
I: Okay. Supposing I had instead said how many moles of B would you need to react completely with 6 moles of A. Supposing I had said that it was 6 moles of A, what would you do?
Eamonn: Okay 6 moles of A… how many of B, so… you would need 4 moles of B.
I: Okay so 4 moles of B.
I: Okay, am… Question 11.
Eamonn: [reading question]… no. Am… so this goes back to what I think about moles and I guess… it’s that… you’d only have the same number of atoms in each sample if you had the same number of moles in each sample.

I: Okay

Eamonn: Or at least that was my understanding of it… and that’s why I said no… because you only have, you only have the mass. There’s no way you’d have the same number of moles of each substance. Not when, not when, they have different formulas and the same mass.

I: Okay so why are you… have I mentioned moles?

Eamonn: No but, but I have to, I have to, am,… but I have to explain that’s why I said it because… what you have mentioned is that they have the same mass and that, that…, I don’t think there is any way you could do any calculations that would show you that you have the same number of atoms… just because you have the same mass, because I know… I thought that, that if, if for example to find out how many moles of vinegar I had.. it definitely wouldn’t be the same… and I thought that only in that case could you have the same number of atoms in each sample.

I: So finding out the number of moles of vinegar… so that’s moles of this (formula) so that’s the same thing as finding out the number of atoms?

Eamonn: Yeah.

I: Okay. And, am… just I’m wondering here did you pay any attention to the formulae and all that kind of stuff?

Eamonn: Well, am…

I: Or did you just notice that they were two different things?

Eamonn: Well what I would have done was made sure that was definitely different to that… and made sure that it wasn’t some kind of… trick to it but… as far as I can tell

I: and would you notice and similarities between vinegar and sugar there

Eamonn: Yeah… yes I do. But…

I: Similarities and differences. What are they?

Eamonn: Well there’s obviously differences in the formula. But they’re obviously from a similar group of chemicals because there’s CHO in each of them… am, am they’re both organic compounds and, am, and right now I can’t really describe the difference but, am… but they probably have some similarities in structure… but as far as I was concerned that was only background information… and it all came back to the…

I: Okay and I’m just wondering if you would have noticed or if it would have made a difference anyway. Would you have noticed that there are three times as many Carbon atoms, 3 times as many hydrogen…
Eamonn: I didn’t really look at them. Oh no… wait finish your point actually.
I: I’m just wondering if noticed that it was 3 times more of each? And would that have made a difference?
Eamonn: No… but I’m curious as to what difference does it make? I’m curious. I’m really curious as to what difference that makes.
I: Am… okay so we’ll keep going so Question 12. What does the 1 molar solution of ethanol mean?
Eamonn: [reading question]… so I just, I just checked how much,… what was the relative molecular mas of that and… it’s, it’s a … a one molar solution is a mole of a substance per litre.
I: And why did you say per litre of solution instead of a solution of water?
Eamonn: Because it’s not water. There’s ethanol in it. Basically.
I: Okay. Question 13. Any difficulties with this one?
Eamonn: [reading question]. Ah sure… I wonder why I didn’t pick this one.
I: You’re wondering why you didn’t pick E is it?
Eamonn: Well that would be the 3D structure of it. That’s only ah… 1D or 2D, a 2D structure… so ah… yeah I went with B because it was proper 3D structure. Because it more accurately shows the crystal sort of structure of it I suppose so yeah… and like if you spend any amount of time in a lab you’ll see the, the… ah representations of that around the place so it’s actually one of the easiest questions there probably.
I: So that representation anyway is fairly familiar to you?
Eamonn: It’s fairly familiar… it should be fairly familiar to everyone I suppose.
Eamonn: [reading question]…
I: So if we just look at the first bit here. Did you understand the question?
Eamonn: Yeah. Okay. Yeah I think I understood the questions.
I: Okay so why… so what does B represent there… or A or C. What do each of those represent?
Eamonn: Ah.. I’m not sure. I think I might have had difficulty with the way the representation worked. Because that gave me the impression that Hydrogen somehow had two electrons to begin with and somehow was then sharing it’s two electrons with flourine or something because… for me… the representation would have had… whatever it was would have had one electron on either side realistically. So that’s why I went with B because it had 2 electrons in the middle which would have been the fairest way of putting it… because Fluorine was only ever going to be sharing one electron and hydrogen was only ever going to share one… it only had one to give… and in that case it looks like the Fluorine is giving the two electrons and hydrogen has nothing. And in this
case it seems like hydrogen was giving two electrons which isn’t true either… so B was the … fairest one even though I didn’t really like the way the representation looked. It wasn’t natural to me.

I: Okay so it had kind of had the two electrons in the middle… is what you were going for?

Eamonn: Yeah yeah because… well it was the fairest representation but, if it were me… if I was writing it myself I would have had an electron on either side… because that’s what happens. One comes from Fluorine and one comes from hydrogen but… maybe that’s a technical definition.

I: Okay and your, your reasoning then?

Eamonn: [reading question]… [murmurs ‘oh yeah that could be it too]… am… I went with B… but B is a rather simplistic way of looking at it… am… C could have a good point there… C yeah so that could… I kind of… if I read through these it kind of explains a little better why the other ones could be right. Ah…

I: So would you… I’m wondering would you still say this and this today? I know that you can see there that the question was marked wrong but let’s say… the question is only right if you get both tiers correct… I’m just wondering would you still probably go with the same option?

Eamonn: Probably not. It seems probable that Fluorine is an absolutely massive atom, am… I can’t… I think it has higher electronegativity values as well so it’s, it’s probable that am… it would have a greater attraction… so it’s probable that A is possibly alright. Am… it’s probable that I would go with C even though I, I’d have reservations about D being right because I don’t think… I dunno if it’s simply because it’s the larger of the two atoms. I think it would be a couple of reasons… so I would probably go with C… and… no no not A… I’d probably go with C if I had to guess.

I: Okay and just here you chose B?

Eamonn: That was because it suited. Yeah what I was doing was that I chose this first and then I chose which one of these most suited my choice rather than allowing for the fact that…

I: Okay. So, am… so just quickly there Question 15?

Eamonn: [reading question]…

I: You selected the option where breaking and forming bonds gives off energy. Did you understand the question?

Eamonn: Yeah I understood the question. Am… possibly I went through the question a little quickly, It wouldn’t make sense if they were both giving off heat… where the hell would you get all the energy from? Am… something… energy is given off when a reaction happens but… it… the energy is needed for forming the new ones so that wouldn’t be giving off energy… so it seems unlikely that they could both be giving off energy.
I: Yeah.

Eamonn: am... am... yeah...

I: So would you say that your answer... you might change your mind now... but that your answer at the time was to do with thinking that when a reaction happens... you said there 'when a reaction happens'.

Eamonn: Yes energy is given off when a reaction happens.

I: So is that why you chose both of them?

Eamonn: The reason why I chose both of them was because... it was when the reaction happens... when a reaction is happening both things are going on, there's there's bonds being broken and bonds being formed so I thought that, tat ah... the heat is given off during the whole process.

I: Okay yeah. Okay I might skip down to some of the more, am,... just down here Question 17?

Eamonn: [reading question]... yeah yeah

I: Did you understand the question?

Eamonn: Yeah. It seems fine. That's impossible [A]. That's impossible because how could it go up and down. Well... no it'd be like a reversible reaction maybe... yeah. Yeah that would be reversible but it doesn't apply here.

I: Why doesn't it apply there?

Eamonn: Because... you have hydrogen and iodine mixing and... it's coming to equilibrium and it's just a forward going reaction and it's just giving me... hydrogen iodide.

I: Because of this arrow here?

Eamonn: Yeah. Am... B is what I went for. C... am... yeah C was kind of odd.

I: Would you have considered it?

Eamonn: No. No I wouldn't have considered that. I think the only other one might have been... no D wouldn't make any sense because it's hydrogen iodide being formed and E... no that wouldn't make any sense at all. I probably would have looked at that [Diagram C] for a while just because it's a bit odd. It, it... it certainly [inaudible] forming iodine to begin with but B realistically would've been the only one.

I: Okay. Am... for your Question 18?

Eamonn: [reading question]... I don't even know what K means.

I: Okay so if I had said which of the following must be the equilibrium constant for this? So K is the equilibrium constant. Would that have helped?

Eamonn: Am no honestly. I don't know what it means when it's greater than 1 or less than 1. I think I just guessed it.
I: Okay so… if I were to give you a reaction and ask you to find the equilibrium constant, would you remember or know…?

Eamonn: No I don’t think so. Am… equilibrium constant… wait a minute… it’s to do the logs and stuff no? I can’t remember being honest.

I: yeah okay so that was really just a guess?

Eamonn: That was definitely a guess.

I: Okay. Question 19. Which of these compounds are isomers?

Eamonn: I was at this before. Am… isomers… isomers are… compounds that have.. the same formula but a different structural… they have the same chemical formula but different structural formula. Am… [reading question]… oh I should have counted up the hydrogens… I probably just looked at it. Those two (A and B) are isomers. I probably just looked at it and thought ‘that can’t be possible’.

I: And why A and B but not C?

Eamonn: Well I had a quick look there and I can see that 3 hydrogens here 3 hydrogens there 3 hydrogens there. Am… [counting]… yeah yeah yeah that one. Oh wait there’s 4 there sorry. [counting] Okay probably that one as well.

I: Okay so if you were to answer now?

Eamonn: Yeah they’re all… they’re all… well probably. I had a quick look at them but they’re all… they all seem to have roughly the same number of carbons, oxygens and hydrogens. They’re probably all isomers. I think at the time I was thinking too much about really small differences like… I dunno… CH3 being here rather than there, or…

I: So the shape was it?

Eamonn: I think the shape just, just… yeah, yeah. I might have confused it possibly with another type of isomer… I think it’s where, where you can have… where it’s different having CH3’s up here rather than down here sort of craic. I can’t remember the name of it now but at the time it’s possible that I confused that and thought they were all different. Am… I think I confused my definition of an isomer… and a quick look would have told me that they were all the same.

I: You’re clearer anyway now at this stage about what it is?

Eamonn: yeah yeah.

I: Am okay. Your Question 20? Did you understand it?

Eamonn: [reading question]… okay, am…

I: So did you understand?

Eamonn: I think I understood. Am…

I: So you chose Y as correct.
Eamonn: Yeah I chose Y as correct. I think, am… there are a couple things at play here. One thing is that it’s Question 20. Another thing is… I probably needed a Periodic Table in front of me to remind me that… well there probably was one I’m not sure… but that, what what exactly nitrogen has in its outer shell. What’s it’s capable of doing? And am… it needed concentration.

I: So if you had a Periodic Table what information would you have taken from it?

Eamonn: How many electrons does Nitrogen have in its outer shell?

I: 5.

Eamonn: Surely not! It could make like 5 bonds then.

I: So if I said it had 5… could it make 5 bonds?

Eamonn: No!

I: No. Why not?

Eamonn: Because it only needs to make 3.

I: Why only 3?

Eamonn: To make 8 electrons in the outer shell… it only needs to share 3. At least I think so. You see that’s what I like about that one. It has 3 bonds there and then you’ve lone pairs. That makes a bit more sense. That is blatantly ridiculous.

I: So you think it would be more likely for there to be two sets of lone pairs on the nitrogens?

Eamonn: Yeah. I don’t think you can even have 5 bonds because… 5 electrons is too many. It only needs 3 bonds.

I: Okay. So you’d now say X because to get a full shell?

Eamonn: Yes to get a full shell… it’s only going to form a compound if it’s getting a full shell. Yeah that would be my reasoning for not choosing Y.

I: Okay so now you’d chose X and D?

Eamonn: Yeah.

I: Okay so the last question then. Do you think you understood this question?

Eamonn: [reading question]… Yeah I understand the question but… I’m not sure I would have been able to answer it.

I: Yeah. So you chose ‘it depends on the first step’.

Eamonn: I think it was a guess. I don’t think I thought about it for long to be honest. [reading question] it probably depends on the collision rate realistically but, am… that would’ve required a certain amount of thought that I didn’t give it at the time.

I: Yeah okay. Am okay. Have you heard about chemistry misconceptions before that [the test] and, if you did, where did you hear of them?
Eamonn: Am... yeah I suppose I probably heard... or saw that people had misconceptions around me like. In general I would consider myself to have quite a good grasp of chemistry and I could see that other people tended to have misconceptions about it... especially other people that would have only done chemistry for the first time in first year in college and am... I might have noticed it a little bit but not that much I suppose.

**SEMI-STRUCTURED INTERVIEW WITH EILEEN**

I: Okay so am... just, I've written down here a few of the concepts that were included in the instrument. So you see the mole, properties of atoms, compounds, elements, mixtures, meaning of chemical equations, you know, ionisation energy is another one. A few other ones in there.

Eileen: Yeah

I: Would you be confident about teaching those topics?

Eileen: Not like... some of them seem okay like the compounds, elements, but like chemical equations... I just... no I find that very...

I: You wouldn't feel confident to teach it?

Eileen: No. No.

I: And is that just... you... feel that your own understanding isn't that good or is it just that you find it difficult... because maybe it's abstract or something... that you think it would be difficult for students to pick up?

Eileen: If I was being honest it would be my own, my own ability at it. Like I don't, I don't know would I be... even though we've done so many chemistry modules in college there's still a lot of basics that I am still struggling with so...

I: Yeah yeah. Am... so what did you think of the instrument?

Eileen: Am... geez I thought it was very hard. I thought it was really... like the questions are totally different and like, they make you just think way more and like the Leaving Cert. is all just define this and d'you know balance this. But these questions I just thought they were very difficult like. The style of them is way different... way different.

I: And, ah, you see there... like some of the questions I would have had... like some are pictorial, for example Question 3 there, Question 5, Question 6, and then others are mostly words, so they're kind of based on language. Did you find one of those more difficult? Were both of them fine?

Eileen: I would probably say the pictures, the pictures were harder... I actually would yeah.

I: And why?

Eileen: Am... because we're just not used to... we're not used to that. Like from the Leaving Cert. and even from the college exams you wouldn't get a pictures and, you know, a choice... multiple-choice questions we're kinda used to them from our modules but the pictures... no. And I can
make more sense of... you know a choice between, like the written ones but the pictures like are just...

I: And is it... would you have difficulty interpreting what they mean?
Eileen: Yeah.
I: Is that... like here let's say for Question 5, would you have difficulty interpreting what A means, B means there?
Eileen: Yeah. Like in some of them yeah I would. Am... yeah they take a longer to look at and figure out whereas when you read it like you understand... you can, you know it's just a question but here it's just... there's no explanation it's just...

I: And do you think, here let's say for Question 5 you have your key, where these big circles are oxygens and the small ones are hydrogen... or whatever there right. Do you think it's anything to do with am... like are you used to visualising... are you imagining what's happening. Let's say you're looking at an equation. Would you normally try to imagine what the... what's happening with the atoms?
Eileen: No I wouldn't because like in school we were never... you know they said that... they suggest for us to teach you know using ... you know, like, if you were doing the atoms using the building blocks or whatever... but we in school... we never, you know they didn't even draw it on the board like so you could kind of visualise it. It was just all written in the book and you kind of have to figure it out yourself.

I: Yeah.

PST; Whereas you're not... you know if they taught us... like this is a kind of way of showing us, you know, different reactions or whatever but they didn't like so I'm just not used to it now. I can't... I find it hard to understand...

I: Okay. So am... do you think the instrument... did it expose areas in chemistry that you thought maybe you didn't understand?
Eileen: Yeah... like d'you know some of them, the questions, you'd think you'd... you know you'd be able for some of the areas but no... the questions, they were so... they were so different to what I was used to so... yeah they were definitely a lot harder and... more surprised that they were... you know I thought I would... I didn't think I'd get... it was a very hard test but I didn't think I'd get... that.

I: Well I know... we're saying it's a test or whatever but, as I said, 80% of people got less than 40% in the test so it's not... I think you're not used to looking at a test and seeing 20% on it but you know it's a different kind of a thing.

Eileen: Yeah.
I: Am I might just go through some of the questions with you just to see how you picked up on them yourself.

Eileen: Okay.

I: So we’ll say Question 1 there if you have a look.

Eileen: {reading question}. Yeah.

I: So did you feel you understood what that question was asking you?

Eileen: Yeah… the properties… like it was more straightforward yeah.

I: So you chose Option C there. Why did you choose that option?

Eileen: Am… I think I was just, am… ‘only D would be the same’… I’m not sure why… I don’t know why… Like it would make more sense yeah… like at the time I don’t know why I was thinking… I don’t know to be honest… I don’t know why I picked that.

I: So if you were to answer it now, what answer would you choose? So you have a sample of solid sulphur. That’s the list of properties… and what would be the properties for a single atom of sulphur?

Eileen: Would it be A no?

I: So that it would be a brittle crystalline solid?

Eileen: Wait no it couldn’t be if it was an atom.

I: So what do you think?

Eileen: Yeah if I was to go again I’d honestly, I’d probably pick A but… I’m not sure.

I: Yeah okay.

Eileen: Yeah I probably thought it was straightforward but… yeah, a single atom of sulphur it’s… I don’t know. It’s confusing.

I: Okay so if we have a look at Question 2 here. Have a look at that question there.

Eileen: [reading question] Yeah I would’ve thought that was right to be honest.

I: Okay so do you feel you understand what the question is asking you?

Eileen: Yeah.

I: Okay so you chose A as a solid. So why did you decide that was a solid?

Eileen: Because… they’re all bunched together… and they’re all in a block like… they’re not moving around freely. Am… I thought liquid would be C and D because there’s spaces you know and they can… I dunno maybe C was am… a solid as well.

I: Why?

Eileen: Because they’re more stacked. They’re more bunched together whereas they [the particles in Option D] have more… they’re more free or whatever. And the gas… yeah I would’ve said B and E because they’re floating around.
I: Yeah. Okay.

Eileen: That’s what I would have thought.

I: Am… so you’d classify this [Option C] now as a solid instead of a liquid?

Eileen: Yeah. Looking at it again I would. I think I had it and then I scribbled it out.

I: Okay. So the second part… you were asked was it a pure substance, heterogeneous mixture or a homogeneous mixture. So I see that you have C as a pure substance. Why is C pure?

Eileen: Am… because they were all the same and am… yeah pure substance, presumably they’re all the same… and heterogeneous if they’re… What one’s did I say there? A, B, D and E… yeah.

I: Yeah you have A, B, D and E as heterogeneous mixtures. So why did you chose those?

Eileen: Because ‘hetero’ is ‘different’ so… in the, in the block they’re all different and homogeneous is C. They’re all the same.

I: Okay so… if I was just to ask you to define a mixture, just any mixture, how would you define that?

Eileen: Am… mixture, like…. could you say, like, atoms that, you know, I don’t know how to, I don’t know how to put a definition on it. I don’t know.

I: Okay. Are all these mixtures so? So you have A, B, D and E as heterogeneous mixtures and C as a homogeneous mixture.

Eileen: Yeah… but that wouldn’t be pure then… would it?

I: Okay so how would you describe a pure substance?

Eileen: Like all the properties would be the same would they? Like the, you know… so I don’t know what… I don’t know would that be… I don’t know. It’s very confusing.

I: Okay. You’re not sure about C as a mixture is it?

Eileen: No. No.

I: Okay. So the next part… what was I asking you to do down here, just to make sure we’re on the same page?

Eileen: Which ones were element, compound or element and compound. I would've taken that as… am, an element is single, on its own, you know. So I said C. And compounds is… one or more joined to together or whatever so I would have said… what did I say… A… or B.

I: Yeah so you have A as compounds. So where are the compounds there in A?

Eileen: The diamond and the circle.

I: Yeah.

Eileen: And, ah, I should’ve said E as well. Should I? E… ‘element and compound’. Element and compound would be A wouldn’t it?

I: Okay so where are the elements then in A?
Eileen: The squares.
I: Okay. So you would now put A as element and compound?
Eileen: Yeah.
I: Okay. And E then you’re saying… you would swap that over now to compound.
Eileen: To compound yeah… because it’s two or more isn’t it so…
I: So let’s say D there if you were to classify it.
Eileen: Am… I’d say they’re all elements… because… they’re not joined together so…
I: Yeah. Okay.
Eileen: I’d say element.
I: Am… okay so we have Question 3 here. Have a read of the question again there.
Eileen: [reading question] Are they asking what would you see here in the gas?
I: Okay.
Eileen: Am… would it be A?
I: Okay so you’d change your answer now to A?
Eileen: I would yeah.
I: And is that… is that kind of because you know it’s [the answer previously given] wrong or… if I was to give it to you again would you definitely chose A now over B?
Eileen: I probably, I probably would’ve said A.
I: You’d go for A okay. And what do you think A is showing?
Eileen: Because it’s a gas and am… they’re far apart and they’re, like, moving around freely so…
I: Okay and what do you think B is now?
Eileen: B… would be probably a liquid, would it?
I: Okay. And what do you think C is?
Eileen: A solid.
I: Okay. And why is that a solid?
Eileen: Am… because they’re am, more bunched together… but I suppose maybe it could be a liquid as well. I don’t know. I find that very confusing… like trying to put a label on them, like, you know.
I: Okay. So would you have realised here… so this is what I had intended here. So this is your liquid ammonia yeah?
Eileen: Yeah I got that.
I: So you liquid ammonia, NH3. You’re evaporating it… so it’s what you would see in here [the second beaker] is what I’m asking. Did you understand that?
Eileen: Yeah oh yeah.
I: Okay. So would you have looked at these [the options]. Would you see that that is the very same?
Eileen: Yeah
I: So tell me how it could end up looking like this, from that?
Eileen: Yeah you wouldn’t have more like. Would you?
I: Okay. Can you see that those are all split up?
Eileen: I never realised that they had little white ones all joined onto them.
I: Okay.
Eileen: Even there I just thought it was a shadow you know.
I: Well I suppose could it be the printing?
Eileen: Yeah it’s the printing. If that was clearer I would have seen yeah that they were… that they’re broken up like… and here they’re together. But yeah I didn’t see that.
I: Okay. Am… Question 4 then. So have a quick look.
Eileen: [reading question]right the weight after heating… it’s the weight of the tube.. and the iodine is it... or are they...?
I: Okay. So if I had put in ‘will the weight…’. So you have your tube, there’s iodine in it and it’s then evaporated so if I had said ‘will the weight of the tube’… if I had put in ‘the tube’ there would that have made a difference?
Eileen: Yeah… because… yeah I just think that that there, you know like, is it saying… I’ve worked out 26 there. D’you know I was kind of saying… together it’s 27 so it’s asked to know the tube now… am… what did I say… I probably would have said A.
I: So, less than 26 g?
Eileen: Yeah.
I: And why?
Eileen: Because yeah you’d just kinda think that a gas is lighter.
I: Okay.
Eileen: And , you know, if it was solid there and it evaporated… it would be less. The gas weighs less.
I: Okay.
Eileen: So if it evaporated it would be less like, because in the solid it would be a gram and if it evaporated it’s gone, you know, it’s a gas so I would have said less.
I: Okay and do you have any idea why you chose 28 grams there?
Eileen: Yeah I don’t know why I’ve chosen… yeah… am… I probably thought… I dunno I just added one. I probably just… I probably thought that… the fact that it was evaporated that… I
don’t know why at the time… I mean now that’s the least thing, like, that it would make it heavier like.

I: Okay.

Eileen: I probably just… because the answers were 26, 27, 28… all around that… so I just added one.

I: Okay. Okay so Question 5. So hydrogen peroxide will decompose to form hydrogen and oxygen gas according to the following equation. So which diagram represents the hydrogen peroxide before it decomposes?

Eileen: [reading question] Am… I’d probably change it to D.

I: To D?

Eileen: Yeah.

I: Okay and why would you choose D now?

Eileen: Am… because… if it decomposes it’s a solid and a solid is… they’re bunched together even here [Tier 1 Response D] and I’d take that as a liquid [Tier 1 Response B] and… maybe a gas that there’s [Tier 1 Response C]… you know that they’re spread out. So I would have said that’s all together [Tier 1 Response D] so that’s a…

I: Okay. So for D there, what… so okay you’re saying it’s a solid… does it represent hydrogen peroxide?

Eileen: Yeah… I would’ve said, like if I’m looking back on it now I probably still would’ve said A if I’m honest.

I: Okay. So for D there, what… so okay you’re saying it’s a solid… does it represent hydrogen peroxide?

Eileen: Yeah… I would’ve said, like if I’m looking back on it now I probably still would’ve said A if I’m honest.

I: And would you have looked up here at the formula for hydrogen peroxide?

Eileen: Yeah because if it’s two like… d’you know I would have thought that [Tier 1 Response D] would be one and that would be two [Tier 1 Response A].

I: Okay so that would be representing… so D would be represented just by saying H₂O₂?

Eileen: Yeah I would’ve said two. That’s what I thought.

I: Okay. And then for your… and which diagram is the best representation of the products after hydrogen peroxide decomposes? Okay so it has decomposed now and you’re looking at the products.

Eileen: I would’ve said A again to be honest.

I: A.
Eileen: I would have said a water… a water and an oxygen.
I: Okay. And why… let’s say, ah, why would you choose A and not E there?
Eileen: Am… yeah… I suppose am I just thought, in my head I thought ‘oh there’s one water, another water and there’s an oxygen’ [about Tier 2 Response A]. So I suppose here [Tier 2 Response E] I would’ve just… I would’ve thought it was just one water and that was an oxygen.
I: So this here [Tier 2 Response E] with the two oxygens and the four hydrogens… that would like one water?
Eileen: Yeah… now that I, I, now that I think like that’s an oxygen, an oxygen and a… four H’s. Now I know that is the two O’s… like I know that’s, that’s right like isn’t it? That’s… that makes more sense.
I: I’ll go through some of the answers with you afterwards but we’ll just ah… chat for the moment.
Eileen: Yeah. To me that would make sense… now that I’m thinking of it… because… hydrogen, hydrogen and… an oxygen…
I: Well I’m just asking because in the previous one… you have 2H2O2 and you chose that one [Tier 1 Response A]. So I’m just wondering down here why you didn’t say 2H2O and an O2 would look like that [Tier 2 Response E].
Eileen: Yeah… I don’t know why I… I just made it like… I was like ‘oh water, water, oxygen’.
I: Maybe are you more used to seeing water molecules? That you just know that’s the shape of them maybe?
Eileen: Yeah… yeah… I’m not sure to honest.
I: Okay. Am so Question 6 there then. So have a quick look.
Eileen: [reading question] Am…
I: Do you understand what the question was asking?
Eileen: Yeah. To show which, which picture represents that reaction. Am…
I: Is it the full reaction? The 3S, the SO2 and the 2SO3?
Eileen: It shows the results so I suppose it’s just the two S O three [2SO3]
I: Okay. So just that part of the… so it’s the product?
Eileen: So, yeah maybe I just saw 2… I took that as an S O three [SO3], an S O three [SO3], two of them.
I: Okay, and am… here what was this showing here in the little diagram [in the stem of the question]?
Eileen: Am… they were your sulphur atoms and your oxygen and… that’s reacting… like a mixture isn’t it?
I: Okay. So which part of the equation would that represent?
Eileen: Am… the starting

I: Okay so it would be the starting yeah?

Eileen: Yeah.

I: Okay and when you were deciding on the correct answer here did you just use the equation or did you use the diagram as well?

Eileen: Am… I probably just used the equations. I probably didn’t take any notice of the top of it. I, I probably just read the first bit and I, I looked at this and I saw the two SO three's [2SO₃’s].

I: And did you notice that it’s “in a closed container”? Would that have…

Eileen: No no I didn’t really notice that. No.

I: That didn’t register with you?

Eileen: No.

I: Let’s say if I had put that in bold, would that have actually changed how you answered the question?

Eileen: Yeah. Like in bold, the same here you know with ‘the results’, you know. I, when I first this and then the second time I saw the equation and I was thinking you know, the two S [2S], and I was looking at it all, whereas if I’d seen that the results was in bold, you know you ‘d just focus on your product… and the same with the closed container. Yeah I just kind of read it and I just…

I: And how would you change the answer? Or how would you change how you’d go about it if you knew that the closed container bit was somehow important?

Eileen: Am… ‘closed container’… so like if it’s, if it’s a gas… you know if it’s closed like they’d… would there be more? Am… I’m not sure to be honest.

I: But you do think... the more important bits should be in bold? Like the results or the products in bold?

Eileen: Yeah. Definitely. Because even in like questions in exams like you, you know you’re reading it fast like and when I was doing the questionnaire you know you just read it and you’re doing the question but… whereas you’d think more about it and you’d look back when you’re… when you’re trying to decide your choice and you’d look back and you’d begin and read again, you know, and think about then why is it closed and stuff.

I: Okay. Am, okay… this question here. So have a read of it.

Eileen: [reading question] That’s very confusing. I dunno, am…

I: You found this question difficult to understand is it?

Eileen: Yeah it’s just kind of a lot to kind of… take in. There’s a lot of different parts to understand. You’ve got the diagram as well so it’s just am… (I don’t know why I chose the first one)… Am… so aluminium has a greater electron… 3s2… so it went onto another energy level, am…
I: Okay.

Eileen: So what were the options then? [reading question]. Am… I’d say C or D like… it’s something to do with the nuclear, you know, another energy level… but then again if I’m looking at that, and I had never known that that one was wrong, I probably would say B again.

I: Yeah.

Eileen: Because I, I just think that… isn’t the 3p, it’s another shell. It’s another… so I said it would have been further away.

I: And if, if you were just, in your own words, to say why are some ionisation energies bigger than others… or what affects ionisation energy? So one of the things you would say is how far it is from the nucleus. Is there anything else you would say?

Eileen: The energy, the energy levels… am… no I would’ve just said ‘yeah further from the nucleus’.

I: Okay. And what effect does that have if it’s further from the nucleus?

Eileen: It would just… I don’t know, it’s… ‘why is it greater than aluminium?’ I would’ve just thought that aluminium… I dunno I would’ve thought that maybe it would… be higher if it was further or… lower energy… no. I don’t know would it be higher or lower energy the further away…

I: Okay.

Eileen: The further away… I don’t know. I would’ve just taken it like that, that, like I remember learning in school about the energy levels and like that stuck with me, whereas the nuclear charge… and things like that I don’t really… I don’t really understand.

I: Do you think that you would have understood what all of the options meant?

Eileen: No. No.

I: Okay.

Eileen: No. Like the question there, it would take me, like, a good half an hour to understand that properly and really think about all the different options… you know, like…

I: It’s a very time consuming question?

Eileen: Yeah and you really need to think about it and there’s so many, so much in each part to… to break down and kind of remember… so…

I: Okay.

Eileen: The quickest thing that would’ve came to me is that it’s… when I look at the difference, it’s another energy level so that’s probably why I would’ve said it’s further from the nucleus.

I: Okay. Okay. So the 3p is a further energy level from 3s?

Eileen: Yes.
I: Okay so Question 8 then.

Eileen: [reading question] Am… maybe I would’ve said A.

I: Okay. So is that because you can see that B is wrong or…

Eileen: No I just don’t really know why the mass would have anything to do with it. You know, I’m thinking now and I think that has nothing to do with it… because the mole like… the mole…

I: Okay so how would you define or, or explain a mole?

Eileen: When I just think the mole like I think of 6x1023, you know, so… because like… isn’t it something, am… like I remember getting questions in college and things… that you’ve to be careful is it… atoms, molecules… you have to be careful what they’re asking you… you know what type it is… or is that elements and compounds… I’m not sure. But I’d say that would’ve made more sense than… I don’t know why I said the mass.

I: So you might choose the type of particles now because you remember there being… something about that…

Eileen: I just remember in college like, or in exams like or even for the Leaving Cert. I remember like 6x1023… but I remember you have to be careful is it atoms or… I know it’s something with type… like you’ve to be careful that, you know… maybe I’m getting mixed up with elements and compounds or… number of moles or whatever but, I just remember that you’ve to be careful of the type like or something like that. So I would’ve just associated with that… not the mass. I don’t know why I put that… cause I don’t see how these…

I: And… how does, does mass relate at all to the mole?

Eileen: Am… like to get mass, if you were getting the moles of iron let’s say it’s the mass, say 12 g, over your 60 grams or 52 whatever it is, your molecular weight

I: From the Periodic Table is it?

Eileen: Yeah. So maybe at the time I thought that’s what it was. I know your formula… your mass over your molecular weight is your moles. So… I probably thought of that so I picked mass. But now when I’m talking about that now, talking about the formula, I probably would, you know when I remember the formula I probably would have picked mass.

I: Okay.

Eileen: Because it relates to the formula.

I: Okay. So… so you’re not confident about that? You maybe would have chosen A or B again if you… if you were to do again is it?

Eileen: Yeah. It’s only when you asked there ’does the mass relate to the mole’ and I remembered the formula. Then I think like maybe that’s not such a silly answer after all. Maybe that’s what I
was thinking at the time. But I just don’t see how any of them… any of those two would help anything at all.

I: So C or D is it?

Eileen: No I wouldn’t have said those at all.

I: Okay.

Eileen: That’d have nothing to do with it.

I: Okay. Am… Question 9. So carbon atoms each contain 6 electrons. What mass of carbon contains a mole of electrons?

Eileen: “What mass contains a mole”, like one mole? The mass of carbon is 12 grams. So… ‘contains one mole’ so the answer would be 12.

I: Okay. So you would chose 12 grams. So 12 grams is one mole of carbon?

Eileen: Yeah. Cause if that had said contain one mole… I just remember, you know, if they had said one mole… I would have said like one mole… See I don’t know how much carbon it is, you know. ‘What mass of carbon contains one mole?’ I would’ve said 12. I don’t think the 6 electrons would have anything to do with it.

I: Okay. So if you were… if I were to ask you to give me some examples… If you were in school and teaching about the mole, what kind of examples would you use if you were talking about the mole? So, like, a mole of carbon might be one example you would give. Are there other examples that you would use that you can think of?

Eileen: Like, as in different elements like.

I: Okay.

Eileen: Like one mole of oxygen… 16 grams like, you know.

I: Okay.

Eileen: I’d just say different elements. Like I would just learn… I know in my head like, well like a lot of them… Iron 52 and am… sodium 23. I just know like some of them the weight of them like.

I: And am, would you ever have, let’s say, a mole of water? Could you have a mole of water?

Eileen: Am… I know water is 18 grams, am…

I: So the molecular weight of water is 18 grams

Eileen: Yeah. So if you wanted a mole of it, would you have to find out the mass then, like, I don’t know I’m kind of getting confused. Would be like, one mole, ‘what mass of carbon is one mole?’. I just know that carbon is 12 so… a mole is 6x1023 as well…
I: I’m just wondering can you have… so you would give examples of elements in the Periodic Table. I’m just wondering is it possible do you think to have a mole of… ammonia? Or a mole of some molecule, or a mole of… can you have a mole of things other than elements?

Eileen: Am… see I’m kind of like, I would have automatically said yeah because you can work out the molecular weight but now I’m kind of thinking… No I’d say you’d… I know you can work out the molecular weight but… I don’t know then is that one mole. Say water is 18 grams, I don’t know is that one mole of water. Do you know…

I: So is it that you could have a mole of water and you’re maybe thinking that you can have a mole of water because you can find out the molecular weight?

Eileen: Yeah. You can find out the molecular weight of it yeah. Yeah.

I: Okay. So Question 10 there. Consider the following generic chemical equation. How many moles of B would you need to react completely with 5 moles of A?... Okay so how did you do this question?

Eileen: “5 moles of A”… so I would’ve said… am… how did I do this question? ‘How many moles of B would you need to react with 5 moles of A?’ So, like, would you get a common denominator, like,… 3 and 2… [laughs] That’s the one I got right then and I don’t know how I got it right!

I: Well suppose I changed the number. Suppose I said how many moles of B would you need to react completely with 6 moles of A? So if I said it was 6 moles of A instead.

Eileen: 3,2… 4 B I would’ve said.

I: Okay so would’ve said…

Eileen: I would’ve said 4,3… it was 6… so I would’ve said 3 into 6 is 2 and multiply that [B] by 2 is 4.

I: Okay.

Eileen: So 3 into… 3 into 5, whatever that was…

I: Yeah.

Eileen: And then multiply it by 2. And is that… I must’ve had a calculator or something. There’s no way that I worked that out in my head.

I: Okay. Am… so Question 11 there if you want to have a read of it.

Eileen: Am… [reading question]… “exactly 1 gram of vinegar and 1 gram of sugar”… Am, yeah I would’ve said no again like.

I: Yeah. Okay and why? Is it the same reason?

Eileen: Yeah because, d’you know, there’s… more than double in… double the number of atoms, like, carbon, hydrogen and oxygen.

I: Okay so is it just double?
Eileen: 2 into 6 is 3… Yeah. Is it? No it’s not double it’s, it’s 3 times isn’t it?
I: Okay. So three times the number of atoms in sugar here?
Eileen: Yeah. So… “would you have the same number of atoms in each sample?” No I would’ve said no. I just would’ve said… because there is three times more, like, so…
I: So is… if I had one gram of each. Would I have… what I’m understanding from your saying is so I’d have one gram of each so I’d have the same number of each. I’d have the same number of vinegar as I would have of sugar? But there’s three times more atoms in one of them.
Eileen: You’d have, like, the same mass of each but would you have the same number of atoms… in each sample? Like, what I would get from that is that, that’s an atom of… two atoms of carbon and that’s six so you wouldn’t have the same.
I: Okay.
Eileen: Because there’s more atoms in sugar than vinegar.
I: Okay. But in my one gram though I will have the same number of molecules of that [vinegar] as I will have of that [sugar]? But the problem is really that this has three times more atoms?
Eileen: Yeah.
I: Is that right?
Eileen: Yeah.
I: So let’s say in vinegar I will have… a hundred of these [vinegar molecules]…
Eileen: Yeah.
I: And in one gram of sugar I will have a hundred of those [sugar molecules]? Is that…
Eileen: I don’t know to be honest now. I find that very confusing now. I don’t know to be honest. I just would’ve said the same kind of answer like.
I: Yeah. So just the fact that they’re different?
Eileen: Yeah that you can just see, like, that it’s three times more that I just… to me I just… like I don’t… just thinking about the mass there… ignoring that now I’m just think do you have the same number? I don’t think so no.
I: Okay. So you pretty much just looked at one of each and you said ‘well no it can’t be the same number because there’s three times as many’.
Eileen: I just looked at the number. Yeah and then when I see that it’s the same number [the mass] I say ‘no because it [sugar] has more’.
I: Okay.
Eileen: That’s what I would say.
I: Am… okay so I’m going to skip over a few because we’re, am… I’m just wondering there for Question 13. ‘Which of the following best represents the ionic compound sodium chloride’?
Eileen: Am… no I probably would have said, maybe… the crystalline, I remember crystalline is am…
I: So you’re saying you wouldn’t choose E now?
Eileen: Am… no.
I: What’s wrong with E that you wouldn’t choose it?
Eileen: I don’t know. It doesn’t really make sense. I don’t know why I picked it like that. Like, I probably would have…
I: What’s wrong with it?
Eileen: … it’s just like a block like. I don’t know. Like, it’s ionic it’s not…
I: So maybe B has the 3D is it?
Eileen: Yeah… like… does it best represent it? Covalent is sharing, ionic is opposite attraction so… I can’t remember is that ionic?
I: D?
Eileen: Yeah… That’s sharing though isn’t it so… A or B I would’ve said.
I: Okay. Am… just down here, 14… “which of the following best represents the position of the shared electron pair in the HF molecule?” Okay so did you understand what was being represented here in each of these three options?
Eileen: Yeah I… well… the two… like that’s a pair. No I don’t really understand it.
I: So the two dots there you were saying…
Eileen: Yeah it’s an electron pair is it?
I: Okay so that’s the pair. So you…
Eileen: I picked B because it said ‘shared pair’… so I just said it was in between them. I just said… shared…
I: Okay.
Eileen: Obviously that was wrong.
I: Okay and then you chose Option B as the reason.
Eileen: I would just associated because it’s covalent… it’s shared so covalent…
I: Yeah.
Eileen: So I just associated shared with covalent and I just…
I: Okay. So maybe it’s the only one that mentioned a covalent bond?
Eileen: Yeah. Because the answers are so detailed that I probably… do you know sometimes you just… you associate shared with covalent so I said that, that… there’s a strong chance of that being the answer even though it wasn’t but I just, do you know you just associate a word with and you just… go with it.
I: Okay, am… ah Question 17 there… you never attempted it.

Eileen: Oh God. I just find that… I find graphs am… very hard to understand. Like… even, even in lecture notes and stuff there would’ve been graphs and maybe saying it shows this and that and I’m… I just find them very… I just don’t even remember they being explained well to me in school and I still kind of… to this day I still find them very hard to understand.

I: So, maybe you didn’t answer this question is it because you kind of saw a graph and you just feel you can’t interpret them.

Eileen: Yeah when I read it and I just saw a graph… If I answered it I would’ve made a complete random guess whereas the others I kind of put thought into them and tried to figure them out or something but…

I: Okay. Am… can I just ask you there about Question, am for Question 18 there you didn’t attempt that either.

Eileen: I don’t really understand equilibrium. I don’t understand the… like, like, why is it K like?

I: Okay. So you don’t know what the K was basically?

Eileen: Yeah.

I: So if I had said which of the following must be the equilibrium constant of this?

Eileen: Oh yeah equilibrium constant… yeah like it’s K like. I know what the signs mean but… I don’t know, I didn’t know what K is like that it was the equilibrium constant, like I didn’t know. I just saw K and I said that… like it didn’t mention anything about it in the question like so… I don’t know what K is. I don’t know how to figure… is it equal I don’t know.

I: Yeah.

Eileen: So I just didn’t know what that meant.

I: Am… for Question 19 there. Did you find that an okay question? Did you understand?

Eileen: No. Isomers like…

I: The content is it? You didn’t know what an isomer was?

Eileen: Yeah like I know it’s something… that can be the same… something with the same… you could have different forms of it… or something. I’ve a very vague understanding of it d’you know.

I: So you know it’s something to do with sameness is what you’re saying?

Eileen: Yeah. Is it like different forms, like different… is it the same?... I don’t know if that’s the right word ‘the same’… molecules, element, whatever… but different forms of it.

I: Okay.

Eileen: I don’t know I’d say like Nitrogen like, different structure forms of it… but it’s the one, it’s the one elements or whatever I don’t know… I just have a very vague understanding, like. You see, like, I suppose we were in the middle of doing our chemistry, like, that I… I probably hadn’t
remembered isomers from… I don’t know did we do it in that module or whatever… but a lot of
the stuff that I learned was in Leaving Cert. and I kind of forget… because that’s the whole thing
that you just forget it, like. I don’t know…
I: Okay. So let’s say… you did chose B and C as isomers. Would you have any idea why B and C
were isomers and not, maybe, A and B or A and C or whatever?
Eileen: Am… do you know to be honest I just saw CH3 CH3 because, like, they look more alike…
like just to look at them straight away
I: Yeah. But this end here is a lot more alike than let’s say
Eileen: Like you know that CH3 and CH2 whatever… but the actual…
I: Is it because this is branched maybe? Is that…
Eileen: Yeah like… am… when I don’t know what the HC is about like. Is that CH3? I don’t know
is that CH3 or… I’m not sure, I just look at it and I just… I just think that looks way different to
the two of them.
I: Okay.
Eileen: But I knew isomers was something the same so I, I just picked the two of them but
obviously…
I: Okay. Okay. Am… so this one here. “Two students come up with different Lewis structures for
N2H4”. So we have Student X comes up with this one and Student Y comes up with that one.
So… which is the correct answer and why? So you chose Y as being correct.
Eileen: Yeah I woud’ve said Y. I’d still say Y is correct.
I: Okay and why would Y be correct… and X incorrect?
Eileen: I always just know… I always remember Nitrogen forming a triple bond. I remember seeing
it and there’s always, you know, NH3. There’s always three. So I would’ve just said… I don’t
remember ever seeing Nitrogen formed like that.
I: With the two… lone pairs.
Eileen: With the lone pairs and the single bond. I always… remember it, anytime I remember…
seeing Nitrogen it’s in a triple bond so… I just remember triple bond, Nitrogen. I just associate it
with that. So that’s why I picked…
I: Okay. Oh and that’s why you chose “Nitrogen forms triple bonds if possible”.
Eileen: Yeah. Do you know when you just associate… in questionnaires like this you just, you
know, I just know Nitrogen, triple bonds, and then I saw a question that kind of, or an answer
that… you know was similar to it I just went with that because the rest don’t really…
I: Okay. So, am, I might just ask you… have you heard about chemistry misconceptions before I
did that test?
Eileen: No.

I: You’d never heard about it anywhere?

Eileen: No.

I: And would you, would you feel, you know, that you might try and find out… Let’s say when you go teaching, would you try to find out anything about those kind of ideas maybe that your students might have or do you think that it matters that they have…

Eileen: It definitely matters that they… d’you know if you, like after doing this like I… there’s a lot of chemistry that I know I don’t know but… like, you, it would be good to give them a kind of test to see… like you know an overall kind of… like the basic parts that they mightn’t even understand. D’you know if I was given that, like, in school, like, our teacher could’ve gone back over the basic things with us like d’you know. I just like, because there’s a lot of the basics, that’s what it is like. Even now, even with our modules now, like, we’re just learning it to pass our exams and… I don’t have a clue of the basics. Like if I was given a, like we were even saying this not so long ago me and my friends, like if we were given a, a basic reaction to balance… we would still struggle at it and probably wouldn’t get it right. Like we’re going to be qualified in a few months like.

I: Yeah. Yeah.

Eileen: D’you know it’s mad. I just don’t think… I don’t know it’s just the basics. I definitely think it’s down to the basics that they weren’t taught right.

I: And is there anything else that you want to say about the whole thing?

Eileen: Like, sorry, I’m probably not…

I: No no not at all.

Eileen: I find it very hard to explain… explain myself and the, the fact that I, the test was like a year ago that I just, I can’t remember. The questions are very… detailed, like they take a lot of probably… you probably would’ve done better in it… if we were given more time. You know we were in the lecture and we were… doing it and we were… we probably weren’t really thinking. We probably answered the first two questions thinking about it, but as time went on, you know you’d use energy. Because I gave out questionnaires to my students on Teaching Practice for my FYP and like you could see them focusing on the first few questions but as time went on then they were just ticking anything you know. It’s a very long questionnaire so… you know you might lose interest in going on with it because it takes an awful lot out of you to… a lot of focus with you you know it’s not just a simple, a simple like, I know they’re multiple choice but there’s so much thinking involved in them it’s very…
I: I know. Just as you’re talking there I see pointing at Question 20. Do you think there’s too much writing in that question?

Eileen: Yeah. Yeah. Like even when we went back to that question there and I saw Lewis structure and I was thinking ‘Lewis structure, do I remember that?’… and then it was like Student X and Student Y and it was a bit confusing like. There’s just an awful lot to take in in it. I know the answers are kind of okay… but there’s a lot in it.

I: Yeah. Okay.

Eileen: You know maybe there’s too much writing in that [the stem] that you kind of read it and you go… ‘woah’ d’you know.

I: Yeah.

Eileen: Trying to figure out… like a lot of these questions, I kinda, there’s different parts to them and you see a word and like ‘I don’t remember that’ and you’re trying to think back to ‘what’s that about again’ and… the different parts so d’you know it’s just…

I: Yeah. Yeah. Okay. Thank you very much!

Eileen: No problem.

**SEMI-STRUCTURED INTERVIEW WITH PATRICIA**

I: Am, okay. So just some of the concepts that were in the test instrument, I’ve written down a few of them there [gives list to PSST]. So like moles, properties of atoms, compounds, elements and mixtures, meaning of chemical equations, ionisation energy, equilibrium, all those. Do you... would you feel confident teaching those at school?

Patricia: Definitely not, no.

I: None of them?

Patricia: No. No. I’ve taught Junior Certificate chemistry the two times I was on Teaching Practice and... I’d always have to read up before going into class a lot.

I: Yeah, but if you had read up?

Patricia: Oh if I had read up yeah I would... for Junior Cert.

I: You’d feel that you understood it or would you feel that...

Patricia: No that I understood it, understood it enough to teach.

I: So, like, would you be confident to take questions and that from students?

Patricia: Yeah... yeah.

I: And on all topics?

Patricia: Ah... well... not the mole. It's not in Junior Cert. I haven't... ah... got my head around that myself. I wouldn't want to go into the class without knowing... what was going on... and that's obviously something major I have to look at if I was thinking of chemistry.
I: Yeah. And... just you have BSc. ed. down there [on the instrument] is it... with...
Patricia: With chemistry.
I: With chemistry.
Patricia: Yeah.
I: Right. Okay.
I: Am, so what did you think of the test instrument?
Patricia: Ah... I found it difficult.
I: Difficult?
Patricia: Yeah.
I: Am... just
Patricia: I know myself that my, am, basic chemistry is diabolical and ... like, I usually get A's in college chemistry and stuff, but it's just that is' not...
I: Yeah. But you don't feel really that you understand it?
Patricia: Oh I don't. I know I don't understand it yeah.
I: Am... just... some of the questions, let's say, you the way some of them are kind of picture pictures, so like, Question 3 there, 5, 6... and then other's, like let's say 4, you know it's just the words... and we'll say a lot of those one's there are just kind of the words. Did you find that you perferred one type or is, is, the language or the picture questions... is one more difficult, or... you know, did you find any difference between the two?
Patricia: I... think it's hard to say. Am... it depends on the question. I suppose for them picture ones, when you're being asked about the pure substance and that yeah the pictures make a big difference there.
I: And did they... did you find that a difficult one, one of the more difficult or an average enough kind of question on the...
Patricia: Well, I found them all fairly difficult.
I: Yeah... but you found having those in front of you... made it clear is it?
Patricia: Yeah. Yeah... for the pure substance anyway. (laughs).
I: Yeah. Okay. Am... oh yes so you... I was going to ask you did you feel it had exposed areas in chemistry that you didn't understand.
Patricia: Yeah.
I: But obviously from what you've said I take it that you...
Patricia: I knew already that there were a lot of areas.
I: Yeah. Yeah.
Patricia: I knew there were a lot of areas. Yeah.
I: Okay.
I: So, just what I'm going to do is go through some of the questions. So I'm going to ask you, like, what do you think it means, you know how did you take it up. So we'll say for Question 1 there. So you didn't attempt Question 1. So...
Patricia: [reading question] Oh, D.
I: Okay so you'd choose D now?
Patricia: Yeah.
I: And do you feel you understand this... do you understand what's being asked of you? I don't mean the content. I mean did you understand what the question is that I'm asking?
Patricia: Yeah.
I: Okay so you would choose D for that. Why would you choose D for that one?
Patricia: Because... all atoms are the same of the same element. Am... they'll all be identical when they're of the same thing.
I: Yeah.
Patricia: So all of the properties should be the same.
I: Okay.
I: Question 2 here... am... Is there anything that you would change let's say about this first part here that you answered where I'm asking about the states of matter?
Patricia: Gas is right.
I: Did you... I just, I notice that you put down one answer for solid, one for liquid, one for gas and the same the whole way down. I'm just wondering did you realise that from this part here [the stem of the question] that I was asking you to put each of these [the Diagrams] into a category? So you could have had more than one solid....
Patricia: Oh right
I: You didn't realise that?
Patricia: No.
I: Even when you went back and read over it there?
Patricia: No.
I: Okay.
I: So am
Patricia: So A and C would be a solid. B... and E are a gas and D is a liquid? Would that be it?
I: Okay so that's how you would do it?
Patricia: Yeah.
I: Okay
I: And am... for down here so, we have pure substance, heterogeneous mixture, homogeneous mixture.
Patricia: Yeah
I: Am, so why did you choose, ah let's say, E as a homogeneous mixture? Why did you decide that E was a homogeneous mixture?
Patricia: 'cause each individual one is the same.
I: Yeah
Patricia: Let's say... that's a water molecule, a water molecule and a water molecule.
I: Mhm
Patricia: So they're all the same.
I: Okay. So they're all the same. So that's you're homogeneous mixture?
Patricia: Yeeah.
I: Okay so...
Patria: It's not really a mixture though... hmmm...
I: So how would you define, or describe, a mixture, let's say?
Patricia: Two... elements, compounds or molecules... that aren't chemically combined. They're just... they can't be separated... ah, without chemical means.
I: Okay. So, am, what would you pick as mixtures there... out of all of them?
Patricia: Am... that's [Diagram D] a mixture but it's a heterogeneous mixture.
I: So that's D, okay. (pause) And why is that heterogeneous?
Patricia: 'cause the... diamond is different from the circles.
I: Okay. So there's two different things in it?
Patricia: Yeah.
I: Is there another one you'd choose as a mixture?
Patricia: This one here [Diagram A] I suppose.
I: So A?
Patricia: Yeah.
I: And what kind of a mixture would you say...
Patricia: That's heterogeneous as well.
I: Okay, and why is that one heterogeneous?
Patricia: Because there's four... three different types of... things in it.
I: Okay so would you, can you, am... I'll come back to A in a minute. Am... is there another one you'd choose as a mixture?
Patricia: ...
I: Okay well what would choose as a pure substance?

Patricia: C

I: C. And C is pure why?

Patricia: Because it's only triangles (laughs).

I: Okay.

I: And if you had to put B into one?

Patricia: I don't know, am... B is a mixture as well.

I: And what kind of a mixture would you call B?

Patricia: Hetero as well.

I: Okay. And that's heterogeneous because...

Patricia: E is a pure substance.

I: Okay so E a pure substance... and C is a pure substance?

Patricia: Yeah.

I: Okay and why is E a pure substance?

Patricia: 'cause it only has one molecule.

I: So it has one molecule?

Patricia: Yeah

I: And C

Patricia: C is the same molecule.

I: Yeah okay. And D you're saying is...

Patricia: Am... mixture.

I: Mixture. Okay and what kind of a mixture do you think it is?

Patricia: A heterogeneous mixture.

I: Heterogeneous. And you're saying A is heterogeneous and you're saying B is heterogeneous. Is that right?

Patricia: ... Yes

I: Okay so what then is the difference between a heterogeneous and a homogeneous mixture?

Patricia: Heterogeneous has two different types of molecules. Homogeneous only has one. There's no such thing as a homogeneous mixture then is there?

I: So... is a homogeneous mixture then the same thing as a pure substance?

Patricia: ... Yeah.

I: Okay. Okay.

I: And ah... down here then. So we have our... am, composition of matter. So elements, compounds or element and compound. Did you know what I was asking you for there?
Patricia: Am... yeah.

I: So you've given A there as an element and a compound. Could you show me why that's an element and a compound?

Patricia: Because the squares are element and the diamond circle is compound.

I: Okay yeah. So it was obvious that these two (the diamond and circle) were joined together as a compound?

Patricia: Yeah.

I: Okay. And you have E as a compound as well... you already described that. Okay.

I: So am, Question 3... you didn’t attempt Question 3. So if you just have a look at it there.

Patricia: [reading question] B?

I: Okay. So you would choose B now. So, I'm just going to ask you, let’s say, what do you… so what’s showing here in my first little picture there?

Patricia: A molecule of ammonia. Hmmm. Sorry A I’d choose A.

I: Okay. So what’s your understanding of here of what I’m what I’m looking for?

Patricia: The gas. It’ll be the same thing, it’s just a gas so it’ll be more spread out. The molecule won’t actually have changed.

I: Okay so you understood this here [pointing at stem].

Patricia: Yeah.

I: So this is the molecules in liquid. It's been evaporated so it’s what you would ‘see’ in here [point at circle in diagram] yeah?

Patricia: Yeah.

I: So you would choose A now?

Patricia: Yeah.

I: So what would you say B is?

Patricia: B is just the same thing [pointing at stem diagram].

I: Okay and what would C be?

Patricia: C is the nitrogen and hydrogen separated.

I: Okay. And D and E?

Patricia: They’re just different compounds. They’re N-two [N2] and H-two [H2].

I: Okay. Am, your Question 4. So if you have a quick read of it there.

Patricia: [reading question] It should still be 27 grams.

I: Okay and why do you think it should still be 27 grams?

Patricia: ‘cause it can’t go anywhere. It’s a sealed chamber.

I: Okay so what reasoning would you choose for that?
Patricia: Am… [reading options] ‘mass is conserved’.
I: Okay and why that one?
Patricia: Am… the conservation law of mass?
I: So it rings a bell with the conservation law?
Patricia: Yeah.
I: Okay so… Question 5… if you have a look?
Patricia: [reading question] Am… I’d still go with B there.
I: Mmhm. Okay so what is the first part mean… what am I looking for there? For you to tell me…
Patricia: Am… just the structure of hydrogen peroxide.
I: Okay… and why choose this one, B, and not D?
Patricia: Am… Oh because it’s 2 [points at equation].
I: Okay so from your formula you know that it’s \(2\text{H}_2\text{O}_2\)?
Patricia: Yeah
I: Okay.
I: So you’re second part there then?
Patricia: [reading question] Am… it splits up into 2 water and oxygen… oh I should have actually put A.
I: Okay. So… it's a long time ago of course, you probably don't remember why you picked B?
Patricia: No.
I: So do you think this question… is it clear?
Patricia: Yeah
I: Is there anything that you would change about it maybe to make it…
Patricia: Am… no. I obviously didn't get the 2 bit at all then. It was just luck that I put B the first time.
I: Yeah, yeah. Okay
I: Am… so Question 6 here then… if you have a look at that one.
Patricia: [reading question] Am… I'd change it to this one C.
I: So you'd go for C now instead of B?
Patricia: Yeah
I: Okay and why? Or what process did you go through to come up with your answer there?
Patricia: Just looking for this… one sulphur and three oxygen's
I: Mmm
Patricia:... and it completely reacts... and all of them are fully formed.
I: Okay and am... would you... is the diagram up here... is there any information from that or is, is it helpful at all?

Patricia: Am... I actually find that less helpful.

I: If I had highlighted here that it was in a closed container... would it have made any difference to how you went about answering that question?

Patricia: Maybe

I: How would that make a difference?

Patricia: Because... they can't go anywhere. I know they can't go anywhere so I have to have this exact amount of pieces in my answer.

I: Okay so would you still choose C then?

Patricia: Am... I don't have enough oxygen's, I've too many oxygen's in C... so then, it'd have to be D [counting] Yeah D.

I: So do you think if that had been in bold or underlined or something do you think maybe you would have

Patricia: Yeah definitely. I'd be looking at that as the important bit completely and then I'd pick D because they're all... I know it says 'as possible' but...

I: So that word has gotten you 'completely'

Patricia: Yeah

I: Okay

Okay. Am.. Okay Question 7...

Patricia: [reading]... am... full shell... I'd still go with B.

I: Okay. So you’d still go with B. Am... first of all, do you think the question... is it clear?

Patricia: It’s fine

I: And all your options, are they all clear? You don’t... they’re easy to understand are they?

Patricia: Am... yeah they’re all fine.

I: Yeah. Okay. So you’d choose B there. So just to find out... if I was just to ask you about ionisation energies and what they depend on. Let’s say if you were just to tell me yourself.

Patricia: Am... I’m not sure. It’s how easy the... the electron can be removed... from the outer shell.

I: Yeah. And what makes it easier for an electron to be removed?

Patricia: If there’s, ah... am, if it’s further away from the positive charge of the nucleus... and... am... it depends on how big the charge of the nucleus is. I think there was another reason but I don’t know what it is.
I: Okay. So those are the main ones?

Patricia: Yeah.

I: Okay. And, am, none of these other options would have... would you have considered any other option?

Patricia: Am... [reading options] Yeah I would consider that one [points to Response A].

I: You would have considered A as well?

Patricia: Am... [reading option again]. Yeah I would consider that. Because it’s... the 3s orbital is more stable. [Reading Response C out loud] ‘The effect of an increase in nuclear charge in aluminium is greater than the repulsion between the electrons in its outermost shell’. Am... I don’t really know.

I: As in... do you know what

Patricia: I find it hard to get my head around. Am... ‘effect of an increase in nuclear charge’. It’s not the way it’s worded it’s just the concept of it.

I: Yeah

Patricia: ‘Effect of an increase in nuclear charge in aluminium’... yeah.... No I still don’t know what that is really.

I: Yeah. So this question... did it take you time to try and figure out what the options meant?

Patricia: Oh yeah! Yeah, yeah. [reading Response out loud] ‘The effect of the increase in nuclear charge is aluminium is less than...’. That’s the same thing again. I dunno [laughs]. [reading Response aloud] ‘The paired of electrons in the 3s orbital of Magnesium experience repulsion from each other, whereas 3p electron in aluminium is unpaired’. I don’t really know if that affects it either.

I: Okay. Okay. Question 8 there.

Patricia: [reading question] I still think them two are wrong [pointing at Responses C and D].

I: So you think definitely not C or D?

Patricia: C and D no. Am... affects the number of particles in a mole. Oh sorry. Not the, none of the above.

I: Okay.

Patricia: Ah... that’s Avogadro’s number and it doesn’t change.

I: Okay. So you wouldn’t choose either A or B?

Patricia: No. No.

I: Okay and so, what is a mole? If I were to ask you...
Patricia: Ah… six by ten to the twenty-three… particles… or anything.

I: Okay. So could you give some examples of what anything could be?

Patricia: Am… an element, a molecule… a compound.

I: Yeah. Okay. Okay. And… is there a relationship between the mole and mass?

Patricia: Yeah.

I: Okay.

Patricia: Am… there is a relationship between the mole, mass and the molecular weight.

I: Okay.

Patricia: And… I dunno [laughs]

I: [laughs] you’re under pressure

Patricia: Am… [starts writing on a sheet]

I: You’re writing a formula here are you?

Patricia: Yeah.

I: Okay so you know there is some relationship but

Patricia: The mole equal mass divided by molecular weight.

I: Okay.

Patricia: Yeah I’m not really able to put it into words for you.


Patricia: [reading question] Am… I’d still go with twelve grams there.

I: Okay. And why? Do you feel, first of all, that you understood the question?

Patricia: The question is fine.

I: Am… why twelve grams?

Patricia: Am… [reading question aloud] ‘what mass of carbon contains a mole of electrons’… a mole of electrons. Am… twelve is the molecular weight of carbon… twelve grams is the molecular weight of carbon and… ah… [laughs] I did say this was my weak spot didn’t I? Am… oh God, I don’t know. I just think it is.

I: Okay so you mean like on the Periodic Table is it?

Patricia: Yeah. Twelve is the molecular mass. So… ‘what mass of carbon contains a mole…’ Am… yeah. There’s a mole of… twelve grams equals one mole.

I: Okay. And that’s where that comes from here.

Patricia: That’s where that comes from [points at questions]. I can’t even think now is it right or wrong.

I: Okay.

I: Am. Okay. So your Question 10 here. So you had your chemical reaction?
Patricia: Yeah.

I: And [reading question aloud] ‘how many moles of B would you need to react completely with 5 moles of A’.

Patricia: Am… [reading question]… I dunno… one point five [1.5] because it’s three divided by two. Am…

I: So three divided by two because it’s three-A [3A] plus two-B [2B]?  
Patricia: Yeah. Am… no… if I have…

I: If I change the question a little bit. If I changed it to say ‘how many moles of B would you need to react with six moles of A’?

Patricia:… am, how many…

I: How many moles of B, if you had six moles of A?

Patricia: Yeah. Then it’s just… three.

I: Okay. Because it’s six divided by two instead of three and two?

Patricia: Yeah.

I: Okay. Am, so five you don’t feel is right now do you not?

Patricia: No. This is wrong [laughs]

I: [laughs]. Okay so Question 11. Have a quick read.

Patricia: Am… [reading question]… Am… one gram. I think I’ll stick with my same answer there.

I: Okay.

Patricia: Because it was a gram. If you had one mole, you’d just have the same number of atoms but because it’s a gram you’d have a different number of atoms.

I: Okay. So if I had said that you have one mole of vinegar and one of sugar, would you have the same number of atoms in each?

Patricia: Atoms… no I’d still have a different number, because these are compounds.

I: Okay. [laughs] I’m starting to feel like giving you a hug. Stop stressing out so much! [laughs]

Patricia: [laughs] oh God!

I: Okay. So for our one gram of vinegar and one gram of sugar.

Patricia: Yeah.

I: Can you explain to me why you say ‘no they don’t have the same number of atoms’?

Patricia: ‘cause they’re… they’ve different… ah… No. They’re different so they’re going to have a different number of atoms!

I: Okay. Let’s… supposing that I could count out… so I’ve one gram of sugar and one gram of vinegar… I could count out the number of vinegar molecules and the number of sugar molecules.

Patricia: Yeah.
I: In one gram, would there be the same number of vinegar and the same number of sugar molecules?
Patricia: Mmm… they’d be different.
I: And how would they be a different number?
Patricia: Because… they’re a different molecular weight. So… it could take more or less to make up the one gram.
I: Okay so which one would take more and which one would take less?
Patricia: Whichever one has the highest… vinegar. Or no sugar.
I: So sugar will take…
Patricia: Am… less molecules to make up the one gram.
I: Okay so fewer molecules to make up one gram and vinegar would take more?
Patricia: Yeah.
I: Could you estimate how many more?
Patricia:… three times more.
I: Three times more. Okay so you’ll have three times more vinegar molecules than you would have sugar molecules?
Patricia: Yeah.
I: Okay. I’m gonna skip down through one or two. Am… just here for Question 15?
Patricia: Yeah. [reading question] A and C are responsible. Umm… no… [reading question aloud] ‘heat is given off when hydrogen burns in air’… so I am… A, B and C.
I: Okay so you’d go for Option E?
Patricia: Yeah. Yeah because you’re breaking and forming.
I: So why do you feel that D is wrong?
Patricia: Because C is ‘forming hydrogen to oxygen bonds’. Oh sorry. Hang on now. Does forming hydrogen to oxygen bonds give off energy? Yeah it does yeah.
I: Okay. And breaking
Patricia: No, no, no, no, no. Forming bonds takes in energy. Yeah I was right the first time with A and B.
I: Okay. And did you feel you understood the question?
Patricia: Yes.
I: Okay.
I: Am… Question 16 there?
Patricia: [reading question]… am… that’s not true [pointing at Response A] because that’s ionic [pointing at sodium hydroxide] and that’s [pointing at water] hydrogen bonding. Ah…
I: So that’s… A isn’t right?
Patricia: Yeah. [Reading question aloud] ‘This is due to the difference in the strengths of the bonds in sodium hydroxide and in the force of attraction between… the molecules in water’. Yeah… well… that is true I suppose. There is a difference in strength… in the bonds of sodium hydroxide and in the force of attraction between molecules of water. [Reading question aloud] ‘The boiling point in sodium hydroxide is higher because it is a solid and water is a liquid’. That shouldn’t really have anything to do with it. [Reading question aloud] ‘sodium hydroxide is made up of a metallic element and this causes an increase in the boiling point’. [Reading question aloud] ‘ionic bonding is always stronger than covalent bonding’. I dunno. B is right. I still think E is right.

I: Okay and do you think the question is clear?

Patricia: Yeah. Is there only one right answer?

I: Yeah.

Patricia: Ah… we can talk about it again at the end.

I: But did you understand the question or did you find it hard to…

Patricia: I understood it yeah. It’s hard when you get a question that one is more right than the other. Maybe it should be to put them in order of preference what you think is most right or something, I dunno.

I: Okay. I’m just gonna skip down. Am… Question 18. Just wondering… why didn’t you attempt that one?

Patricia: [reading question] Am… I don’t know it. I’m not great at equilibrium.

I: Do you know what K is?

Patricia: It’s the equilibrium constant.

I: Okay. So what you’re saying is that it just would have been a guess?

Patricia: Yeah.

I: Okay. I’ll just give you one last one - Question 20.

Patricia: [reading question] am… oh God I can remember doing this one. The reason I went for E there is because I didn’t think any of the rest of them were wrong.

I: Oh so you didn’t think Y was incorrect. So you just said that one or the other could be true?

Patricia: Yeah.

I: Okay. Do you think… is there any way you’d improve that question?

Patricia: Am… no.

I: Do you think it helped to have… let’s say I have the pictures here but I also have a description up here so [reading question aloud] ‘Student X placed a single bond between the centre’. Do you think that that helped?

Patricia: I actually don’t think that helps at all.
I: So if I took out that [the start of the description] would I leave all other stuff about either structure? Do you think it’s necessary?

Patrícia: No I don’t think the student thing is necessary.

I: Okay. So if I just said ‘two students come up with different structures’ and I have them [the structures] there? Would that improve it?

Patrícia: It’s just the fact that it’s so long.

I: Yeah. There’s a lot reading there.

Patrícia: Yeah. I don’t like reading.

I: Okay. Am… oh yes. I was wondering have you heard of chemistry misconceptions before you did that [points at the instrument]?

Patrícia: That it’s a thing? No.

I: You hadn’t heard anything about it before hand?

Patrícia: I know there are chemistry misconceptions.

I: Yeah. You knew that before this?

I: Did you? Like that it’s an actual problem, it’s not just that people haven’t learned stuff or don’t understand it or

Patrícia: Oh well I would have known it’s an actual problem yeah.

I: Yeah. Okay. And, ah, let’s say when you go out teaching, would you… do you think it’s important to, let’s say, maybe you’ve a question, like one or two questions to get students to answer them maybe and fine out

Patrícia: Yeah.

I: Do you feel confident to find out what students actually think… what their misconceptions are? And then try and address them?

Patrícia: After that [pointing at instrument] I don’t know [laughs]. I don’t know what my misconceptions are so yeah you definitely should try and address them. Am… clearly something that was never done for me [laughs].

I: [laughs] Is there anything else you want to say about the instrument?

Patrícia: No.

I: Well thanks a million for doing this.

_SEMI-STRUCTURED INTERVIEW WITH NORA_

I: Okay. So you're doing... biological sciences is it?

Nora: Yeah.

I: And is it with the chemistry elective or...

Nora: Yeah, with chemistry yeah.
I: With chemistry.

Nora: Yeah.

I: Am, just I wrote down there [gives list to PSST] some of the concepts that, just that were in the test. So like the mole, properties of atoms, compounds, elements and mixtures, meaning of chemical equations, ionisation energy, chemical equilibrium, all those. Would you feel confident to teach those in a classroom?

Nora: Not all of them no.

I: Which ones would you feel confident and the ones that you feel you particularly confident about?

Nora: Am... atoms, compounds and elements, the mole, mixtures. Those things I'd be fairly confident about doing. But when it comes to ionisation energies, it's a step up kind of.

I: Yeah.

Nora: I'd kind of be a little, a little less confident doing those.

I: Yeah. And, am, what about chemical equilibrium... would that be...?

Nora: Equilibrium I think I'd be okay with teaching.

I: Yeah.

Nora: Just cause there's a good few, like, examples you can give you know. It makes it easier.

I: Yeah. Okay.

I: Am... oh yeah, what did you think of the, of the instrument or...

Nora: The test?

I: Yeah. Did you find it... tough, easy, medium?

Nora: Am... I think it was kind of... medium I'd say. Like there's a lot of the concepts in it I'm familiar with... but some of the questions I wouldn't be familiar with.

I: Mmm. So, like some of the questions there, d'you know like Question 3,5, Question 6, are based on d'you know like pictures... and then I've other ones there just based on the words, d'you know, like 4, let's say, 8 there, some of these ones... did you find one more difficult, one style more difficult than the other or did you like the style of one?

Nora: I prefered the pictures.

I: You prefered the pictures?

Nora: Yeah. But that's because I struggle myself with reading.

I: Yeah.

Nora: So I do prefer the pictures.

I: Yeah.

Nora: Yeah... It's tougher kind of to imagine just from the words... d'you what I mean?
I: Yeah. Okay. And do you think, would you be used to, let's say, am, you know if you were given a chemical equation, would you normally try and visualise, let's say, what, what molecules or maybe what compounds or what...

Nora: Yeah. I would yeah.

I: So you would be kind of used to trying to imagine what's happening, let's say, at the microscopic level?

Nora: Yeah.

I: Okay.

I: Am... oh yeah, I was going to ask you do you think that, say that this [the instrument] exposed areas in chemistry that maybe you might not have understood as well as you thought?

Nora: Yeah I think so.

I: Okay. So what I’m going to do is just go through a couple of the questions just to, am you know, just to see if you interpreted them as I planned for you to interpret them. Okay? So I just want you to have a quick look at Question 1 there. So you can read through it there for a second.

Nora: [reading question] Okay.

I: Okay. Do you think you understood what that question was asking of you?

Nora: Ah, the second questions? Oh the second part? Or the first part?

I: Question 1 yeah.

Nora: Well I understand the first part anyway. It’s just looking through physical properties… and chemical ones. And the second one then, now I’d be a bit…

I: Did you think this was two questions, a Part A and a Part B?

Nora: Yeah.

I: Okay. So ‘following is a list of properties of a sample of solid sulfur’ and then there’s the list A to D. You thought you had to tick one of those did you?

Nora: Yeah. Yeah I did. But they’re all properties of sulfur aren’t they?

I: Yeah. They’re all properties of the sample of solid sulfur. So what this was, was just a list of the properties of a sample of solid sulfur.

Nora: Yeah.

I: Okay. So what about the second bit? What did you think?

Nora: Um… are they not kind of the same thing? ‘cause it’s a single atom but it still has the same… doesn’t it?

I: Okay, yeah, so here [points to the Response Options] you were being asked for the properties of a single
Nora: Yeah.
I: So you selected D there ‘all of these properties would be the same’. So that is your, am, idea that it'll be a brittle, crystalline solid; melting point blah blah; density would be the same, and combones with oxygen to form sulfur dioxide?
Nora: Yeah… some of that would be different would it? I haven’t got a clue. Sorry.
I: Okay. Would you still choose the same?
Nora: Yeah I’d still go the same… no I think I’d change it to, maybe, E.
I: So, maybe E ‘none of them’?
Nora: Yeah.
I: Okay. Okay.
I: Question 2 there... what did you think of that question?
Nora: I think it's understandable. It looks... to be okay like, am...
I: Mmhmm
Nora: I liked that kind of question... just cause of the visual aid. Am... yeah. Seems straightforward enough like.
I: Okay.
I: And, ah, why did you just am, let's say, C and D you chose as liquids. So could you explain what it is about those diagrams that...
Nora: Am, they're just not as, say, uniform....I guess that would be the word I'm looking for. They're kind of close together but they're not packed tight together. So that would kind of remind me of the, am, atoms in a liquid. They're still close together. They're all in the one area but it looks like they'd slide over each other.
I: Okay.
I: So you chose A as a solid then because...
Nora: because it, it looks to be very, am... kind of placed uniformly and it looks set and it can't move kind of.
I: Okay. And C then?
Nora: C is very like it but I dunno I think it's probably closer to a gas.
I: Okay... because of the gaps?
Nora: Yeah. I woulda thought that, am, it would slide over like a gas but... on the other hand that could just be a little air pocket.
I: Okay.
I: And, am, you chose B and E as gases then because...
Nora: Because they're so dispersed over the, the box.
I: Okay.

Nora: There doesn't seem to be anything kind of pulling them together or...

I: Okay.

I: And am, for part then here. So you had to decide if it was a pure substance, heterogeneous mixture or homogeneous mixture. So... am, let's say, for homogeneous mixture here you have A and E. So why would you have chosen those?

Nora: Am, because with A and E, what I'd see to be one molecule, say, for A is that box, box, diamond, circle diamond, circle... or no box, box, diamond circle. I'd see that to be one molecule... and they're all the same.

I: So, this let's say these two boxes, the diamond and the circle, that's one molecule is it?

Nora: Yeah that's what it looks like to me so they all look the same. So that's... to me homogeneous is the same. And they're very... with A they're dispersed kind of evenly.

I: Okay.

Nora: With E then, I think it's just because all the molecules are exactly the same... but they're not dispersed evenly. I guess that's because it's a gas.

I: Okay.

I: And, ah, C you chose as a pure substance.

Nora: Am, yeah because it was full of all triangles.

I: Okay. So if you were to define, or tell me, what is a pure substance how would you do that?

Nora: It is, am, so it can contain only one kind of an atom.

I: Okay.

Nora: An element.

I: And a homogeneous mixture then?

Nora: A homogeneous mixture would be kind of like, am... a mixture of all the same molecules.

I: Okay.

Nora: Yeah... that's...

I: Okay so like how there's one type of molecule here [Diagram A] and one type of molecule here [Diagram E]?

Nora: Well not that there's... well... yeah.

I: In A let's say there's one type of molecule and it's the two squares, the diamond and the circle?

Nora: Yeah.

I: Okay.

I: And D and B then you have as heterogeneous mixtures so... why are they?
Nora: They're heterogeneous cause... they're like, am, they look to be different molecules... in a mixture.
I: Okay.
Nora: And... am, they're kind of like, am, I know E is like dispersed and kind of all over the place but they are like dispersed as well so they would be kind of, kind of the same... I dunno... gradient concentration the whole way through.
I: Okay. So is D made up of am... so you're saying it's molecules in D?
Nora: I'd say they are, to be honest, two different elements. That's what it looks like.
I: Okay.
I: So if I go down here then to, am, the third part. Okay. So did you understand what you were being asked to do there?
Nora: [reading] I think I'm being asked which one's of these are elements, which are compounds or element and compound.
I: Okay.
I: So you have C as an element. Why is that?
Nora: Am, 'cause it's all the same.
I: Okay.
I: And you have D as an element and compound.
Nora: Am... I don't know... 'cause looking at it now it seems to be two separate elements. I'd say at the time I just probably got confused.
I: So would you put D here with C now?
Nora: Yeah. 'cause it's two separate elements.
I: Okay.
I: so am, so you have E as a compound and element and compound you have A and B. Okay, so A is element and compound?
Nora: I'd probably change that to being a compound now.
I: Okay. So you'd say that it's made up of one compound?
Nora: Ah, yeah.
I: Okay.
I: Am... I'm going to ask you next about Question 5... so if you want to have a look over that?
Nora: [reading question] Okay
I: Okay so did you feel you understood?
Nora: Ah yeah I think I understand what is being asked.
I: So for the first part there which diagram is the best representation of hydrogen peroxide before it decomposes as given by the balanced equation? So would you still choose the same answer there [Tier 1 Response B]?
Nora: Yeah I think so yeah.
I: And why that one [Tier 1 Response B]?
Nora: Because it's given by the balanced equation so you need two molecules of H two O two [H₂O₂]
I: Okay
Nora: And that [Tier 1 Response B] seems to be the only one that has two separate molecules of H two O two [H₂O₂]
I: Okay. And would you have been tempted by A?
Nora: Am... no because it looks like all one.
I: Okay... so if that was to be written out in an equation for that [Diagram A] to be a thing what would it look like?
Nora: H four O four [H₄O₄]
I: H₄O₄ okay.
I: And then, down in your second level here, which diagram is the best representation after it decomposes?
Nora: Am, I'd still stick with A.
I: Yeah.
Nora: Because... it looks like it's got one O two [O₂] molecule and two H two O's [2H₂O's]
I: Okay. And, again, E there wouldn't have.. even tempted you at all?
Nora: Am, no. I don't think so.
I: Okay.
I: Am... for Question 6 there?
Nora: [reading question] Am, I think I'd stick with the same answer anyway.
I: Okay, and... am, how are you coming up with your answer? Could you explain what you're thinking?
Nora: Am... well I'm basically just looking at the pictures, am, because it's two S [2S] plus three O two [3O₂] so... I'm kind of like, so I start with these ones up here, so for every two S [2S]... three O two's [3O₂'s] so I'm kind of like... those four, five molecules go together... those five go together
I: Which 5 go together?
Nora: As in the two blocks here and then the three circles
I: Okay
Nora: So, am like, that's the way I kind of do in my head.
I: Yeah.
Nora: Am... [reading question]... two S O three's [2SO₃'s] so it looks like these [pointing at Response C] are the only molecules here that look like S O three's [SO₃'s]... because it's got the one block and the three O's.
I: Mmmhmm.
Nora: So that's why I kind of take it.
I: So... D has some of the same type... so why would C be preferred to D?
Nora: Actually yeah. I think I prefer C over D, D is probably actually the right answer...
I: And why are you thinking that now?
Nora: Because I just kinda looked at the two pictures... and... there shouldn't be enough O two's [O₂'s] to make up... all those in C.
I: Mmhmm.
Nora: So there would be some S atoms left over. So... yeah no I'd change it to D. Sorry.
I: Okay. So you'd change it to D.
Nora: Yeah.
I: And if I had, if I put closed container in bold there would that have helped you at all?
Nora: I think it would. Yeah something like that. Just to draw my attention to the fact that it was a closed container.
I: Okay.
I: Am... Question 7 there.
Nora: [reading question] okay.
I: Do you think that question is clear?
Nora: Am... it's clear in what it's asking [pointing to stem]. I think it's just I'm getting confused in the answers... yeah.
I: So maybe some of these options aren't that easy to read?
Nora: Am... I think it's not that. It's just I'm going through my head... all the... like, I know they're written there, the electronic configuration, but I'm actually trying to remember the pictures... you know the diagrams of the levels.
I: Yes. Yeah.
Nora: So I think that's the reason why I'm... getting a bit stuck on it. Like, it's actually straight forward, like.
I: Yeah. And let’s say here for ‘nuclear charge’... what do you understand nuclear charge to be?

Nora: Am... like the amount of protons and neutrons in the nucleus.

I: Okay. And, ah, you picked A there. Do you think you’d pick the same again?

Nora: [reading options] No I don’t think I would ‘cause... I’m just looking at it now and I’m going towards E or D or something.

I: Okay and why E or D now instead of A?

Nora:... ‘cause... it just sounds like it could be more right.

I: Yeah.

Nora: D’you know what I mean? Am...

I: So are you confident about...

Nora: No. No. Not that confident no.

I: It would be kind of a... educated guess maybe?

Nora: Yeah.

I: Okay. Am... just quickly, Question 8. Would you go for the same one again?

Nora: [reading question] am... I think so... because a mole is, like, Avogadro’s number... the amount of the particles. I know remember off the top of my head but that number of particles so it shouldn’t have an effect on it.

I: Okay. So a mole is... Avogadro’s number of particles?

Nora: Yeah.

I: Okay. And is there any relationship between mole and mass?

Nora: Am... there is. It’s, like am... it’s, like whatever, a mole... sorry now.

I: What are you trying to think of?

Nora: D’you like a table, the Periodic Table, like am... one mole of, am... is chlorine is 35 grams and it’s the same number... I’m trying to think now, is it the number of protons or something like that, like am... I don’t know. Sorry.

I: Okay. But from The Periodic Table you know... one mole of chlorine is going to have a mass of 35 grams?

Nora: Yeah. That it’s going to be that.

I: And does that mass affect the number of particles in a mole?

Nora: No.

I: No.
Nora: No it doesn’t affect the number of particles.

I: And does it matter whether it’s, you know... the type of particles, does that...?

Nora: Well no, like if it’s like an element it’s going to be all atoms. If it’s water or whatever it’ll be molecules but it’s still going to be sixteen by ten to the twenty-two \([6 \times 10^{22}]\), or like whatever, molecules of water.

I: Okay. Okay perfect. So for your... could you explain how you went about doing Question 9 there?

Nora: [reading question] If I was doing it again, the way I’d go... I’d, am like, one atom of carbon has six electrons so I think what I’ve done there is because I want six by ten to the twenty-three \([6 \times 10^{23}]\) or whatever, what I did was I divided six into twelve to give me two ‘cause for every one atom of carbon there is gonna be six electrons. So that’s how I came up with two grams.

I: And how did you know that 12... so why six into twelve? Why did you choose twelve to divide six into?

Nora: I probably... twelve grams or carbon... oh that’s why because in twelve grams of carbon you had one mole and so six grams, I mean six moles of electrons.

I: Okay perfect. I’m gonna hop down here to Question 11.

Nora: [reading question] Am... I’d go with the same answers again.

I: Okay. So you have ‘No it wouldn’t have the same number of atoms because one mole is Avogadro’s number of atoms. They each contain a different number of moles’. So one gram of vinegar contains a different number of moles than one gram of sugar?

Nora: Yeah.

I: So... could you explain that out a bit more?

Nora: Okay. Am... where I’m coming from is, like am, right one mole of vinegar is 60... 60 grams.

I: Mmm

Nora: And one mole of sugar is one hundred and eighty [180] grams. So in each of those, there’s going to be Avogadro’s number of moles or number of molecules I mean.

I: Mmhmm.

Nora: So if you’re dividing each of them to one gram there has to be different amounts... cause for vinegar, let’s say, you’re dividing Avogadro’s number by sixty.

I: Mmhmm.
Nora: To get it down to one gram. For sugar you’re dividing it by one-eighty \( \frac{1}{180} \) to get it down to one gram.

I: Okay. So they’d have a different number of molecules in one gram for each of them?

Nora: Yeah.

I: And would you be able to estimate what would be the difference? Which one would have more molecules and which would have less in one gram?

Nora: Yeah, am... [muttering maths] yeah vinegar would have more.

I: Okay. And could you estimate how much more?

Nora: Oh 3 times more.

I: Okay. So I have one gram and I have three times more vinegar molecules than I have sugar molecules?

Nora: Yeah.

I: But I’ll also have different number of atoms... is that right?

Nora: Yeah.

I: So I’ve a different number of molecules and a different number of atoms?

Nora: Yeah.

I: Okay. Am... I was going to... oh yeah... Question 13 I was going to ask you about as well.

Nora: [reading question] Okay. If I was doing that again I’d probably change to B.

I: Okay and why would you change from E to B?

Nora: It’s just the sizes of the atoms and the molecules. The size of the atoms... the difference is shown with B, as well as the, d’you know, which ones are positive and which ones are negative. And kind of the structure as well. The actual structure.

I: So do you mean in three-D [3D]?

Nora: Yeah it’s in 3D and that it’s compact. And that it... the... the sodium atoms kind of slotted in between. There [Option E] the sodium and chlorine atoms then look the same size and they look 2D.

I: Okay. Okay. So, if I have this one [pointing at Option E] in 3D, and all that, and the sizes were different... that would mean it would be pretty much the same as option B is it?

Nora: Yeah I think so yeah.

I: Okay. Am... sorry now. Am... okay Question 16 there.

Nora: Yeah. [Reading question]. Okay. Am... I think I might probably stick with the same one [Response Option E]. Or I’d... I might say B.
I: Mmhmm

Nora: Because... [reading question]... no I think I’m gonna stick with the same one [Response Option E] just because there is a metallic element in it and from what I know that does increase the boiling point of it and stuff like that.

I: Okay. And why would B tempt you?

Nora: Oh no just cause am, one of the reasons that I know of that water has a boiling point of a hundred is ‘cause of the hydrogen bonds in it.

I: Okay.

Nora: So when I’d be reading sodium hydroxide I’d be thinking that maybe there’s more of... there’s different bonds in it. So that’s why...

I: Mmhmm. So is there some truth to this statement [Response Option B] but it’s not actually the reason?

Nora: I think so yeah.

I: Okay. Okay. Am... just, ah, Question 17 there.

Nora: Ah... [reading question]... okay. Am... [reading question]... oh sorry now I got a H-two [H₂] out of them [laughs]... [reading question]... yeah I reckon B because... uh I can’t remember the H-two [H₂] or I-two [I₂] but obviously the levels of the H-two [H₂] would have to go down because it’s going into the HI.

I: Mmhmm.

Nora: It’s going off into that. So... that’s why I said it’s gonna go down at a steady rate and then it’s going to level off ‘cause at equilibrium it’s not gonna need anymore H... or I-two [I₂] ‘cause, like, it’s gonna be equal concentrations. That’s where I’m coming from.

I: Okay. So it’ll be equal concentrations of... what at equilibrium?

Nora: Am... like it’ll be equal concentrations of H-two [H₂], I-two [I₂] and two HI [2HI].

I: Okay.

Nora: Or at that just going back and being made.

I: Mm. So... okay, if I had had, let’s say... you know the double arrow, would that have made any difference?

Nora: It shouldn’t when it comes to equilibrium.

I: Okay. So you didn’t take this to be just a forward reaction?

Nora: Am, I think... maybe if I had seen it I could have taken it to be a forward reaction.
I: Mmm. So just wondering here, if we have... so we have equal concentrations of these three [pointing at chemical equation] and these [pointing at reactants] and making this [pointing at product] and that [pointing at product] is making these [pointing at reactions]. Is that what you’re saying?

Nora: Yeah that’s what I’d say.

I: Okay so would... A there wouldn’t have tempted you would it not?

Nora: No I don’t think so because from what I understand of equilibrium it’s going to stay the same. Like, they might be changing but the concentrations stay the same.

I: Okay.

Nora: So that’s where I’m coming from.

I: Okay. Am, okay, so you didn’t attempt Question 18.

Nora: [Looks at question] Oh right. Okay. [reading question]

I: So you said you didn’t try it because you didn’t know what K is?

Nora: Yeah.

I: Okay so if I had said, am, ‘which of the following must true of the equilibrium constant’... would that have made a difference?

Nora: I’d say so.

I: So if you had it explicitly there that K is the equilibrium constant?

Nora: Yeah.

I: So would you be able to... which... would you be able to pick an answer now?

Nora: Am... [reading question]... I don’t think I would now to be honest.

I: Okay. Because you’re...

Nora: just because I’m struggling to remember equilibrium.

I: Okay. So you remember anything about the equilibrium constant?

Nora: I remember how to get a formula for it.

I: Okay.

Nora: The concentrations of the right hand side over the left hand side. So... I’d say maybe C.

I: Okay. C ‘less than 1’ [< 1] and why?

Nora: I’m just kind of clutching at straws here now like but, am, you could write down... I’m saying it’s less than one because if it’s, if it’s two molecules of A to make B...

I: Okay. So you’re plugging into your formula are you?

Nora: Yeah.
I: Okay so you’re not get any information here from the diagram really?
Nora: No.
I: Okay. And one more.
Nora: You’re alright.
I: Question 20 and that’s it.
Nora: [reading question]... I’d pick the same answer for that one anyway.
I: You’d still pick the same answer?
Nora: I think so.
I: Did you find the question clear?
Nora: Yeah. The question is clear... the pictures are clear so that’s grand like.
I: Okay so you would say that [reading question aloud] ‘X and Y are resonance structures of each other’.
Nora: Yeah I think so yeah.
I: Okay. And, ah, I just have one or two questions to... did you hear about chemistry misconceptions before you had done that test?
Nora: Ah... oh yeah... just generally talking between each other. Especially in that module we were in at the time ‘cause, ah, a lot of the stuff we were doing at the time was, ah like, drawing molecules and whatever.
I: What module was that?
Nora: Inorganic chemistry.
I: Oh, inorganic chemistry. So ye would have been aware that ye have similar... similar ideas about things that maybe weren’t right?
Nora: Yeah. Yeah. I remember doing the test and the, the girl beside me we were, like, trying to... like, ‘no that’s wrong because of such and such a thing’ and I’d be like ‘no’. We were kind of finding out that way.
I: Yeah. But had you heard of the term chemistry misconceptions in lectures or anything like that?
Nora: Yeah. I had.
I: Oh you had.
Nora: In our, ah, pedagogics.
I: In, am, the chemistry pedagogics in third year or in the science in second year?
Nora: Am, I think it was in science pedagogy that that was brought to our attention. Like, that pupils can have misconceptions and all that.

I: Mmhmm.

Nora: So it’s not like just in the chemistry pedagogics that we did hear that.

I: Okay. And in chemistry lectures then ye would have been made aware of this or did ye talk about some of them or...

Nora: Ah, lectures were just very... it was kind of like, ah... made aware of misconceptions with compounds and that was it.

I: Yeah. So you touched off it but you had heard of it before?

Nora: Yeah.

I: Oh yes, am, would you consider, let’s say when you go out teaching... do you think this idea, like chemistry misconceptions, that you have to tackle them? Do you think that’s an important thing or is that just something that happens in the course of teaching? Like you’re teaching something so you just teach it correctly?

Nora: I think, like am, for the pupils’ own benefit we should be teaching it in that, like we ah, target misconceptions. But at the end of the day, like, I’d end up looking at it as a teacher and I’m towards the exam.

I: Yeah.

Nora: I know it’s not a great way to be teaching but you do have to help them that way. So you’re kind of like if you can get them to understand a thing without going into the detail as to why it is you kind of leave them with the misconception but you know that they won’t be asked it.

I: Yeah.

Nora: Do you know what I mean?

I: Like that they can get away with it in an exam?

Nora: Yeah. So I know that’s kind of, like, bad teaching but I do think misconceptions should be targeted but, like, it’s just so varied. D’you know even if was cut down a bit you could tackle stuff like that.

I: Yeah. So the exams create pressure?

Nora: Yeah. Yeah. But like if I had any TYs I’d definitely spend a lot of time going through stuff like that.

I: Mmhmm.

Nora: Yeah but a lot of schools don’t do TY so I dunno if I could do it.
I: Yeah. Yeah. Okay. Are there any general comments you want to make about the test or the topic general or…
Nora: I think I just want to go to bed! [laughs]
I: [laughs]
Nora: I don’t think so. I just remember doing the test and the lot of us were, like, putting down different answers. So, like, even our level you’d see some or a lot of misconceptions which I’d say kind of began in Leaving Cert.
I: Yeah.
Nora: D’you know? So…
I: Yeah. Okay. Thanks very much.

**SEMI-STRUCTURED INTERVIEW WITH DEIRDRE**

I: Okay so just for this, kind of am, thing here we, like some of the concepts that I… oh first of all what course are you doing? You’re… biology?
Deirdre: Yeah biology.
I: And chemistry is it?
Deirdre: Am well I haven’t picked yet but it’ll probably be chemistry but I don’t have it for the Leaving.
I: Okay. Oh you don’t have it for the Leaving Cert. or anything. Yeah.
Deirdre: I just had biology.
I: So some of the concepts that were included are the mole, properties of atoms, compounds, elements and mixtures, the meaning of chemical equations… I know there’s equilibrium in there, ionisation energy and so on.
Deirdre: Yeah.
I: Do you think you feel confident about teaching those topics?
Deirdre: we’re going out on Teaching Practice but that’s only Junior Cert. No I wouldn’t really feel confident.
I: About none of them or is there some that you would maybe be confident about and others definitely not?
Deirdre: Am… well… some of them are a lot easier than others but, like, you’d need ot be doing it constantly to, ah, work up any bit of confidence. Shur we’ve no, even, chemistry module this semester… we’ve got teaching practice so it’s more education.
I: Yeah. Yeah.
I: So your chemistry… what you done so far is General Chemistry, Organic and Inorganic?
Deirdre: Yeah.
I: So that’s what you’ve done so far?

Deirdre: Yeah.

I: So you say some were easier… which ones or which areas would be easier?

Deirdre: Ah… well I though inorganic was very hard so I’m not sure if that was the lecturer or just the module itself but that was hard. Am… organic wasn’t too bad. Am… like just different aspects of each of them are obviously just hard questions or just… easier.

I: Okay. Okay.

I: So for this, this instrument here, some of the questions are based on pictures, like you've got 3, 5, 6 there. Others are based on the words like, am, down here.

Deirdre: Yeah yeah.

I: So what did you think of those questions?

Deirdre: The visual ones is it?

I: Well, comparing the two. Were they both kind of the same? Was one easier than the other? Did you prefer one type?

Deirdre: I suppose for conceptualisation the visual ones are probably easier... but then if a question is well worded you should have no problem. It's just, if there's any sort of, misunderstanding about it, it can be very tricky. It really depends on the question, like. That's probably a very vague answer but...

I: Well, you wouldn't be used to one that are visual questions would you like that one [Question 2]?

Deirdre: No, no.

I: Did you find that a problem, or was it, was it fine?

Deirdre: Well I suppose it can kind of confusing yeah cause I wouldn't have seen what the difference was between say C and D there. Like, d'you know some of them look very similar it's almost kind of... hard to pick out the differences between them.

I: Okay. Okay.

I: Am… so what I’m going to do is, am, just go through a few of the questions in the, kind of, instrument that I know from talking to other people maybe that they found them easy or hard or whatever.

Deirdre: Yeah.

I: And, am, I'll give you a chance to look back over them but, am… Are there any questions first of all that you’d pick out as being particularly difficult? If you flick through it or maybe you’d remember?

Deirdre: Am… [looking through the instrument]…
I: Okay so let’s just say Question 1 there. Did you find that easy enough to understand? What was it asking you?

Deirdre: Am… [reading question]… ah, well it’s a simple one actually if you know the answer but I didn’t [laughs]. I didn’t know.

I: Okay and what answer would you choose now? Would you still go for the same one?

Deirdre: Am… [reading question]… am… D

I: So you’d… you’d go for D still is it? As in Option D [points at response option]

Deirdre: Yeah. Oh you’re looking for this one are you? [points at the stem with list of properties]

I: Okay. So did you think that this was a two, two part question?

Deirdre: Oh. I just thought that they were two separate questions. [Reading question]… yeah I’d still go for this one [pointing at Response Option D]

I: Okay. You’d still go for D.

I: So if you were just to explain what this question was asking you?

Deirdre: They’re asking you to say how the properties of sulfur… you know what’s in it, what kind of… it’s more kind of just facts about it, it’s kind of… true or false for them [Stem list]

I: Okay and

Deirdre: And for this bit [response options] it’s kind testing your understanding that, we’ll say, that one atom still has, still has everything that’s kind of… built up to a whole thing, like d’you know… the atoms still has all the, the elements of the stuff like.

I: Okay. Okay.

I: Am... so Question 2 there?

Deirdre: Am...Yeah that’s, it’s kinda hard to know by looking at it but I'd still probably... the only one I woulda been unsure about was that one... cause if it was a solid it was kind of...

I: So you felt you weren't that sure about C is it?

Deirdre: Yeah I suppose

I: For if it was solid or not?

Deirdre: Ah... yeah.

I: So why did you choose A and C as solids?

Deirdre: They look kind of in block format and they look, d'you know, tidy enough, pack together and... they seem kind of really rigid and stuff.

I: Okay.

Deirdre: While D looks kind of flowy and they’re not in straight lines and then E and... B are kind of just all over the place, like dispersed like a gas.

I: Okay.
I: Okay so for the second part there. So you were asked to decide if it was a pure substance, heterogeneous mixture or homogeneous mixture. So you have A, D and E as homogeneous mixtures. So why would you have chosen those as homogeneous?

Deirdre: Am... cause their kind of... I can’t remember (laughs)... just because their made up of like two of them, two of the same, d'you know...

I: So okay let's say D there?

Deirdre: Yeah.

I: Why would you say that's homogeneous?

Deirdre: I'm probably wrong now. I think it's... because I don't want to say... like obviously I'd say C is your pure substance, but then like... I'd probably just, I'd probably get confused between say then... how to classify the rest. (laughs)

I: So if I was to ask you what is a pure substance? Just in your own words.

Deirdre: Well say just from the pictures it's kind of like... it's all, it's all made up of the same thing like kind of.

I: Okay.

I: And a heterogeneous mixture. What does that mean?

Deirdre: Different. Kind of... yeah. I, I, I'm getting confused.

I: Or a homogeneous mixture. What might you say that would be?

Deirdre: It'd be kind of... have a kind of a pattern to it like.

I: Okay. (pause)

I: Okay so that's why A is a homogeneous mixture? Because it has a pattern to it? Is that...?

Deirdre: Well yeah. When they're kind of... they both have got, I would say, the same things but it's kind of in order if you get me.

I: Okay.

I: And D then?

Deirdre: I dunno why I picked D.

I: Okay.

I: And, ah, just down here, down on the bottom. Am, so, did you understand what you were being asked there?

Deirdre: [reading] Well... yeah to a certain degree because I understand what the elements are. They're all made up of the same... say, matter like or something... obviously they're all kind of uniform, so that's C, and then compounds... they're kind of a mixture... so A.

I: So if you were to point out there on the Diagram A what are the compounds in A?

Deirdre: In the middle.
I: Okay. So you have... as in the diamond and the circle is it?
Deirdre: Am yeah. I think.
I: Okay. And what are the squares there? (pause) Is that another compound or...
Deirdre: Am, well no it's all kind of the one compound, d'you know.
I: Okay. Okay yeah. So the whole thing there in A is the compound?
Deirdre: I think so.
I: Okay.
I: Oh I see you have element and compound for A as well. So...
Deirdre: Yeah...
I: Am, I'm just wondering here, seeing as you have, you know put down C and you put down A... did you understand from the question that you were, like that it was every single diagram should have been put somewhere?
Deirdre: Ah... well I probably thought it was a... I thought it was kind of a trick question cause I thought that like, everything wasn't... d'you know...
I: Wasn't going to be an element or a compound or an element and a compound?
Deirdre: Yeah. It could be a mixture you know.
I: Yeah.
Deirdre: I don't know.
I: Okay. Yeah.
I: Am... Question 5 there. So if you have a look.
Deirdre: Am... [reading question]... yeah
I: Okay. So is it clear? Do you understand?
Deirdre: Am... yeah it's clear enough.
I: Okay so, for your first bit here... the best representation of hydrogen peroxide before it decomposes. So you chose A there so could you... would you still choose A? And why... if you would still choose it?
Deirdre: I don't know if I would really... but then I don't see any other answer that would really fit it... I don't know.
I: Okay so would you go with A?
Deirdre: I probably would.
I: Okay so what ... you know, why would you choose A and none of the others?
Deirdre: Because, say, because there's only two hydrogens and then, say, 2 is four hydrogens, and, just, there should be two oxygen's off each of them but there's only... there seems to be only one oxygen off each of them. I, I dunno.
I: Okay. So for, here, because you have 2H2O2... so that four hydrogen's?
Deirdre: Yeah
I: And then for your oxygen's how many?
Deirdre: There should be two.
I: Okay so two oxygens. So didn't feel maybe that...
Deirdre: Am...
I: So does this big two here in front... does that only apply to the hydrogen?
Deirdre: No, oh no, there should be four there. No I'd pick A again.
I: Okay. Okay.
I: And for your second part... the best representation of the products afterwards?
Deirdre: Am... [reading] so that would be two H two O [2H2O] plus O two [O2].
I: Yeah.
Deirdre: Which would be... ah, there should probably be four hydrogens over here [Tier 2 Response E] as well, but none of the others have four joined, so, I dunno.
I: So for E is it?
Deirdre: Yeah.
I: So your... hydrogen's and your...
Deirdre: Yeah I'd probably go for E again.
I: So you'd go for E. So that's your 2H2O there is it? [pointing at shape H2O4]
Deirdre: Yeah
I: And this is your O2 then?
Deirdre: Yeah
I: Am... just for Question 6 then.
Deirdre: [reading question] Yeah. That's kind of confusing, like.
I: What's confusing about it?
Deirdre: Am... the diagrams, I guess, is just confusing then in that kind of scenario. It's hard to kind of distinguish between them and then... it's just more, kind of, for people to look at I suppose, but when you start going through them all... it just kind of looks confusing like. Just, just...
I: You're okay.
Deirdre: Am... what do you want me to answer it again is it?
I: Do you think you'd still go for B or would you...
Deirdre: Yeah I'd probably still go for it.
I: Okay. And why would go for B and not, say, E... because they're quite similar?
Deirdre: Am... actually I probably would go for E there.
I: Okay, and why?

Deirdre: Because that one [B] has two loose one's. It probably shouldn't have two loose ones.

I: If I brought your attention here to this word 'in a closed container', what would that mean to you?

Deirdre: Not much.

I: Okay. So that wouldn't really make any difference would it?

Deirdre: It probably should but... my chemistry is very bad like.

I: But it would be B or E anyway that you would choose?

Deirdre: Yeah.

I: Okay.

I: [laughs] stop freaking out!

Deirdre: [laughs]

I: Okay sorry yeah I wanted to ask you about eight [Question 8] so…

Deirdre: [Reading question]… I'd probably pick C.

I: C… so how closely they're packed together. Okay. So would be tempted at all by B this time?

Deirdre: No. No I don’t think so.

I: Am… if you were to explain in your own words what a mole is, how would you?

Deirdre: Am… the smallest unit of a, kind of, substance you can have. Am…

I: Okay.

Deirdre: D'you know?

I: Yeah.

Deirdre: [laughs] that’s kind of it.

I: Hmm?

Deirdre: Yeah… am. That’s it.

I: So a mole is the smallest unit of a substance you can have?

Deirdre: Yeah… no, no that’s not… hold on. Well, like, it’s… oh, uh, am… am… like it’s… yeah a mole is, kind of, say… it’s, it’s kind of… it’s made up of atoms and they’re just the smallest unit. So kind of… it’s the smallest kind of unit with them all together. It’s kind of hard to explain.

I: Okay. Okay. Am… so I just wanted to ask you as well about Question 9 there.

Deirdre: [Reading question]… am… I'd probably say six.

I: You go for six now is it… instead of twelve?

Deirdre: Yeah.

I: And, ah, why would you go for six?

Deirdre: Am… just ‘cause it contains six electrons.
I: Okay and do you have any idea why you might have picked twelve?

Deirdre: It’s probably cause it was the atomic weight or something.

I: Okay so you might have picked twelve because… that’s the atomic mass of carbon?

Deirdre: Yeah.

I: Yeah?

Deirdre: Yeah.

I: Just, ah, I wanted to ask you as well about Question 10.

Deirdre: Um… [reading question]… okay… shur you just have to do it out of, like, maths like.

I: Mm.

Deirdre: Am… you’d like need to do it with a pen and piece of paper.

I: Okay so you’d need, whatever, to calculate that out?

Deirdre: Mmm yeah, like… yeah but you’re given three variables as well like so… d’you know… shouldn’t be like. You should only really have two variables shouldn’t you? I dunno.

I: So because there’s an A, a B and a C in it?

Deirdre: Mmm… yeah!

I: So you need to take into account C as well… is that what you mean?

Deirdre: Am… yeah. Am… I’d probably say six but six isn’t there so…

I: Okay and why would you say six?

Deirdre: D’you know, trying to get a common, like a common denominator across for the equation… and you want five like… so…

I: Well suppose I changed it and I said ‘how many moles of B would you need to react completely with six moles of A’? Supposing I changed and said six moles of A? Would that make it any easier?

Deirdre: Just… just multiply it by two is it… so four.

I: Okay. So… it’s moreso here is it because I’ve said five that there’s maths to it?

Deirdre: Am… well no like. I could… I just, uh… [laughs] I’m under pressure now!

I: [laughs] I’m sorry. I know it’s hard.

Deirdre: We’ll say I’d get the common denominator fifteen and then I’d probably just divide it across. D’you know… you have your six B [6B] there so… like six all over two or something… or six all over fifteen. I dunno is that… and then you’d have to get your decimal or something like that.

I: And that’s for the five moles is it? If you’re working with the five?

Deirdre: Yeah.

I: Okay.

Deirdre: Or divide it across by three and then you’d see what B is.
I: Okay. So it’s five A so you’re going to get the common denominator?

Deirdre: Fifteen say by six and divided by three would be… five, am, ah, two. Yeah I’d say two now.

I: Okay. You’d go for two?

Deirdre: Yeah.

I: Am… just there Question 11. Have a quick look.

Deirdre: [reading question]… am… yeah… ugh… this is making me not want to do chemistry [laughs]. Am… ah… you probably wouldn’t have ‘cause you’ve got the same particles in the formula but they won’t have… they’re still different like, they’re still… like two, four, two there and six, twelve, six, there like so there’d be more in the sugar.

I: Okay so you’ve more atoms in the sugar molecule? Is it? So you would chance your answer now would you?

Deirdre: I think so. Even though I’d probably question that the first time…

I: Okay, am, there was one more question, am… Question 17 I wanted to ask you about.

Deirdre: [Reading question]… yeah I don’t think I had a clue about that question. I think I just picked D.

I: So it was maybe a guess. And, am, would you, would you be able to answer it now?

Deirdre: No.

I: And did you understand the question? What is the question asking you?

Deirdre: That if you have H-two [H₂] and I-two [I₂] together what will your graph look like [laughs].

I: Okay. My graph of what?

Deirdre: Of… two-HI [2HI].

I: Why do you think it’s two-HI [2HI]?

Deirdre: Am… because that’s what the reaction gives you.

I: Okay so you didn’t… let’s say down here I have [reading question aloud] ‘if H₂ and I₂ are mixed together and allowed to come to equilibrium, what would the graph of the concentration of H₂ look like over time?’

Deirdre: Oh.

I: If I had bolded ‘concentration of H₂’ would you have

Deirdre: Yeah. I kind of skimmed over that bit.

I: Yeah.

Deirdre: Yeah I was kind of thinking… I didn’t even read that. Yeah it would help to put that in bold.
I: Yeah. Okay. And there were just a few final questions. Oh yeah I want to ask you… did you ever hear of this thing, like chemistry misconceptions, before?

Deirdre: Ah, no but I’m sure there’s a lot of them [laughs].

I: There are. There are loads and you’re not the only one. Your score was around the average actually.

Deirdre: Oh that’s bad [laughs]

I: Would you… let’s say for when you’re going out on Teaching Placement, do you think it’s important or do you think these sorts of things need to be directly targeted, these kind of wrong ideas, do you think they need to be directly hit or if you just teach them it will indirectly do it? Is that enough do you think?

Deirdre: Ah… well I think when you’re teaching something, you need to get the prior knowledge of it and, say, if they have misconceptions try to correct them through the way you’re teaching it. So you’re doing both. You need to teach it clearly, like, you need to ask them questions to see if they still have misconceptions and then if they do you need to go back I’d say, maybe and rectify it and make it clearer.

I: And would you feel confident to maybe be able to find out what the students’ misconceptions are? Let’s say, students’ ideas about, for example… am, chemical equations. Do you feel confident that you’d be able to either look something like that up or…

Deirdre: Not really. I’d be afraid that they’d ask me something I don’t know.

I: Yeah. Yeah. Okay and is there any other comments you want to make about this instrument or the topic in general?

Deirdre: Am. No not really [laughs].

I: [laughs] not really. Okay.

SEMI-STRUCTURED INTERVIEW WITH ANNE

I: Okay. So just first of all… we’ll say on the instrument I included concepts like ionisation energy, the mole, am, properties of atoms, mixtures, elements and compounds, things like that.

Anne: Yeah.

I: Would you feel confident to teach those?

Anne: Am…

I: Or some of those concepts?

Anne: Yeah I would. I’ve taught matter and all this kind of thing here [pointing at first questions on the instrument]

I: Mean of chemical equations and that?
Anne: Yeah. Am... well... yeah some of those diagrams and here as well. You know the... solid, liquid gases for Junior Cert.
I: Yeah.
Anne: I did that last semester when I was on Teaching Practice. And, am... the more I taught it, the more I understood it myself.
I: Yeah. Yeah.
Anne: But you know when you're kind of... I don't know, when you’re in college and you only kind of study for the exam and then you just... you know it's really hard to go beyond and do the reading and all that.
I: Yeah.
Anne: I dunno and then I kind of forget a lot of it as well.
I: Yeah.
Anne: You know looking at it now I’m like when we’re doing it now and I’m look at it saying ‘Geez why did I answer it that way’ and ‘why didn’t I answer that question’.
I: Yeah.
Anne: Some of them are basic.
I: And, am, it's biology with chemistry is what you’re doing?
Anne: Yeah, but I would prefer biology.
I: Yeah.
Anne: I got an A for that in Learving Cert.
I: Yeah. Yeah. But you did chemistry as well for the Leaving?
Anne: I did chemistry as well yeah, yeah. But I got on better in biology. That’s probably because I liked it more. I had two very good teachers though for each subject.
I: Yeah. Am... so you know, let’s say in the test, you have some questions based on pictures and then others that just using the words.
Anne: Yeah.
I: So how did you find those kind of questions?
Anne: Am...
I: Did you find one easier than the other or... would you prefer one type or another type or...
Anne: Sometimes I’d kind of prefer just a straight... I’d probably spend more time at these ones [pointing at picture questions]
I: At the picture ones?
Anne: Yeah because we didn’t do those. We never did those really in secondary school.
I: Yeah.
Anne: I don’t think we ever really did them.
I: Yeah.
Anne: It’s more learn of a definition of what a gas is, d’you know, or a solid is. You don’t really get the pictures. So then, like, sometimes you have to think ‘what is… what could be here’ or… d’you know and we never used the shapes, the molecule shapes to make up something.
I: Yeah. Yeah.
Anne: You know the bass-and-stick, we never used any of that.
I: Yeah. Yeah.
Anne: Then when you’re looking at this [pointing at picture questions] it can be a little bit confusing.
I: So… you didn’t find… or it’s just that you’re not familiar with that style of question is it?
Anne: Yeah but if our teacher went over it, it would be really good to teach students, d’you know, how to use that and memorise and all that.
I: Yeah. And, am, do you think that doing this, maybe, exposed a few areas that
Anne: Oh for myself?
I: Yeah.
Anne: Yeah. Definitely.
I: You know that maybe you felt there were a few areas that when you walked away you thought ‘well maybe there are a few areas that I don’t understand as well as I had thought’.
Anne: Oh I was mortified after I handed it up.
I: [laughs]
Anne: I didn’t even want to see the results.
I: Yeah.
Anne: Except d’you know to get feedback on it. D’you know I was saying after ‘I shouldn’t even be teaching’ like, d’you know. It was just so many small things. But then I know, some of this goes… well I suppose it’s not more in-depth than Leaving Cert. at all like.
I: Well they are a lot of them that you would want to know for the Junior Cert.
Anne: Well definitely yeah.
I: But then there are some that are Leaving Cert. but we tried to keep them basic well I mean as possible, you know not
Anne: well I should know way beyond it.
I: Well we all should but we don’t you know.
Anne: Yeah.
I: That’s just the reality you know.
Anne: Yeah. Yeah.
I: But, am, yeah so what I want to do is just go through a few of the questions just to see. So I'll e asking you, you know, did you understand the question, what did the question ask you, would you choose the same answer, why did you pick that, and stuff like that.

Anne: Yeah.

I: So, am, first of all…

I: If we just start on Question 2.

Anne: Yeah. Of yeah I was just looking at that there.

I: Yeah. Have a quick read of it there.

Anne: Am... [reading]

Anne: So I said A and C, they were solids because I said they were more tightly packed together.

I: Mmhmm.

Anne: And... E and D... well that looks like am... looks, could, could be a CO2... a gas... or it could be water as well H2O

I: Mmhmm.

Anne: But am... oh I said it was a liquid there actually sorry. In D. Yeah I said that looked more like a liquid... cause it was further apart, but then... I dunno why I guessed... D a liquid... yeah it's not. It's tightly packed togerther as a solid.

I: Okay. So would you still go with D as a liquid?

Anne: Am... I dunno what I'd go with. It could... I, I don't know what D is to be honest.

I: So you're

Anne: And I dunno is that a mistake there, you know the (points at typo).

I: Oh yeah that’s, that like kind of bracket there is just a

Anne: And B a gas? I dunno, if I probably did it again now I’d say E would proabably be a gas.

I: So E as a gas and

Anne: Is it? Is it actually a gas?

I: Yeah it is yeah.

Anne: E is a gas.

I: And B... what would you say B is?

Anne: Probably a gas as well.

I: So you'd still go with a gas as well.

Anne: What would it be?

I: Why... if I go through it

Anne: Oh sorry yeah yeah yeah

I: I don't want to influence what you're saying
Anne: Yeah.
I: So then at the very end, you know we can
Anne: Yeah
I: We can go through all the answer no bother.
I: I'm just wondering there for C... let's say you've C and A as solids and D as a liquid.
Anne: Yeah
I: Or as a ... no yeah a liquid
Anne: A liquid yeah
I: But you're torn between liquid and solid is it for D? You're not sure
Anne: Yeah. But I probably would, like I would probably stick with the liquid because it's more separate than...
I: Okay. So it's separated out more?
Anne: Yeah but I know then that there's different, am, atoms there as well, d'you know.
I: Mmhmm
Anne: Well then you ask that later on is it?
I: Mmhmm
Anne: In chemical composition but am... am... yeah I probably would stick with liquid.
I: Okay.
I: And E then you're saying...
Anne: I'd go with that one as gas.
I: Okay.
I: So for the second part there? Pure substance, heterogeneous mixture or homogeneous mixture. Do you know...
Anne: Yeah.
I: Do you remember what was the difference between heterogeneous and homogeneous?
Anne: Yeah. Hetero is like two different, different, you know not the same.
I: Okay. So two different...
Anne: Like I always think male female
I: Okay yeah so it's just it's made up of different things?
I: Different things yeah. And then homogeneous is all the same.
I: Okay.
Anne: And then pure is there's nothing else... in it.
I: Okay.
Anne: If that makes sense. But then... yeah pure is...
I: So you've C as pure because...
Anne: Yeah. Because there's nothing... let's say it's just say all triangles.
I: Okay.
I: And then you have, ah, A and E as homogeneous mixtures.
Anne: A and E. Yeah... that's all the same... oh because there's a pattern.
I: Okay. So a homogeneous mixture...
Anne: It's d'you know, it's square, square, diamond, circle... d'you know it's following a pattern almost.
I: Okay.
Anne: And then E is kind of the same as well it's... a pattern.
I: Yeah.
Anne: But then I said D and B were a little more shuffled.
I: Okay.
Anne: Well definitely D anyway looks heterogeneous because there's no real pattern there.
I: Okay. (pause) So if it's kind of random, then it's...
Anne: Yeah.
I: Random is heterogeneous is it?
Anne: Yeah. I think.
I: Okay.
I: And, ah, for down here?
Anne: Mmhmm.
I: So did you understand what you were being asked here [part 2(c)]?
Anne: Yeah.
I: And, ah, you have C and D as elements...
Anne: C and D as elements... yeah I guessed, I, I'd still say C is an element, say like carbon cause it's a pure substance or whatever.
I: Yeah.
Anne: E as a compound as you could say H2O.
I: Yeah
Anne: And then element and a compound is A and B.
I: So... for A there, where is... where are the compounds and where are the elements?
Anne: The compounds could be the... one's in the middle and then the elements could be just the little squares.
I: Okay. So the elements are the squares and the compounds are the circle diamond... together?
Anne: Yeah.
I: And B
Anne: Yeah I said that was an element and compound as well. You have you compounds (points to square-circle combination) and then diamonds are elements.
I: And then D?
Anne: I said element, I dunno why... I said element as well... oh elements (emphasising plural) yeah. I'd still say elements for that one.
I: Because you have...
Anne: Your triangles and your little kind of wheel thing.
I: Okay.
I: So the next one... were there any questions actually, that you found particularly hard?
Anne: Am... I, to be honest I actually found those hard [Question 2]. I did find those...
I: So Question 2?
Anne: Yeah. Yeah. And probably here now again [Questions 5 and 6].
I: Okay. Those are next two I was going to ask you about actually so...
I: Question 5 there... if you want to have another look?
Anne: [reading question] I probably would still go with that one [Tier 1 Response B].
I: Mmhmm
Anne: 'cause you've the two oxygen's and you've the two hydrogen's and there's... multiply by two, d'you know, there's two of them.
I: Okay. And are there any other one's that you'd be tempted by there?
Anne: Am... maybe that one [points at Tier 1 Response D]
I: Maybe D?
Anne: Yeah... maybe.
I: And why would you choose B over D?
Anne: Am, because there's two in the front [referring to the coefficient]. If there wasn't 2 in the front I'd go for that one [points at Tier 1 Response D].
I: Okay. I'm just wondering about A there. That one didn't...
Anne: Oh I didn't really look at that. Oh.
I: I'm not saying it's right or wrong now I'm just asking.
Anne: Am... I dunno... I just imagine that there would be two separate hydrogen peroxide, rather than a whole chain.
I: Okay. If that were written out how would it be written?
Anne: I'd probably say H four O four [H₄O₄]... is it O four [O₄], d'you know.
I: Okay. Okay.
I: Okay for your second one there...
Anne: [reading question] okay so I'm looking for water and oxygen. I'd probably still stick with this one [Tier 2 Response A].
I: Okay.
Anne: Because you've the... two water and the oxygen.
I: Okay.
Anne: But if I'd have gone for A there [in Tier 1] I probably would've gone for E there [in Tier 2].
I: Okay. Yeah.
Anne: D'you know.
I: Okay.
I: And so... your Question 6, if you want to... give it a quick read?
Anne: [reading question] Am... I probably would still say that one.
I: Mmhmm
Anne: [reads question again]
I: And why are you choosing that one?
Anne: Actually I dunno know I'm thinking here again.
I: So what are you thinking about?
Anne: Just...
I: So that's C you were going to choose?
Anne: Yeah but I'm just thinking now... because there's only two of them. So S... that's S O three [SO₃] I would say.
I: Mmhmm
Anne: Oh no. Each one is... is it each one... is it two for O two [O₂]... d'you know?
I: Say again?
Anne: Is it two little circles for O two [O₂], so it's one each, one O is it is a circle?
I: Yeah... so like that's two oxygen atoms there together.
Anne: Yeah. Well yeah I still think I'd stick with that one [Response C].
I: Okay. And if I were to highlight there 'closed container' would that affect your decision at all?
Anne: I don't think it would to be honest... maybe they'd be more tightly pack together.. maybe that [Diagram E]... oh wait now [counting] maybe that one...
I: When you're counting there what are you doing?
Anne: I'm saying [points at both sides of equation] two by three is six O and then two S .
I: So you're making sure it's still balanced?
Anne: Yeah. Like obviously 'closed container'... I didn't really... I just kind of looked at it but never really saw that there.

I: And did you take any information from the diagram at all? From the first diagram there.

Anne: Mmm... that one [points at molecule shown at an angle] just looks a bit different from the others [molecules] but...

I: Okay.

Anne: But the oxygens always kind of stay together in that one [stem diagram].

I: 'This diagram represents a mixture of S and O₂ molecules in a closed container' so that's what this is here.

Anne: Yeah. And down here is the products.

I: Yeah. 'which diagram shows the results after the mixture reacts according to the equation'.

Anne: Yeah so you're looking for three's not two's... down here... like three [points at oxygen atoms on a SO₃ molecule] together

I: Yeah. So you understood that this diagram [the stem diagram] represents the first...

Anne: The first part of it yeah.

I: And that the products then was one of these?

Anne: Oh yeah yeah.

I: Okay.

I: Am... so just Question 7 there, if you want to...

Anne: Yeah. I was looking at that a little bit earlier. [Reading question]... it's because of the, the 3p... it's another orbital... d'you know what I mean it's a p-orbital but... [reading question]

I: So... it's because there's... a 3p orbital in aluminium and there isn't one in magnesium?

Anne: Yeah. Yeah. But... [reading question]... but as you move down The Periodic Table... the ionisation energy... decreases doesn't it? No... it's across, yeah, it's moving across the ionisation energy decreases... from magnesium to aluminium isn't it?

I: Well you see there [pointing at diagram in stem] that there's a pattern like aluminium should be going up but it's actually lower.

Anne: Oh okay so it should be increasing, as in ionisation energy increases across. I didn’t really look at that [the diagram]. Okay. And [reading from question] why would it be that?

I: Yeah. So why is this decreasing?

Anne: [reading question]...

I: Do you think, let's say, can you understand all of those options?

Anne: Am some of them. To be honest I find this really hard, this part [point at response options].

I: Yeah.
Anne: I find it, I dunno. We’ve done loads of modules in it but I still find it really tough.

I: Mmm.

Anne: I just, like, d’you when you’re doing the arrows and things, I just don’t really get… about that really.

I: Yeah.

Anne: But I, I honestly can’t give you a proper answer for that one really because I’d, I’d probably just guess it. I wouldn’t even know to say now, d’you know, the way the pattern is going that way but you could say that why is phosphorus going like that and why is isn’t it going… or maybe that’s…

I: Well I suppose you could say it’s a similar question.

Anne: Yeah.

I: But all you’re focusing on here is aluminium and magnesium.

Anne: Yeah.

I: And why there is a difference. Would you be able to say any reason why ionisation, in general, ionisation energies, why would an ionisation energy be higher or lower or what does it depend on?

Anne: The ionisation energy is lower in this one because it’s farther away. Would that be a… I don’t know.

I: So one of the reasons is how far away the electron is from the nucleus?

Anne: Yeah. Yeah. And there’s a balance, like you know, like that one’s full and that one’s not full.

I: Okay. Okay so you’ve… so that’s you’ve selected A but…

Anne: I don’t think I’d put that one again. I’m not removing it from the 3s, there’s nothing being removed from the 3s… you know of magnesium… s is still full here and s is still full here.

I: But, so if I… so if I am going to ionise something, how am I doing it?

Anne: You’re adding an ion to it.

I: Okay. So here for the one-s two-s two-p three-s…

Anne: Yeah

I: So the first ionisation energy of magnesium… will that electronic configuration change at all?

Anne: It would, am… if it was given, if it was in a… an ionic bond or… something.

I: Okay.

Anne: Yeah? Would it go increasing or decreasing? I’m not sure.

I: Okay. So ionisation energy… like, you’re not confident basically anyway about, about that question.

Anne: No. No.

I: Am, okay so just here Question 8.
Anne: [Reading question]… Like could you take carbon as an example here?
I: Sorry say again?
Anne: Could you take carbon as an example?
I: Yeah. You could take carbon.
Anne: Would it be carbon-six, carbon-twelve, carbon-fourteen. Would that be… you know if you’ve carbon-twelve then you’re mass will be twelve.
I: Okay.
Anne: So wouldn’t it be the mass of the particle?
I: Okay so you might say the mass of the particle now?
Anne: Yeah. I might yeah.
I: Okay. And, ah… am, are there any others that you’d consider?
Anne: Probably the size of the particles as well.
I: Okay and, ah, so what…
Anne: Oh no… the numbers of them… no I’d probably say the… or actually I don’t know would I… I wouldn’t be too confident. I think I’d actually stick with none of the above now, like.
I: Okay. So what, what is a mole in your own words?
Anne: Am… the… I’m trying to think how it gives it… like, am… the number of moles is equal to the mass of an element, say carbon, over its GMM.
I: Okay.
Anne: or the molecular weight.
I: Yeah. Yeah.
Anne: So… I suppose it’s just a kind of, am… it’s a figure really kind of. D’you know…
I: Okay.
Anne: Number of moles, how many moles are in an atom… what it’s made up of…
I: Okay.
Anne: Am…
I: So why would you say none of the above affect the number of particles in a mole of something?
Anne: Would it not be more the atomic number and…
I: Okay so you have… what are you thinking of… your equation?
Anne: I’m kind of thinking of The Periodic Table, kind of… carbon-twelve, carbon-fourteen…
I: Okay.
Anne: I don’t know. I’m, I’m… I really need to brush up on that.
I: Okay. Okay. And… so you didn’t attempt 9 there.
Anne: Yeah. I don’t know why… yeah… [reading question]… I was gonna probably say six ‘cause, you know… I dunno maybe I would say six.
I: And why six?
Anne: Because isn’t the… the number of atoms gonna be the mass when it’s… six electrons so it’d be six grams.
I: Okay.
Anne: I’m working that out in my head.
I: Okay. So as in
Anne: No they don’t… no because the mass of carbon is twelve grams. Yeah isn’t it? Carbon-twelve… when you measure the weight it is twelve?
I: Okay. Yeah on The Periodic Table it is twelve yeah.
Anne: Yeah. [Reading question]… maybe I would go with twelve.
I: Okay. So
Anne: But then you could say twelve divided by six gives you two… or it could be six because it’s one gram each. I dunno there’s a few.
I: And why would you divide it by six?
Anne: What?
I: You said twelve divided by six would give you two…
Anne: Because your atomic mass is there and you’ve six electrons so you might divide it by six to give each electron a mass.
I: Okay. Okay. Am… what’s the other one I wanted to ask you… am, I just notice here, as well, for any of these equilibrium ones why would you think maybe you didn’t attempt those?
Anne: Am…
I: Let’s say 17 or… is it clear or… have a read of it there now.
Anne: Am… [reading question]… I’d say, I dunno, I’m kind of… I don’t really like graphs too much. [Reading question]… it says ‘over time’ so you’re looking at it from the start to the end?
I: Mmhmm.
Anne: And equilibrium is a balance isn’t it? I, I think I just didn’t know an answer for it because… how do you know which you’ve a higher concentration of? D’you know, how do you know which is pushing the other one?
I: Which one is pushing which substance?
Anne: Yeah. D’you know what I mean?
I: Okay. Yeah. So you
Anne: In a way you could say… that one [Option A], you know, because it’s going up and down… but it’s not…

I: Okay. Maybe A?

Anne: But it hasn’t come to equilibrium there [Option A]

I: Okay.

Anne: That would be equilibrium there wouldn’t it [pointing at Option E]

I: So E? Okay.

Anne: Maybe it could be something like that [pointing at Option C] because it’s going up and then it could go down to concentration at equilibrium.

I: Yeah. Okay so there’s a lot of options there for you, you just weren’t sure which

Anne: No I wasn’t sure actually.

I: Okay. And, am… just the last one I’m gonna ask you there is Question 13. So you didn’t attempt that one either.

Anne: Oh Question 13 okay. [Reading question]… oh I remember looking at this one actually. [Reading question]… but they all do represent it don’t they?

I: Okay. So how, how so?

Anne: Well this [Option A] is the… d’you know the way you’d teach Junior Cert. Na-plus, Cl-minus [Na⁺Cl⁻]. Wait let me just count…

I: Well they are the correct number of electrons.

Anne: Okay.

I: So that’s A…

Anne: Wouldn’t that be correct? Na-plus Cl-minus [Na⁺Cl⁻]. [Reading question]… ionic compound… I remember, like, we did this, both of these ways for Junior Cert. You know we learn how to draw them out.

I: Yeah. A and D yeah?

Anne: Yeah. The this one looks like a solid and it is a solid.

I: Okay so that’s E yeah.

Anne: And then this is a solid [Option B]. That’s a lattice energy kind of isn’t it?

I: Okay. So you feel B and E are…

Anne:… looking like the solid.

I: Mmm.

Anne: I don’t think C.

I: Okay so C is the only one that you would… definitely rule out is it?

Anne: Yeah I think so.
I: And why would you rule out C?

Anne: It’s probably more a gas than… d’you know?

I: Okay. Okay. Am…

Anne: Just say like compared to those [Options B and E].

I: Yeah. So when you compare C to B and E you feel that… it’s not solid?

Anne: Yeah.

I: Okay. Am… okay so just a few final questions. I want to ask you… did you ever hear of this thing, like chemistry misconceptions, before you did that?

Anne: No I don’t think I did. We’re hearing a lot about it this year.

I: Okay and where are you hearing about it now?

Anne: Mmm we’ve [name of a lecturer] for… we’ve [name of a lecturer] and [name of another lecturer]… we’ve the two of them for science education modules and we heard loads about misconceptions.

I: Okay. And what, what have you heard about it?

Anne: Am… well we haven’t gone into it in much depth yet but you know a student be in your class and you might feel that you’re teaching it wrong or it could be something that they picked up from third year. So you’ll be teaching it and you don’t want to take it for granted that they know it ’cause then that misconception could carry on.

I: Okay.

Anne: I think everyone would.

I: Have you heard any examples yet maybe or…?

Anne: Am… wait I think I did hear her saying one… I think I took it down in my notebook [reaches into bag]

I: Oh it’s okay there’s no need to go get it.

Anne: Yeah I’m just trying to think… a lot of the time it’s kind of with atoms and things.

I: So… you have heard of some to do with that?

Anne: Yeah. Yeah.

I: Okay. And, am, so know from that …

Anne: You need to know yourself. You need to know yourself to be able to point out the… you have to put yourself in their shoes.

I: Yeah. Yeah.

Anne: You need to know what the misconceptions are.

I: Okay. And so if you were going teaching, is it something you would take into account?

Anne: Now I would.
I: Now you would, say if you were going for your fourth year Teaching Practice?

Anne: Yeah. Definitely.

I: And how would you… what would you maybe do differently? In your planning maybe or whatever…

Anne: Am… I think I’d probably… use, kind of, these little diagrams more often… because you can’t just talk about it all the time you need diagrams

Anne: But not too simplified either because they’re not going to be that simple, like say if it was a Leaving Cert. paper. Am… maybe, like, if you were doing… you know the bonding?

I: Yeah.

Anne: Say it’s more advanced in Leaving Cert. I’d start from scratch from Junior Cert. if I was teaching Leaving Cert. because other teachers might not be doing it.

I: Yeah.

Anne: Just, like, see what misconceptions there are rather than continuing and them getting confused.

I: Yeah. And, am, would you… as in during your teaching you would, let’s say, teach it from the basic up, let’s say.

Anne: I think so yeah.

I: Fairly basic anyway.

Anne: Yeah. And build it up yeah.

I: And, ah, do you think that you’d find out what the students think maybe as you were doing that?

Anne: Yeah ‘cause you could see… like if you were starting with basics they might be able to understand this question [pointing at Question 13] but then when start on bonding you could see if you lost a few.

I: Yeah.

Anne: Like so you would be able to say ‘why didn’t I do it better there now?’ So maybe something like that.

I: Yeah. Okay.

Anne: So I’d have it planned step-by-step.

I: And, am, is there any other comments you want to make on the test or on the topic?

Anne: Generally I wish I’d done a little bit in first year. ‘Cause… yeah we probably should have all done it in first year because there’s, these are some Leaving Cert. questions and…

I: Well half are from the Junior Cert. as well.

Anne: Yeah but it would have kind of given myself the cop-on to…

I: Well we’ll see because the first years did do it as well so [laughs]
Anne: Yeah well you know to… maybe at the end of first year, when you’re kind of about to go on TP and then get the results before you go on TP.
I: Mmm.
Anne: Because nobody probably really introduced the word misconceptions before… on second-year TP.
I: Yeah.
Anne: So you could go and, kind of, well you know that people, like students, might be slower but you know really they could be a bright student but just be carrying a misconception.
I: Yeah.
Anne: So it’s I think maybe something like that… if we’d learned it a little bit earlier.
I: Yeah.
Anne: ‘Cause I’ve loads of misconceptions. Like I need to sit down and learn a load of stuff now.
I: Well everybody does you know so…
Anne: Yeah. Yeah.
I: Thank you very much.
Anne: No problem.