Teacher responses to inquiry-based pedagogy in Irish post-primary schools: Case studies on the use of a virtual chemistry laboratory as a vehicle for educational change

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Abstract

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The lack of uptake of science subjects in Post-Primary Schools (Secondary/High Schools) and onto university is a continuous cause for concern, both nationally and internationally. In the Strategy for Science, Technology and Innovation Report (2006 – 2013), the Irish government highlights the need for a greater focus on investigative approaches, the assessment of practical work, and the more effective use of Information and Communication Technologies (ICT). The National Council for Curriculum and Assessment (NCCA) are currently attempting to address these issues through a revision of the current Irish science syllabi. This project describes the application of a Virtual Chemistry Laboratory (VCL), developed at Carnegie-Mellon University, Pittsburgh, to the Irish context in an attempt to address the aforementioned issues.

The research consisted of 4 stages employing primarily qualitative data collection methods. Stage 1 entailed interviews with teachers and educational stakeholders around issues relating to the use of a VCL within the Irish education system. Stage 2 involved a case study of 5 teachers integrating the VCL into their classroom practice in whatever manner they saw fit. Pedagogical Content Knowledge (PCK) was used as a research lens to capture features of teachers’ practice. Stage 3 followed on from Stage 2 with a case study of 4 teachers directed to use the VCL in a guided inquiry manner. Research tools included Inquiry Science Implementation Scale (ISIS), Reformed Teaching Observation Protocol (RTOP), and Student Self-Assessment. Finally, Stage 4 required teachers to suggest problems they would like to be included on the VCL.

The key findings of the research highlight the potential of the VCL as an ICT tool to act in an integrative manner to mediate and facilitate holistic change, rather than simply focusing on one individual aspect of change, e.g. concept development, making curricular intentions explicit (inquiry), new student and teacher roles, shared meaning in the change process (teacher ownership), curricular alignment, assessment of practical work or teachers as curriculum makers. The VCL provides a vehicle for change with the potential to integrate all of these things. Despite this potential, the findings also indicate a conflict in teachers’ practice between the entrenchment of cultural norms and change attempts relating to practical work, inquiry-based approaches, and the integration of technology. The findings would suggest that the high-stakes assessment is the seed of this conflict in teacher practice and it undermines many change efforts, in that it rewards mostly rote-learning. This is not to say that the attempts at change are not possible within the current assessment structure, but are significantly impeded by the cultural norms that the current assessment has created. In order to notably change how science is taught in schools, assessments must be developed that align with the espoused change efforts of the NCCA.
Declaration

I hereby declare that all work detailed in this thesis is my own. All use of other research and material throughout this thesis has been clearly cited and referenced.

Signed __________________________

Dermot Donnelly, University of Limerick
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<tbody>
<tr>
<td>BEME</td>
<td>Best Evidence Medical Education</td>
</tr>
<tr>
<td>BOD</td>
<td>Biological Oxygen Demand</td>
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<tr>
<td>CMU</td>
<td>Carnegie-Mellon University</td>
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<tr>
<td>DES</td>
<td>Department of Education and Skills</td>
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<tr>
<td>IBSE</td>
<td>Inquiry-Based Science Education</td>
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<td>ICT</td>
<td>Information and Communication Technology</td>
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<td>ISIS</td>
<td>Inquiry Science Implementation Scale</td>
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<td>IT</td>
<td>Information Technology</td>
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<td>NCCA</td>
<td>National Council for Curriculum and Assessment</td>
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<td>PCK</td>
<td>Pedagogical Content Knowledge</td>
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<td>PK</td>
<td>Pedagogical Knowledge</td>
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<td>REx</td>
<td>Real Experimentation</td>
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<td>ROSE</td>
<td>Relevance of Science Education</td>
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<td>RTOP</td>
<td>Reformed Teaching Observation Protocol</td>
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<td>SEC</td>
<td>State Exams Commission</td>
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<td>SLSS</td>
<td>Second Level Support Service</td>
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<td>SMK</td>
<td>Subject Matter Knowledge</td>
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<td>SSA</td>
<td>Student Self-Assessment</td>
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<td>TICTIM</td>
<td>Teacher ICT Integration Model</td>
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<tr>
<td>TPACK</td>
<td>Technological, Pedagogical And Content Knowledge</td>
</tr>
<tr>
<td>ULREC</td>
<td>University of Limerick Research Ethics Committee</td>
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<tr>
<td>US</td>
<td>United States</td>
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<tr>
<td>VCL</td>
<td>Virtual Chemistry Laboratory</td>
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<td>VE</td>
<td>Virtual Environment</td>
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<td>VEx</td>
<td>Virtual Experimentation</td>
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<td>VL</td>
<td>Virtual Laboratory</td>
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<td>VR</td>
<td>Virtual Reality</td>
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<td>ZPD</td>
<td>Zone of Proximal Development</td>
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Chapter 1: Introduction

1.1 Overview of the chapter
This chapter consists of six subsequent sections detailing

- the significance of this research (Section 1.2),
- the background of this research (Section 1.3),
- the research rationale (Section 1.4),
- the research questions guiding this research (Section 1.5),
- the structure of this research (Section 1.6), and
- a concluding summary of the chapter (Section 1.7).

1.2 Significance of this research
The declining uptake of science in Post-Primary schools (Secondary/High schools) has been a well documented and strong cause for concern in the science and the wider community over the last two decades, both in Ireland (Expert Group on Future Skills Needs, 2009; Report and Recommendations of the Task Force on the Physical Sciences, 2002; Matthews, 2007; Regan & Childs, 2003) and internationally (Barmby, Kind, & Jones, 2008; Bennett & Hogarth, 2009; Hassan, 2008). Post-Primary schools in Ireland consist of a Junior Cycle of 3 years known as the Junior Certificate (12-15 year olds), an optional year after the Junior Cycle known as Transition Year (15-16 year olds), and the Senior Cycle of 2 years known as the Leaving Certificate (15-18 year olds). In the Junior Certificate students do one encompassing subject of Science and in the Leaving Certificate, Science is split into the subjects of Agricultural Science, Biology, Chemistry, Physics and/or a subject of Physics and Chemistry combined. Science at Junior Certificate level is not compulsory in all schools and all science subjects for Leaving Certificate are optional. Students who complete Transition Year are given a taster for what Science subjects would be like for the Leaving Certificate. Matthews (2007) carried out a Relevance of Science Education (ROSE) Survey with 688 Irish Transition Year and Fifth Year students. This sample consisted of 330 girls and 358 boys with an average age of 15.5 years. Despite students’ acknowledgement of the importance of science and technology in society, a large majority of students did not want ‘to become a scientist’ (55 % of students
choosing the extreme disagree) or ‘to get a job in technology’ (44 % of students again choosing the extreme disagree). The findings noted that in terms of preferences for careers in science, both boys and girls favoured ‘activities that had a biological/medical/health theme’ (p.5).

These findings present a strong concern for the Physical Sciences. Matthews (2007) highlights various student science views, but the reasons as to why the above views exist are partly explained by the views students have of the Junior Certificate Science Syllabus. It was noted that students gave low ratings to core topics of the syllabus, such as ‘atoms and molecules’, ‘how plants grow and reproduce’, and ‘electricity’, even though a slight majority expressed positive views about the Junior Certificate overall (p.4). However, interest was expressed by both girls and boys ‘in how mobile phones, CDs or DVDs work’ (p.4). This may point to a need to revise the syllabus in terms of its relevance to today’s students. Riegle-Crumb, Moore, and Ramos-Wada (2011) detail more clearly other important factors in determining students’ aspirations towards science, such as student achievement, attitudes, and enjoyment. They also explain how these vary across different ethnic groups and thus note that there is ‘no singular solutions that will promote equity for all groups’ (p.17). In a study by Vedder-Weiss and Fortus (2011), they distinguished a difference in science motivation between traditional and democratic schools (students have greater choice about their learning), where students in the latter schools had a greater motivation to do science. They suggested this difference may not be a result of home influence, but more a result of school influences, such as instructional practices, organisation, and culture. They also noted that students in traditional schools perceive a greater emphasis on performance goals than democratic schools. Many other possible features in the difference between the two types of schools were suggested in terms of ability grouping, assessment, and student/teacher roles, but they noted that further research is needed. What can be taken from this study though is the importance of student involvement and decision-making in motivating their interest in science.

Figures quoted by the Report and Recommendations of the Task Force on the Physical Sciences (2002: i) highlight lower student interest in the Physical Sciences compared to the Life Sciences. In 2001, only 12 % of Leaving Certificate students kept on Chemistry and 16 % took on Physics, compared with 44 % of students who
took on Biology. The report also explains that students perceive the Physical Sciences as difficult subjects and as a result, difficult to get good grades in for their final examinations. The importance of these final examinations is that they determine college entry. This viewpoint has also been reinforced by Kellaghan and Millar (2003) and more recently by Matthews (2007), so it becomes apparent that this student perception of the Physical Sciences has not changed. The current Leaving Certificate examination consists of two sections A and B. Section A relates to 28 mandatory experiments students must complete over the two years of the Leaving Certificate course, while Section B relates to theory based questions. There are 3 questions in Section A and 8 questions in Section B (11 in total). Students have to answer 8 questions in total, at least 2 of which must be from Section A. Each question is worth 50 marks so there are 400 marks in total. The State Exams Commission (SEC) are responsible for setting the examination paper and as can be seen from the explanation of the structure of the paper, they are strongly focused on reliability of assigning marks.

In publication of the Strategy for Science, Technology and Innovation 2006 – 2013 (2006), the Irish government identifies the need to significantly change the nature of instruction of the Physical Sciences in Post-Primary schools, in recognition of the continuing decline in numbers taking science subjects through to Senior Cycle and beyond to university. The report stressed that this is critical in order to ensure national competitiveness in the global ‘knowledge’ economy and emphasises the need to focus on investigative approaches, problem solving, the assessment of practical work, and effective use of ICT. The Department of Education and Skills (formerly known as The Department of Education and Science, DES) again re-iterate in a Statement of Strategy for 2008-2010 the importance of tackling the number of students pursuing the physical sciences:

‘It is of critical importance that we reverse this trend and increase the number of students studying the physical sciences for Leaving Certificate, and pursuing engineering and science courses at third level.’

(Statement of Strategy, 2007: 2)

The National Council for Curriculum and Assessment (NCCA) are the government body responsible with the challenging task of tackling the poor uptake of the Physical Sciences in Post-Primary schools and implementing changes towards this end. The
NCCA works on a partnership model of curriculum change with schools. Since 2002, they have been engaged in consultation on the Senior Cycle curriculum and assessment with teachers, students, and management in schools. From early on in this consultation there has been a strong focus on

‘building on the strengths of the current system towards a senior cycle where ‘getting the Leaving’ remained important but where greater emphasis was placed on an improved relationship between the acquisition of skills and knowledge, on learners taking more responsibility for their own learning, and on improving the learning culture and environment in schools’.

(Towards Learning Report, NCCA, 2009)

This quote illustrates the NCCA’s awareness of the current school culture of students and teachers focused on ‘getting’ good grades in the Leaving Certificate. However, it is clear that the NCCA would like this focus to bring about other practices within schools. Following consultation with schools and research, the NCCA have outlined five ‘key skills’ that are central to teaching and learning across the Senior Cycle curriculum: information processing, being personally effective, communicating, critical and creative thinking, and working with others. It is envisioned that these key skills will become embedded within a revised Senior Cycle curriculum that has ‘more varied assessment arrangements’ (Towards Learning Report, NCCA, 2009).

Many of the suggested changes noted for the Irish Post-Primary School system fall in line with trends in the European community. In a European Commission Report, Rocard, Csermely, Jorde, Lenzen, Walberg-Henriksson, and Hemmo (2007) state that Inquiry-Based Science Education (IBSE) has proved its utility in improving students’ interest and attainment levels in Science, in particular girls, while it is also effective in invigorating teacher motivation. Also, they view a renewed school science teaching pedagogy based on IBSE as a means to encourage relationships between formal and informal educational stakeholders, such as firms, scientists, parents, and other kinds of local resources. Significant investment has been made at the European level towards implementing recommendations of the Rocard Report. One such European funded project looking to disseminate inquiry-based practices in science and mathematics is the Fibonacci Project (2010-2013), which has involvement from 21 European countries and is subsidised by up to 4.78 million euro (The Fibonacci Project Presentation Booklet, 2010). The dissemination strategy for the Fibonacci
Project is based around 12 reference centres across Europe that have expertise in the implementation of inquiry-based approaches to science and mathematics.

Myers-Kelson (2000) notes that the development of proactive lifelong learners requires a congruent assessment system which reinforces and models the approach to problems that is required of them. However, the current Leaving Certificate assessment system places a premium on content coverage, thus militating against a meaningful integration of the ‘key skills’ and inquiry-based practices within the current curriculum. Therefore, it is important that any attempt at curriculum change is reflected by the tools used to assess it. The NCCA’s concerns lie with how to effectively embed the ‘key skills’ within teacher practice, but to also consider assessment tools that reinforce and model the ‘key skills’. In terms of practical work a Virtual Chemistry Laboratory (VCL) could aid in this process. This research considers the former concern of teacher practice through the use of the VCL with some considerations in relation to the latter concern of assessment. The rigorous evaluation of the VCL’s potential for assessment will be considered in future work.

The use of simulation-based software is becoming more mainstream within science education both at tertiary level (Dalgarno, Bishop, Adlong, & Bedgood, 2009; Jara, Candelas, Torres, Dormido, Esquembre, & Reinoso, 2009; Su, 2008) and in Post-Primary schools (Ketelhut, Nelson, Clarke, & Dede, 2010). Virtual experimentation offers many potential learning gains: it gives space and time independency, it is low cost and easy to access, and overall it shifts the centre of learning from the teachers to the students (Georgiou, Dimitropoulos, & Manitsaris, 2007). What is clear is that virtual experimentation should provide opportunities for more inquiry-based learning and falls in line with many features of the NCCA’s key skills. However, the assessment of inquiry is problematic (Deignan, 2009), as it necessitates that both teachers and students have ‘new roles and responsibilities’ (van der Valk & de Jong, 2009) as distinct from traditional teacher-led classroom settings. This educational change is a complex one and concrete models of how it can take shape need to be developed. There are also issues as regards teachers’ perceptions of the use of ICT and willingness to integrate it into their practice in a meaningful manner.
A VCL can serve as an important enabling infrastructure that can support this educational change. The ways in which a VCL can facilitate the change process is through making inquiry explicit in terms of teaching, learning, and assessment, scaffold teacher adaptation to inquiry through multiple, high-quality problems exemplify the principles of inquiry, and provide teachers with the opportunity to take ownership of this educational change through their own development of problems. Both Fullan (2007, p.92)

‘To achieve large scale reform you cannot depend on people’s capacity to bring about substantial change in the short run so you need to propel the process with high quality teaching and training materials (print, video, electronic).’

and Penuel, Fishman, Gallagher, Korbak, and Lopez-Prado (2009, p.659)

‘Sustained, content-focused professional development is key to helping teachers gain practical knowledge of specific curricular activities and develop an understanding of what classroom instruction with the materials should look like.’

recognise the critical need to make the change process visible and explicit in action. It is hoped that in this way the VCL can act as a scaffold, and be of significant service to Irish teachers and the relevant stakeholders.

The net result of these changes in terms of students will be that they may take greater ownership of their learning of science and develop critical thinking skills that mirror those of practising scientists (Key foci of the NCCA). This will in turn lead to greater enjoyment, engagement, and understanding of chemistry for the Leaving Certificate through relevant and varied problems that can be supported through the infrastructure of the VCL. This would allow for great steps to be taken in tackling the entrenched perception of Chemistry as a difficult subject. Over time this would certainly cause students to more carefully consider Chemistry as one of their subject choices for the Leaving Certificate.
1.3. Background of this research

In 2000, staff from the Chemistry Department in Carnegie-Mellon University (CMU) set up the Chemcollective, an online repository of chemistry educational resources. Within these resources is a Virtual Chemistry Laboratory (VCL). This work proposes the application of this VCL to the Irish context, in particular examining how teachers react to the affordances to inquiry provided by the VCL (changes in role, interpretation of inquiry, time, and classroom management etc.). The VCL is very distinct and different from other Virtual Laboratories (VLs) in that it has a very open infrastructure in which all variables are left to the students’ experimental design (see Figure 1). Students can chose from a large database of solutions (stockroom on the left-hand side of Figure 1), mix them in whatever way they see fit on the workbench (centre of Figure 1), and see detailed solution information for each addition they make (right-hand side of Figure 1). Also, with an extensive homework repository the VCL provides students many affordances to challenge themselves to solve varying problems. The topics in the homework repository include molarity and density, stoichiometry and limiting reagents, quantitative analysis, chemical equilibrium, solubility, thermochemistry, and acid and base titrations. The VCL is a Java applet and is available free online and to download at www.chemcollective.org/vlab. There is also an authoring tool for the VCL that allows problems on the VCL to be modified.
The Chemcollective have carried out various research on the use of the VCL (Cuadros, Yaron, & Leinhardt, 2007; Yaron, Evans, & Karabinos, 2003; Yaron et al., 2006), particularly in terms of introductory college chemistry courses. Yaron et al. (2006: 179) highlight some key affordances of a VCL: it allows students the opportunity to easily connect their ‘mathematical problem-solving to performing an experiment’, students have greater flexibility in experimental design due to the safety of the VCL, and can more quickly alter variables within an experiment. The next section explains the rationale behind researching the use of this VCL in Irish Post-Primary Schools.

1.4 Research rationale

Practical work in schools has been shown to have many inherent issues, but it is also noted as a key reason in why many students chose to study science over other subjects (Report and Recommendations of the Task Force on the Physical Sciences, 2002; SCORE Report, 2010). Therefore, students’ enjoyment of practical work would suggest that practical work should be kept as a core part of science, but it is important that what students achieve from practical work is critiqued and that ways of improving the student learning experience are sought. With the increasing availability
of technology, virtual experimentation has emerged as a potential means to enhance the student learning of experiments. It is important to note that this is not an attempt to replace practical work, but to support, complement, and enhance it, in particular the “minds-on” as opposed to the “hands-on” aspects of scientific work. However, research on the application of a VCL within a Post-Primary School is lacking and thus the exact role a VCL would play in schools is unclear. Also, there are important considerations of how students, teachers, and other educational stakeholders would react to the use of a VCL.

The intended purpose of this research is to see how the VCL (explained in the previous section) could be adopted, adapted, and embedded into the Irish context in relation to Post-Primary Schools. This research would have a particular focus on teachers’ existing practice and how this practice can be supported towards greater IBSE through the use of the VCL. In attempting to carry out this research important findings would emerge that would have important implications for many contemporary areas in science education: practical work, inquiry-based approaches, and the use of ICT in schools. These findings would also have implications on a broader level in relation to educational change in schools.

Of key interest is how the VCL may provide an enabling infrastructure to effectively support, develop, and exemplify inquiry in practical work for all teachers and stakeholders. This would also be a strong interest of the NCCA in their attempts to revise the current science syllabi for the Leaving Certificate towards the key skills. The research would also be of interest to any person involved in science education and looking for ways of adequately supporting sustained inquiry practice in Post-Primary Schools. Teachers would have time to develop their understanding of inquiry through the infrastructure of the VCL as an example and in turn, could start to design their own problems on the VCL. The use of the VCL in this way could also impact on aspects of teachers’ practice outside the use of the VCL and even lead to more effective approaches for physical experimentation, science instruction in general, and increased collaboration (beyond the scope of this project).

This project would also have important consequences on the broader issue of ICT integration in schools and its effective use within schools. How teachers integrate the
VCL into their practice would shed light on their decision-making when faced with incorporating a new resource and the factors underpinning this. It would also be informative of the teaching methodologies ICT resources are being used to support. If teachers were then challenged to use an ICT resource in an inquiry framed manner, other important aspects of teachers’ practice would come to the fore. These aspects of teachers’ practice would be informative in further attempts to integrate ICT based resources into teachers’ practice. The next section outlines the research questions of this research.

1.5 Research questions

The nature of this project provides many potential angles of investigation as can be seen from the wide scoping nature of the issues touched on in the previous sections. The overall interest of the author lies in uncovering how the use of a technology (the VCL) may impact or be seen to impact on educational change towards more inquiry-based approaches in schools and the implications this has for current syllabi revision with respect to teaching, learning, and assessment. Hence, the primary focus of the project ultimately resides with teachers’ practice and the factors underpinning it. Other considerations include student responses to the VCL and input from broader educational stakeholders including the NCCA, the DES, the States Exam Commission (SEC, responsible for developing, assessing, accrediting and certifying Post-Primary School examinations in Ireland), and teacher educators.

The following two questions have been decided by the author as the core questions in helping to shape the research design:

1. What are stakeholders’ views of the current science culture in Irish schools and how does this relate to the integration of a VCL to support educational change in chemistry?
2. How can the VCL act as an enabling infrastructure for IBSE in teachers’ classroom practice?

For question two the following subset of questions applies:

a) How do teachers’ knowledge of the teaching of particular content relate to how they adopt the VCL within their classroom practice?
b) In what ways do teachers integrate an ICT resource into their practice?

c) In what ways does the teachers’ use of the VCL support inquiry-based approaches?

d) What are teachers’ and students’ reflections on the use of the VCL as a potential teaching, learning, and assessment tool?

These research questions will be explored in more detail in the methodology chapter (Chapter 3) and will be considered in light of the literature review (Chapter 2).

1.6 Structure of the thesis

The thesis consists of six chapters. These include the Introduction (Chapter 1), the Literature Review (Chapter 2), the Methodology (Chapter 3), the Findings (Chapter 4), the Discussion (Chapter 5), and the Conclusions (Chapter 6). The bibliography and appendices are included after Chapter 6. An overview of each chapter will be explained at the start of each chapter and each chapter will also end with a concluding summary of the key points discussed. Each page also consists of a header and a footer, detailing the page number and the relevant section for ease of navigation throughout the thesis.

1.7 Chapter summary

This chapter highlights the critical need for the nature of Physical Sciences instruction to change in Ireland and abroad, so as to encourage more students to pursue science subjects throughout secondary school and on to university. The problem with the Physical Sciences seems to focus on issues of relevance and interest to students, and there is also a gender dimension. IBSE and using ICT have been proposed by some as possible means to address these issues. However, there are many caveats to supporting both IBSE and ICT in schools. The NCCA are currently reviewing the Senior Cycle Syllabi in Ireland with a view to incorporating more IBSE and alternative forms of assessing practical work, and are interested in the role ICT may play in this process. Ultimately, it is teachers that matter if fundamental change is to occur. High-stakes assessment and its impact on teachers is seen by many as a major obstacle to change. The NCCA believe the incorporation of alternative forms of assessing practical work may support teachers in the enhancement of the quality of
practical work. The VCL offers an infrastructure that could readily tackle many of the issues raised, particularly through matching student skills and conceptual development in practical work (Abrahams & Millar, 2008). The VCL is in need of further development to realise its full potential, but it already provides an important starting point to highlight how important changes could be supported in taking shape. Through feedback from students, teachers, and stakeholders the VCL could make a unique contribution to the Irish education system and provide insight for other countries tackling similar issues.
Chapter 2: Literature review

2.1 Overview of the chapter

This chapter consists of five subsequent sections detailing

- the potential of ICT to act as a catalyst towards educational change (Section 2.2),
- an insight into teachers’ decision making (Section 2.3),
- educational change towards inquiry (Section 2.4),
- a virtual laboratory as an enabling infrastructure to inquiry (Section 2.5), and
- a concluding summary (Section 2.6).

2.2 ICT: A potential catalyst towards educational change in schools

2.2.1 Educational change: Understanding interactions in the school system

‘We need to know what change feels like for teachers, principals and students and we need to understand institutional and organisational factors that affect the occurrence of change through the interactions between government, teacher unions, schools and communities’ (Fullan, 2001: xi). Any effort at educational change that does not ‘address the underlying organizational conditions [of the school system] can be viewed as doomed to tinkering’ (Stoll & Fink, 1995: 80). This section explores some of the issues revolving around these key stakeholders responding to change initiatives in schools.

Educational change is dependent on ‘what teachers do and think – it’s as simple and as complex as that’ (Fullan, 2007:129). Korthagen (2010: 99) proposes a three level-model (Gestalt-Schema-Theory) to explain teacher decision-making. Firstly, teachers act primarily on the basis of their ‘gestalt’ i.e. ‘perception of the here-and-now situation’ (Korthagen, 2010: 101). In other words, how a teacher makes a decision in the spur of the moment. Secondly, these gestalts lead to teachers constantly forming and developing appropriate ‘schema’ i.e. ‘a conscious network of concepts, characteristics, principles, and so on, helpful in describing practice’ (p. 102). This schema relates to teachers ‘knowing how to act’ in a particular situation and can be
greatly enhanced through reflection. Finally, having developed appropriate schema, teachers can then unlock the door into ‘theory’. This relates to the importance of teachers reflecting on their own experiences.

This 3 level model could aid in explaining a great deal of teacher practice in relation to educational change and how it may be improved, particularly in relation to inquiry. Simply providing teachers with the theory of inquiry may have little effect, if any, on action taken by teachers in practice. When faced with educational change teachers are less likely to engage with policy documents as ‘the size and prettiness of the planning document are inversely related to the amount and quality of action’ (Fullan, 2007: 41). In a study on curriculum implementation through alignment (consistent, coherent and feasible for goals at all levels) of standards, curriculum, assessment, and professional development, Penuel et al. (2009) found that the alignment of curriculum materials with policies at the state level was insufficient for effective implementation. The views of teachers on the suitability of materials for teaching standards (schema) diverged from those of policy makers and professional developers, and despite involving a school wide participation the number of teachers involved had little effect on teachers’ perceptions of the coherence or use of the materials provided (again schema). It was also found that ‘professional development had little impact on teachers’ perceptions or on protocol implementation’ (p.671). Teachers were provided with many opportunities in workshops for hands-on practice in implementing protocols and there was also a system of mentors available for classroom-based support. On top of this teachers also received all the equipment they needed to implement the protocols. Despite these efforts teachers still rated the alignment of their professional development to their school’s goals as modest and implementation was disappointingly low. They highlighted the need for better tools to aid the development of ‘teachers’ construal of the relationship between standards and curriculum materials’ (p.656) as well as more planning time in school. This example highlights the need for a focus on teacher schema levels i.e. an awareness of their current schema and appropriately providing other means of ‘knowing how to act’ within their practice. From these experiences, teachers may then be supported to more adequately incorporate theory within their practice.
Chapter 2: Literature Review

The most effective source of help for teachers tends to be other teachers (Fullan, 2007:133). As reinforced by Tyack and Cuban (1995:10) teachers look towards resources, practical designs for change, and collegial support in bringing about change. This would lead to schema development and as grounds for engagement in educational theory (Korthagen, 2010). Ultimately, successful change processes require a ‘bias for action’ (Fullan, 2007: 41) i.e. conditions under which people become motivated to change. Priestley (2011) suggests the importance of strong leadership in encouraging and sustaining change, as it is a source of impetus and support for teachers, but that this also needs to be combined with teacher ‘participation, professional trust and autonomy’ (p.20).

Structural and cultural changes to schools make little improvement, unless the importance of teachers is taken into account from their construction of ‘the reality of educational practice on a day-to-day basis in their schools and in their classrooms’ (Helsby, 1999: 30). This is not surprising as any form of change leads to intensification of teachers’ work by adding burdens to a job that is already excessively demanding (Hargreaves & Evans, 1997: 4). However, many teachers are interested in adopting change in their classrooms and ‘will do so under the right conditions’ (Fullan, 2001: 60). What is needed for effective educational change is ‘reculturing’ (Fullan, 2007:25) of teacher schema and this can only come about through the development of shared meaning in the change process which ‘is at the heart of the matter’ (Fullan, 2007: 42).

Students can also play a great role in educational change in helping to be part of the solution and in many cases they can actually provide better ideas than those already considered (Fullan, 2001: 162). Unfortunately, in many educational change initiatives students are ‘vastly underutilized resources’ (Fullan, 2001: 162). As a result, students oftentimes ‘appear increasingly disenchanted’ with school’s failure to engage their deeper concerns (Trant, 1998). Despite the obvious importance of student voice, it has been found that students are ‘continuously neglected, even actively denied, any sort of role in their school’s improvement programs’ (Fletcher, 2004).

Moving from internal factors influencing school culture to external factors outside schools adds another dimension to the issues that must be considered. In curriculum
reform efforts towards assessment, Trant (1998) highlights various underlying tensions in the Irish education system between teachers, curriculum developers, the Department of Education and Science (DES, now known as the Department of Education and Skills), and teacher unions. He notes the ‘hostility from the guardians of the system’ (p2). For example, teachers can feel a lack of ownership in curriculum development and therefore do not readily engage with it (Trant, 1998). Fullan (2001: 87) reinforces this notion in that ‘local school systems and external authority agencies have not learned how to establish a processual relationship with each other’.

In examining trends in testing and accountability reform in the United States over the past decade, Supovitz (2009: 222) argues that there is a question of ‘whether, in practice, curriculum and standards are being aligned to the tests, or whether (as is more appropriate) the tests are being aligned to the standards’. Current large scale assessments provide limited use in terms of instructional guidance for teachers as there is no insight into student thinking or misconceptions and as a result, motivate superficial changes in teachers’ practices towards content coverage and test preparation activities (Supovitz, 2009: 212). Supovitz (2009) stresses a greater need for ‘a more comprehensive system of assessment’ with different assessments integrated into it and he believes with technological advances this integration is more feasible than ever.

The above discussion highlights some important areas in need of change and what shape these changes might take. In summary, the key findings from the literature to guide this research are:

- Educational change involves a change in culture and therefore necessitates the construction of shared meaning from all people involved so as to influence teacher schema.
- Teachers are most strongly guided by other teachers and are less influenced by policy documents.
- Change requires a bias for action, and must focus and build on that action in the classroom to develop new schema.
- Curricular alignment is not enough – a rich and comprehensive set of resources that exemplify curricular intentions is needed.
• Change must encourage collaboration.

Ultimately, in educational change, partnership based on co-operation, and the recognition of the rights and responsibilities of all involved is required (Trant, 1998). As the educational change being proposed for this project involves ICT this area will now be considered.

2.2.2 Educational reform efforts using ICT

Many researchers believe the question of whether computers should be used in schools is a non-issue and believe instead, that the concentration has now shifted to a paradigm of how computers can be used effectively for new opportunities in teaching and learning (Valanides & Angeli, 2008), while other researchers have also included the potential of computers to support new opportunities for assessment (Nix & Wyllie, 2011; Terzis & Economides, 2011; Webb, 2005). However, some researchers maintain the paradigm of questioning why computers should be used in schools before the how should be considered (Cuban, 1986, 1993; Postholm, 2006). Some of the uses of computers in terms of teaching science concepts are (i) to teach concepts considered too abstract to be taught through traditional methods, (ii) to support constructivist learning, (iv) to support inquiry-based pedagogy (Valanides & Angeli, 2008). Despite the differing paradigms the potential utility of ICT is largely agreed upon. However, many school obstacles need meticulous consideration if the new affordances of emerging technologies are to be effectively utilised.

Many barriers must be overcome to bring about successful integration of ICT within Post-Primary school classrooms. Ertmer (1999) described a simple model of two types of barriers, first- and second-order, that are commonly cited as issues in ICT integration. First-order barriers refer to missing or inadequately provided resources, such as equipment, training, and support. These are barriers that are easily removed once money is provided and hence, are usually the first barriers concentrated on in reform efforts. For example, in a multiple case study of three universities using software called CyclePad for thermodynamics, Baher (1998) noted difficulties in using the software, such as a lack of computer facilities, constraints of the courses, and student scheduling. Second-order barriers are ones that impact on fundamental
change and are typically rooted in teachers’ core beliefs, and are therefore the most significant and resistant to change. These beliefs revolve around issues relating to teacher-student roles, teaching methods, organizational and management styles, and assessment types. Teachers’ knowledge of practice, underpinned by beliefs, is difficult to articulate as it is oftentimes tacit and implicit within the practice of teachers (Berry, Loughran, Smith, & Lindsay, 2009).

Zhao, Pugh, Sheldon, and Byers (2002) presented an expanded model of barriers to technology integration. They identified 11 salient factors that influence the success of technological innovations in classrooms. These factors were placed within three interactive domains of the teacher, the innovation, and the context. The factors within the first domain, the teacher domain, will be discussed in the next section. The factors in the second domain, the innovation domain, revolved around two areas: distance and dependence. The first area, distance, referred to the deviation of the innovation from the status quo. This encompassed three sub-areas within distance: distance from the existing school culture, distance from existing practice, and distance from available technological resources. The second area, dependence, referred to how much an innovation relied on other people or resources, in particular people or resources that are beyond the innovator’s immediate control.

The third domain, the context, had three aspects that were of key importance to the impact of an innovation. These were the human infrastructure, the technological infrastructure, and the social support. The first aspect, human infrastructure, refers to organizational preparation to support technology integration in the classroom. The second aspect, the technological infrastructure, refers to how much resources are currently available in a school to meet the needs of the innovation. The third aspect, the social support, refers to the extent to which peers support or discourage the innovators.

Various studies on the implementation of ICT innovations in schools highlight factors of success or failure that can be related to Zhao et al. (2002)’s three interactive domains (for examples see: Brinkerhoff, 2006; Chen, Looi, & Chen, 2009; Lowther, Inan, Strahl, & Ross, 2008). In a study by Tondeur, Devos, van Houtte, van Braak, & Valeke (2009) of 527 primary school teachers in Belgium, they found that schools
classified with greater structural and cultural characteristics (context domain) had a greater frequency of educational ICT use. Similarly, it was argued that the development and dissemination of new practice using ICT is not just impacted by the availability of reliable resources, but also by a supportive organizational culture (social support factor) and a collegial work environment (Deaney & Hennessy, 2007).

In terms of the Irish context, a study on the historical development of ICT within Irish Post-Primary schools (McGarr, 2009) highlighted significant trends between ICT initiatives and the resulting ICT use in schools. It was found that despite ICT reform efforts little influence on teachers’ practice had occurred. Teachers’ ICT use had in most cases developed independently of these reform efforts, in particular within informatics subjects where teachers put a greater onus on learning about the particular ICT, rather than learning with it. Issues for consideration from the study expressed the need for future initiatives to be presented as teaching and learning initiatives, and not as ICT initiatives. Also, it was recommended that future ICT policy needs to be mindful of previous ICT initiatives in schools and how current teacher ICT use affects external ICT initiatives. These findings are of concern in that teachers’ level of integration of ICT within their subject area can reinforce gender stereotypes associated with these subjects and can act as one indicator of student subject choices (Abbiss, 2009).

This section has discussed some of the important issues to consider for ICT based reform efforts in Post-Primary schools. In summary, the key findings from this literature to guide this research are:

- Both the why and the how of integrating technology in schools needs be carefully considered.
- Effective ICT integration is inherently difficult, in particular in terms of addressing teacher beliefs.
- Change attempts need to be mindful of the current school system and of previous change attempts.
In the next section the discussion will narrow to matters specifically relating to ICT integration from the perspective of the teacher as the teacher’s role in ICT-based learning environments is of significant importance (Lim, 2007).

2.2.3 The role of the teacher’ beliefs in ICT integration

When looking at factors that affect technology use the teacher is ‘naturally’ the first person one can look to (Zhao et al., 2002). In the teacher domain, Zhao et al. (2002) explained three factors associated with the teacher that impacted technology integration in classrooms: technology proficiency, pedagogical compatibility, and social awareness. The first factor refers to not just knowledge of the technology but also its enabling conditions. Schibeci, MacCallum, Cumming-Potvin, Durrant, Kissane, and Miller (2008: 318) present a useful 4-stage framework that details this teacher progression in proficient technology use:

- ‘Stage 1: Where’s the ON button? ’
- Stage 2: Black line mastery
- Stage 3: Routine student use
- Stage 4: What’s in the curriculum?’

Stage 1 focuses on learning the technical aspects of the ICT and developing confidence with it. Stage 2 refers to the use of ICT for particular tasks in the current curricula by students and the teacher. Stage 3 relates to regular use of ICT and learning that is outside of the sphere of the ICT itself. The final Stage 4 looks at the bigger picture of curriculum development and school change resulting from the use of the ICT. Schibeci et al. (2008) noted in their study of 12 schools that the majority of the 200 teachers demonstrated characteristics specific to Stages 1 or 2, fewer teachers reached Stage 3, while there was no real evidence to suggest any had reached Stage 4.

It is important to have an awareness of what stage each teacher may be at in terms of their use of technology, but the second two factors that Zhao et al. (2002) note may uncover deeper explanations of teachers’ ICT integration i.e. pedagogical compatibility and social awareness. Pedagogical compatibility refers to the compatibility of the teacher’s pedagogical beliefs and the technology being used. Social awareness highlights the significance in the ability of a teacher to negotiate the social facets of the school culture. This social awareness relates importantly to the fatalist nature within the teaching profession (Portelli, 2010) in that teachers believe
change to be beyond their control. The rest of this section is going to expand on these two factors under a broader umbrella of teacher beliefs as they are not necessarily specific to technology. If teachers’ use of technology is to change then their beliefs about the technology has to change (Russell, Bebell, O’Dwyer, & O’Connor, 2003), but teachers’ broader beliefs may need to be addressed first. However, changing the underlying beliefs of teachers in terms of teaching and learning and their use of ICT is always a challenge (Lim, 2007).

Within schools some teachers still hold the belief that they can keep out change by shutting the classroom door, while other teachers concur that this is too much of a simplistic description of how their work as teachers relates to the wider society (Robertson, 1996). More recently, in a study of English Post-Primary school teachers in core subjects, such as English, Maths, and Science, the teachers did feel the inevitability and acceptance of the role of technology in education (Hennessy, Ruthven, & Brindley, 2005: 185). These teachers, however, also expressed an air of caution to some forms of technology use portraying a reflective and critical standpoint on the use of ICT to support learning. It is clear that the adoption of any new technology depends on the values and beliefs of teachers about the importance of the ICT for learning (Webb & Cox, 2004).

Sorienta and Jimoyiannis (2008) categorised 3 discrete groups of physics teachers from their examination of teachers’ beliefs and perceptions of laboratory and ICT supported instruction. This could easily be broadened to all science teachers. The 3 groups they presented were (i) traditional, (ii) non-traditional, and (iii) undecided teachers. Firstly, the ‘traditional’ teachers had beliefs and perceptions dominated by the rigorous presentation of ‘content knowledge based on the textbooks and by conventional paper-pencil problem solving’ (p.198). These ‘traditional’ teachers were unwilling to use ICT within their classroom practice. Secondly, the ‘non-traditional’ teachers had educational beliefs of a student-centred orientation and are positive about ICT within their practice. Finally, ‘undecided’ teachers combine beliefs and approaches of traditional and non-traditional approaches in integrating ICT into their practice. Factors highlighted that were reflective of these belief structures were the teachers’ ‘teaching experience, age, school type, and ICT competence’ (p.198).
In a study of science teachers’ beliefs and practices (Monsour, 2009), it was highlighted that not all beliefs are reflected in practice. Teachers explained that there are many barriers that hinder them from putting their beliefs into action, for example the changing of teaching approaches under the pressures of preparing students for examinations. Hence, it was explained that an understanding of the role of external influences e.g. curriculum, principals etc. was important to make sense of teachers’ mismatches between their beliefs and practice. Significantly, these influences militated against constructivist approaches. This mismatch has also been reported in other research (Ertmer, Gopalakrishnan, & Ross, 2001; Fang, 1996). Ertmer (2005) highlighted the importance of sorting through the apparent contradictions of teacher beliefs and practices, in order to understand their use of technologies. However, she notes these beliefs can be tacit and the difficulty with the contradictions is determining what belief caused what action.

Dexter, Anderson, and Becker (1999) found that teachers who adopted more progressive teaching practices found computers helped them change, but the teachers did not view computers as a catalyst to changing their practice. Instead, the teachers cited catalysts, such as reflection upon experience, classes taken, the context, or the culture of the school. These factors aided in the knowledge construction process of teachers in terms of what they felt worked and did not work. Webb (2005) explains ICTs from the point of view of the affordances they provide to support learning, and the need for teachers and curriculum developers to see how these affordances could be used to support other innovations, such as cognitive development, formative assessment, and new science curricula.

Baggott La Velle, Wishart, McFarlane, Brawn, and John (2007) echo the importance of ICT as a tool that allows teachers to transform the learning in their classrooms as it aids them in the development of new Pedagogical Content Knowledge (PCK) domains (Shulman, 1987) i.e. new ways in how they make concepts understandable for students. From a knowledge of how ICT affordances can support other innovations combined with a knowledge of learners and pedagogical content knowledge, teachers can work with students to develop ICT-rich learning environments that provide appropriate affordances to student learning (Webb, 2005).
Therefore, in understanding teachers’ use of any new technology it would be important to grasp their PCK.

This chapter section has looked at educational change through the use of ICT and how teachers react to innovations within their classroom. Important points emerging from this literature are:

- Teachers need time to develop their technology use, but still may not reach a stage of questioning the curriculum. This highlights the importance of scaffolding adequate professional development.
- Teacher beliefs, not just specific to technology, need to be addressed. An awareness of how these beliefs may differ from practice is also important.
- Technology would not solely cause improvement in teachers’ overall practice, but improvement may result more on teachers’ reflection upon using the technology.

This literature highlights the difficulty in understanding teachers’ beliefs and practices, hence important research tools are needed to make teachers’ beliefs and practice far more explicit. The next chapter section will explain the construct of PCK as a means to gaining a deeper insight into teachers’ knowledge, practice, and their use of ICT thereof.

### 2.3 An insight into teachers’ implicit knowledge

#### 2.3.1 Pedagogical Content Knowledge (PCK)

Shulman (1986) proposed the concept of Pedagogical Content Knowledge (PCK) as a missing knowledge link between teachers’ Subject Matter Knowledge (SMK) and their Pedagogical Knowledge (PK). In essence it encompassed how subject matter was understood and thus internalised by teachers, and then the decisions made by teachers as to how this content was structured and communicated in a way that could maximise student learning. Shulman (1986) explained PCK as the ‘ways of representing and formulating the subject that make it comprehensible to others’. In trying to elaborate on where PCK fell within the ‘knowledge base’ of teaching
Shulman (1987) attempted a list of seven categories that would constitute a ‘knowledge base’ of teaching beyond simply focusing on PCK. The seven areas he listed were

1. ‘Content knowledge;
2. General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;
3. Curriculum knowledge, with particular grasp of the materials and programs that serve as “tools of the trade” for teachers;
4. Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
5. Knowledge of learners and their characteristics;
6. Knowledge of educational contexts, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and
7. Knowledge of educational needs, purposes, and values, and their philosophical and historical grounds.’ (p.8)

Much research has evolved from this based on the knowledge teachers draw upon, with a great deal of research focused on PCK. Ben-Peretz (2011) selected nine papers from the journal of *Teaching and Teacher Education* (TATE) ranging from 1988 to 2009 that related to teacher knowledge. The papers were analysed in terms of their definition of teacher knowledge and their emphasis on one or more of the kinds of knowledge suggested by Shulman (1986). Ben-Peretz (2011) notes that the definition of teacher knowledge has expanded beyond teacher knowledge related to teaching particular content. Instead teachers have greater knowledge of global issues, multiculturalism, and societal issues. However, these are issues that can still be noted as falling within Shulman’s knowledge of educational contexts.

PCK is argued as an established (Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001) and useful (Abell, 2008) construct in educational research. However, other studies exist to caution against the assumption that teachers’ SMK affects the teaching approaches adopted (Deng, 2007; Lederman & Gess-Newsome, 1992; Zeidler, 2002). To this end, Lederman and Gess-Newsome (1992) cautioned against PCK research devoid of direct observations. These differing viewpoints may offer a significant insight into why the construct continues to be a disputed topic with many differing responses to Shulman’s conception of PCK being offered. These viewpoints are most likely very valid, but unfortunately for some research on PCK, a clear and
comprehensive explanation of how researchers’ ideas build on or distinguish from Shulman’s original conception of PCK is lacking. The problem with this is that new links being made and the extended use of terms are not clarified clearly in light of Shulman’s original work. Therefore, the intended use of the construct is not always apparent. Ball, Thames and Phelps (2008: 394) note this in their argument that PCK has been used ‘as though its theoretical foundations, conceptual distinctions, and empirical testing were already well defined and universally understood’. A more explicit and coherent use of PCK by researchers in framing their studies has been advocated (Abell, 2008: 1407). This section will look at interpretations of PCK from the research literature, as developed by Shulman (1986).

Shulman (1986) described PCK as an ‘amalgam’ of subject matter content knowledge and pedagogical knowledge, and of key interest as it ‘identifies the distinctive bodies of knowledge for teaching.’ (p.8). Researchers have wrestled with the place and relationship of PCK and the other knowledge types within this categorisation, with many conceptualizations being offered. This is clear from Lee and Luft (2008)’s table of the different conceptualizations of PCK (Table 1). Other examples of these will now be discussed.
Table 1. Different conceptualisations of PCK

<table>
<thead>
<tr>
<th>Reference</th>
<th>Knowledge of</th>
<th>Subject Matter</th>
<th>Representations and Instructional Strategies</th>
<th>Student Learning and Conceptions</th>
<th>General Pedagogy</th>
<th>Curriculum and Media</th>
<th>Context</th>
<th>Purpose</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shulman (1987)</td>
<td>a</td>
<td>PCK</td>
<td>PCK</td>
<td>a</td>
<td>a</td>
<td>a</td>
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<tr>
<td>Tamir (1988)</td>
<td>a</td>
<td>PCK</td>
<td>PCK</td>
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<tr>
<td>Grossman (1990)</td>
<td>a</td>
<td>PCK</td>
<td>PCK</td>
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<td>PCK</td>
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<td>PCK</td>
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<tr>
<td>Marks (1990)</td>
<td>PCK</td>
<td>PCK</td>
<td>PCK</td>
<td>b</td>
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<td>b</td>
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<tr>
<td>Cochran et al. (1993)</td>
<td>PCKg</td>
<td>b</td>
<td>PCKg</td>
<td>PCKg</td>
<td>b</td>
<td>PCKg</td>
<td>b</td>
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<td>Fernandez-Balboa and Stiehl (1995)</td>
<td>PCK</td>
<td>PCK</td>
<td>PCK</td>
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<td>PCK</td>
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<tr>
<td>Magnusson et al. (1999)</td>
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<td>Carlsen (1999)</td>
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<tr>
<td>Loughran et al. (2001)</td>
<td>b</td>
<td>PCK</td>
<td>PCK</td>
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<td>b</td>
<td>PCK</td>
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</tr>
</tbody>
</table>

Notes: a, distinct category in the knowledge base for teaching; b, not discussed explicitly; PCK, pedagogical content knowledge; PCKg, pedagogical content knowing.
Veal and MaKinster (1999) presented two taxonomies allowing for what they described as ‘a relatively comprehensive categorization scheme for future studies of PCK development in teacher education’. These taxonomies were a General Taxonomy of PCK (Figure 2) and a Taxonomy of PCK Attributes (Figure 3). In the General Taxonomy of PCK, Veal and MaKinster (1999) argued three types of PCK that teachers demonstrate: general, domain-specific, and topic specific (Figure 2). Based on their definition, general PCK refers to having a good understanding of pedagogical concepts that are more specific than general pedagogy as the concepts and strategies used are specific to the disciplines, domain-specific PCK refers to subject matters within a particular discipline, e.g. Biology, Chemistry, Physics, and topic-specific PCK refers to concepts within the subject matter.

![Figure 2 - General Taxonomy of PCK (Veal & MaKinster, 1999)](image-url)
The Taxonomy of PCK Attributes (the second taxonomy, Figure 3) is a hierarchical structure for PCK and its attributes. The structure is meant to suggest the importance of content knowledge and knowledge of students, and it is on these that the other attributes can be developed more thoroughly. It is of course possible for teachers to have a knowledge of the higher attributes, but Veal and MaKinster (ibid.) argue that these attributes are integrated better with a developed knowledge of content and of students. This taxonomy does not represent the core aspect of PCK in its structure i.e. the important interaction of pedagogy and content. However, there certainly are many comparisons that can be made with the structure and other research (Barnett & Hodson, 2001; Cochran, DeRuiter, & King, 1993; Magnusson, Krajcik, & Borko 1999).

Figure 3 - Taxonomy of PCK Attributes (Veal & MaKinster, 1999)
Magnusson et al. (1999) explained their interpretation of PCK graphically with the intended aim to show that PCK is a result of a transformation of knowledge of 3 areas: pedagogy, subject matter and context. This is a broader definition of PCK than that of Shulman’s (1986, 1987) and differs from Veal and MaKinster (1999) with a greater emphasis placed on context. Magnusson et al. (ibid) conceptualized PCK as consisting of five components (a) orientations toward science teaching – this relates to teachers’ knowledge and beliefs about the aims of teaching science to a particular level (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students’ understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. This interpretation has been adopted, adapted, and largely agreed with in other research (de Jong, van Driel, & Verloop, 2005; Henze, van Driel, & Verloop, 2008; Käpylä, Heikkinen, & Asunta, 2009).

Unlike Magnusson et al. (1999), Cochran et al. (1993: 266) explained PCK as an integrated understanding by teachers of four areas: subject matter content, pedagogy, student characteristics, and the environmental context of learning. Also, Cochran et al. (ibid) highlighted the dynamic nature of PCK by coining the phrase PCKnowing. The purpose of this was to explain that the areas listed above should not be considered in isolation, but experienced simultaneously by teachers, so as to develop their knowledge on these areas concurrently.

Barnett and Hodson (2001) differ from Magnusson et al. (1999) and Cochran et al. (ibid) by not directly including context within the PCK framework. They instead coined the term pedagogical context knowledge as a means to indicate that good science teachers’ knowledge, actions, and thoughts are located in the finer points of everyday classroom experience. The sources of this knowledge were explained as both internal e.g. reflection on teaching and external e.g. subject matter knowledge and school policies. Within this pedagogical context knowledge framework four knowledge areas were included: academic and research knowledge, professional knowledge, PCK, and classroom knowledge. As can be seen this knowledge categorisation differs quite significantly from Shulman’s (1987) categorisation.
Deng (2007) provides an interesting insight into assumptions underlying PCK. He argues the transformation of subject matter is not just a pedagogical task, but also a complicated curricular task in relation to developing a school subject or course of study. Deng critiques Shulman’s conceptualization in that it is incomplete and should focus more on the ‘heart and core of teaching and learning – the curriculum’.

A more recent expansion of the PCK construct has occurred in relation to where ICT fits within teachers’ knowledge. Rodrigues (2003) discusses ICT Pedagogical Content Knowledge. Ferdig (2006) coined the term Technological PCK (TPCK, more commonly known as TPACK: Technological, Pedagogical and Content Knowledge). How TPACK relates to or builds on PCK is not made explicit by Ferdig (ibid), but Mishra and Koehler (2006) present a framework that outlines various features that would constitute TPACK and where PCK fits within the construct of TPACK. Angeli and Valanides (2005) however, discussed what they term as ICT-related PCK. They describe ICT-related PCK as being a special amalgam of different types of knowledge, such as pedagogical knowledge, knowledge of students, knowledge of environmental context, subject area knowledge, and ICT knowledge. ICT knowledge was based on knowing how to use a computer, knowing how to use a certain amount of tools/software on it and the affordances (Webb, 2005) the tools/software offers. Five areas were outlined as important characteristics for a teacher’s demonstration of ICT-related PCK. Some examples were: being able to identify topics to teach with ICT, the ability to select ICT tools to afford content transformations and support teaching strategies. Angeli and Valanides (2009) have since defined ICT-related PCK as ICT-TPCK.

This section has addressed varying interpretations of the PCK construct. The key findings of the research on PCK for this research are:

- PCK is only one aspect of teachers’ knowledge base despite the large volume of research based on the construct. It is important to bear in mind how other knowledge areas relate to PCK.
- Classroom observations of teachers’ practice are essential to effectively explain teachers’ PCK.
PCK has varying representations and thus researchers must make their interpretations and use of the construct as explicit as possible.

The measurement tools of PCK being used in this research will be discussed in the methodology chapter. The next section will make explicit the author’s interpretation of the PCK construct so that the use of the construct is more transparent.

2.3.2 Author’s interpretation of PCK

The interpretations of the knowledge areas that constitute PCK, as can be seen in the previous section, show similar yet distinct elaborations on the knowledge areas originally outlined by Shulman (1987). These interpretations are justifiable in their own right. However, the author desired an interpretation that integrated Shulman’s (1986) original conception of PCK, while still reflecting the importance of the other types of knowledge. However, not neglecting the other knowledge areas, SMK, PK, and PCK remain ‘at the forefront of what is essential to effective science teaching’ (Zeidler, 2002: 27). This interpretation will now be explained with the aid of a diagram (Figure 4).

![Figure 4 - Graphical Representation of PCK Interpretation](image-url)
Shulman (1986) described PCK as only (no other knowledge area included in his description) an ‘amalgam’ of content knowledge and pedagogical knowledge. As has already been made clear other authors have tried to include other knowledge areas in this ‘amalgamation’. Instead of doing this and confusing Shulman’s original idea, the author felt the most apt interpretation was to make an addition to PCK that underlies Shulman’s original idea. Before doing this the author would rather use the word ‘synthesis’ than ‘amalgam’ as synthesis indicates a clear and focused reason to why two things are combined i.e. to obtain a particular result. Amalgam implies a combination but not specifically towards a key focus. Therefore, according to this changed viewpoint, PCK would be the ‘synthesis’ of content knowledge and pedagogical knowledge.

Another ‘synthesis’ that the author feels must occur is one that the PCK synthesis builds on. This synthesis refers to how the other knowledge categories listed by Shulman (1987) i.e. curriculum, learners, educational contexts, and educational needs are combined by a teacher to influence their pedagogical knowledge. The subject matter content knowledge interacts with each knowledge area in this synthesis, but they can all be tied to a teacher’s pedagogy. Zeidler (2002: 28) explains PK as pertaining ‘to a teacher’s knowledge of generic instructional variables such as classroom management, pacing, questioning strategies, handling of routines and transitions, and the like.’ The author believes that the other knowledge types relate to instructional variables toward a teacher’s ‘pedagogical synthesis’.

The quality of the ‘pedagogical synthesis’ would be seen as being indicative of the quality of a teacher’s subsequent PCK synthesis. It is important to note that PK is a separate knowledge type in the above diagram, but that the pedagogical synthesis is a strong influential factor on it. These knowledge categories are building blocks related to how a teacher’s pedagogy is constructed and thus eventually leading to how their ‘pedagogy interacts with subject matter content knowledge’ i.e. PCK. Shulman (1986) noted an imbalance between the teaching of content and pedagogy in teacher education programmes and Figure 4 is suggestive of this, in that pedagogy has much more factors influencing it, hence drawing more attention.
ICT knowledge has not been included in Figure 4. Instead the author felt knowledge of resources would be more appropriate as it has a broader inclusion that ICT knowledge fits within. Also, as noted previously, McGarr (2009) notes that ICT initiatives should be presented as teaching and learning initiatives so that the focus is not based on the ICT, but the student learning occurring. Lee and Luft (2008) found that knowledge of resources affected teachers’ ‘curriculum organisation, selection of teaching strategies, and use of assessments’ when the teachers conceptualized PCK and therefore that it is worth consideration as an element of PCK. Hence, it has been included in Figure 4. Another knowledge area of contestation that has been argued to be neglected is that of the emotional aspects of students (McCaughtry, 2004; Webb & Blond, 1995). The author does not dismiss the importance of the emotional aspects of students, but feels this would be better encompassed within knowledge of learners.

There have been varying conceptions on the area of content knowledge (Henze et al., 2008; Wilson, 2008). However, the one considered must applicable to this framework was Ball et al.’s (2008) content areas of PCK which he described for mathematics teaching, but they have been adapted here. These are

- **Common Content Knowledge (CCK)** – referring to general knowledge of subject area e.g. being able to solve a Science problem.
- **Specialized Content Knowledge (SCK)** – referring to particular knowledge specific to teaching. It is felt that Shulman’s (1987) knowledge types of educational context, educational ends, and curriculum should be included in this knowledge domain as these knowledge types are specific to teaching.
- **Knowledge of Content and Students (KCS)** – knowledge of knowing students and knowing the subject matter. This refers in particular to knowledge of common student conceptions and misconceptions of the subject matter.
- **Knowledge of Content and Teaching (KCT)** – knowing about teaching and knowing about the subject matter. This refers to how teachers design their instruction by evaluating teaching methods in light of student understanding. Resource knowledge would be included in this PCK knowledge area.

These four areas merge subject matter content knowledge with areas underlying pedagogical knowledge, and thus serve to highlight the interactive and dynamic
nature of knowledge types within the PCK structure. It is made explicit that these knowledge types associated to the PCK construct are a result of a merging of the more elementary knowledge areas outlined by Shulman (1987), excluding PCK. Hence, the author would adopt and use Ball et al. (2008)’s framing of knowledge types relating to PCK. Using this as a framework one can then start to get a clearer picture of PCK within science education.

This section has made explicit the author’s interpretation of the PCK construct. In summary, the knowledge areas explained in the Figure 4 will be used as a means to analyse data for explanations related to PCK. This provides explicit detail of how the PCK construct is being utilised. The next section will explore some of current uses of PCK as an academic construct.

2.3.3 Utility of PCK to explain teachers’ practice

Shulman (1986) sought to re-address the relationship in teacher education programmes between pedagogy and content knowledge with the coining of the phrase PCK. This issue is certainly worth developing a greater awareness of as content knowledge has been shown to influence many aspects of a teacher’s pedagogy e.g. planning, response to student questions, and lesson structuring (Hashweh, 1987). PCK has since developed well beyond Shulman’s initial construct to an instrument that could be used to not just describe teachers’ practice, but to potentially explain key areas in science education: ‘How science teachers develop, what experiences influence this development, why science teachers teach the way they do, and why they change in response to an innovation’ (Abell, 2008: 1413). Abell (2008) explains current research needs to ‘shift from description to explanation’ for the usefulness of PCK to be increased. This section will look at how some of these key areas in science education, outlined by Abell, have been touched on in other literature.

PCK serves as a medium to explicitly show how expert teachers and experienced teachers compare and contrast with beginning teachers, in how they make the subject matter comprehensible to students. A distinction between expert and experienced teachers has been intentionally made here as expertise is not necessarily assured by a teacher’s years of experience (Hattie, 2003). It is the development of ‘complex
cognitive schemata through planning, interactive teaching, and reflecting’ that adds to a teacher’s level of expertise (Sanders, Borko, & Lockard, 1993: 724). As expertise increases, teachers then become better placed to utilise their experience and knowledge (Clermont, Borko, & Krajcik, 1994). Teachers generally agree on what constitutes PCK, but differ in how these components connect with each other depending on the ‘different points in their career’ (Lee & Luft, 2008: 1360). A great deal of research has attempted to show clear distinctions and comparisons between expert and novice teachers (Henze et al., 2008; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008; Sanders et al., 1993; Seymour & Lehrer, 2006). PCK, combined with Zhao et al. (2002)’s model, as discussed in the previous chapter section, could be used to help shed greater light on how and why teachers at different career points react differently to ICT innovations in their classroom.

Of interest are findings from studies on how teachers’ subject matter content knowledge affects their confidence in teaching (Nilsson, 2008; Sanders et al., 1993). Teachers, teaching in their area of certification, were able to take advantage of unexpected events or questions in class, have a more student-centred class, and did not rely on the textbook (Sanders et al., 1993). However, this reverted significantly when teaching outside of their area of certification. The dynamic nature of PCK, referred to as PCKnowing by Cochran et al. (1993), is difficult for beginning teachers (Penso, 2002), but experienced (varied levels of expertise) teachers’ pedagogical knowledge shows through when they are teaching content they are not too familiar with (Sanders et al., 1993). Hence, pedagogical knowledge would appear to impact more on a teacher’s overall PCK. Research on PCK could be targeted at ways to help teachers explain more clearly the differing levels of difficulties they experience when faced with a new innovation for their classroom and also explain the decisions influencing their usage. McGarr (2009) found that how ICT was used in Post-Primary Schools was not a result of outside initiatives, but rather was constructed ‘within schools to meet their needs and interests’. PCK would be a useful vehicle to develop a clearer understanding of these needs and interests.

As of yet though, there are limited studies on the explicit teaching of PCK in teacher education. Loughran, Mulhall, and Berry (2008) however did this with a teacher educator and five of his student-teachers. They explicitly used the construct of PCK
with pre-service teachers and found it allowed the pre-service teachers to ‘delve into deeper understandings’ of how they connected teaching and learning. They found that the student-teachers used PCK to better align the content matter to be taught with pedagogy so that students may understand the content better. This in turn led the student-teachers to a better understanding and appreciation of educational theory, such as PCK. This serves to strengthen Loughran et al. (2001)’s point that PCK aids teacher professional development as it provides a ‘language of practice’ within its framework in which teachers can develop and share their ideas. This would fall in line with Korthagen’s (2010) teacher schema development and how through developing schema teachers would be more likely to draw on educational theory. The student-teachers in Loughran et al.’s (2008) study were keener to make links between teaching and learning instead of simply looking to deliver prescribed content. Through the lens of PCK the student-teachers developed a positive stance on their integration of theory into practice. The net result suggested by Loughran et al. (2008:1316) is that the pre-service teachers began to see ‘teaching and learning about science to be complex and problematic as opposed to rule-driven and propositionally based’. The obvious utility here is that this falls in line with a shift towards inquiry-based methods of learning and teaching; a central focus of this project.

This section has highlighted the utility of PCK as a lens to understand teacher practice and this encompasses ICT related knowledge. In summary, the key findings for this research are the utility of PCK to:

- Explain why teachers teach the way they do and how this relates to technology integration.
- Aid in distinguishing between expert, experienced, and novice teachers.
- Act as medium through which educational theory becomes more relevant to teachers.

The next chapter section focuses on the type of change that would be envisioned in teachers’ practices that may be aided through ICT i.e. inquiry-based methods.
2.4 The educational change in focus: Scientific inquiry

2.4.1 An explanation of scientific inquiry as a teaching methodology

It is acknowledged in the research that a universal process of scientific inquiry may not be possible and/or fully understood (Alters, 1997; Huberman & Middlebrooks, 2000; Windschtl, 2004), but in order for scientific inquiry to be taught in schools then some basic model of scientific inquiry is required (Park, Jang, & Kim, 2009). As will be seen in this section choosing an appropriate model has many intricate and complex factors underpinning it.

Certain difficulties arise when trying to explain inquiry as its characteristics are so varied and can be combined in different ways. The following explanation reflects the wide scope of inquiry. Inquiry is

‘a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations’

(NRC, 1996).

An instructional model for scientific inquiry that has received significant attention is the 5 Es model: engagement, exploration, explanation, elaboration, and evaluation (Bybee, 2006; Gejda & LaRocco, 2006; Tytler, 2007) as described by Lawson (1995). This model can be adopted as a planning framework for classroom activities that encompass the features of inquiry referred to above. Urhahne, Schanze, Bell, Mansfield and Holmes (2010) present an instructional model for collaborative scientific inquiry when using computers that could also be referred to as a 5 Es model (see Table 2).
Lucas, Broderick, Lehrer, and Bohanan (2005) explain some important features of lessons that reflect critical scientific inquiry and that resonate with the 5 Es. Firstly, natural curiosity is important as students develop curiosity from observations and in turn, ask questions. Alternatively, the teacher could pose a question for guided inquiry leading to class discussion (Freedman, 2005: 22). Ultimately, students are like scientists in that they like to ask questions that interest them and that they can discover the answer for themselves (Hills, 2006).

Secondly, the importance of asking not just questions, but good questions was highlighted – students must refine any question into one that meets the following characteristics: it is answerable; not fantastical, it is do-able, it is genuine i.e. something we do not know already and it is sensible, containing individual and collective aspects. A study aimed at improving question posing for 12th grade honours Chemistry students (Kaberman & Dori, 2009) found that students equipped with a metacognitive strategy for analysing the questions they posed, significantly improved their questioning and the complexity of their questioning. It gave them a greater awareness of their own cognitive process and how to regulate it themselves.

Thirdly, students can then generate evidence, but within this they must decide the information needed, how they are going to get that information (internet, paper or people), what records they should keep, and how the findings should be noted. Finally, students grow and develop their expertise on their initial question from having reviewed, analysed, and interpreted the data (Miller, 2006:32). Certain studies have also highlighted the importance of teachers providing historical perspectives as it allows students to make a real-world connection to the material being learned and not devalue the role of the individual in a concept’s generation (Bybee, 2000; Wong & Hodson, 2008).

<table>
<thead>
<tr>
<th>Principle</th>
<th>Short description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envision the lesson</td>
<td>Create an image of the lesson, plan and organise student tasks</td>
</tr>
<tr>
<td>Enable collaboration</td>
<td>Arrange small groups or pairs so that one can learn from the other</td>
</tr>
<tr>
<td>Encourage students</td>
<td>Support learners and provide guidance during knowledge acquisition</td>
</tr>
<tr>
<td>Ensure learning</td>
<td>Monitor learning processes and check learning outcomes</td>
</tr>
<tr>
<td>Evaluate achievement</td>
<td>Choose suitable means to assess processes and products of learning</td>
</tr>
</tbody>
</table>

Table 2 - Five Principles for the Role of the Teacher in Collaborative Inquiry Learning (Urhahne et al., 2010)
It becomes clear that inquiry is a multi-faceted and diverse activity, and important decisions must be made by a teacher in how it is operationalised in the classroom. Abrams, Southerland, and Evans present a useful table (Table 3) that illustrates different levels of inquiry that a teacher may wish to engage with in their class. This table has been adapted from descriptions of inquiry by Schwab (1962) and Colburn (2000) that focus on three particular features of inquiry: source of the question, data collection methods, and interpretation of results.

<table>
<thead>
<tr>
<th>Level</th>
<th>Source of the Question</th>
<th>Data Collection Methods</th>
<th>Interpretation of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0: Verification</td>
<td>Given by teacher</td>
<td>Given by teacher</td>
<td>Given by teacher</td>
</tr>
<tr>
<td>Level 1: Structured</td>
<td>Given by teacher</td>
<td>Given by teacher</td>
<td>Open to student</td>
</tr>
<tr>
<td>Level 2: Guided</td>
<td>Given by teacher</td>
<td>Open to student</td>
<td>Open to student</td>
</tr>
<tr>
<td>Level 3: Open</td>
<td>Open to student</td>
<td>Open to student</td>
<td>Open to student</td>
</tr>
</tbody>
</table>

Table 3 - Levels of Inquiry (Abrams et al., 2007) adapted from Schwab (1962) and Colburn (2000)

As can be seen from the table Level 0 represents very much a ‘cookbook’ type approach (Abrahams & Millar, 2008) in that all activities are teacher-led with an expected result at the end of the experiment. Blanchard, Southerland, Osborne, Sampson, Annetta, & Granger (2010) highlight that Level 0 still represents an inquiry, despite the inquiry being quite limited. As one progresses through the levels the different features of inquiry open up to the students. The teacher still plays an important role in encouraging, prompting, and guiding students on things they may need to consider. An important note on this table is that Level 3 should not by viewed as representative of the ‘ideal’ way to teach science (Settlage, 2007), but that ‘the optimal level of inquiry will vary according to the classroom context and the demands of the material’ (Blanchard et al., 2010: 582). Within classroom context the table could be argued in terms of aiding teachers’ understanding of students’ engagement in inquiry in that some students may prefer Level 0 (verification), while other students would excel given more ownership in experimental design and so on. Many reasons can be argued for these student preferences and some will be explained in the following section, but ultimately, it is important that a teacher has an awareness of these preferences.
In a study of practising physicists Park et al. (2009) proposed five different models of inquiry: linear, cyclical, multi-cyclical, the non-linear process and mixed process. From this study it is clear that practising scientists use many different approaches in attempting to answer their questions. The key findings from the literature for this research are:

- Scientific inquiry is a multifaceted and multi-levelled activity, and thus the models of inquiry being used in research must be made explicit if it is to be effectively utilised.
- Following on from the previous point, teachers have varying conceptions of what inquiry is and these also need important consideration.

The next section discusses the rationale behind current efforts to embed these characteristics in current classroom activities.

2.4.2 Rationale behind scientific inquiry

‘One had to cram all this stuff into one's mind for the examinations, whether one liked it or not. This coercion had such a deterring effect on me that, after I had passed the final examination, I found the consideration of any scientific problems distasteful to me for an entire year.’

Albert Einstein (Internet source: STANDS4 LLC)

The majority of students’ dream is not to become a quiz show participant (Alberts, 2000: 3). However, the current focus in the education system is on memorising, rather than on understanding (OECD, 2006), so one may be forgiven for thinking otherwise. The idea of inquiry is a very appealing concept in this regard as it looks to move beyond the simple learning of facts to a greater understanding of scientific process. As Suchman (1968) argues inquiry is not just a ‘method of science, inquiry is science.’ Alberts (2000) uses the analogy of watching a live sporting event to learning science by inquiry. We are on the edge of our seats watching the event live. However, we have little interest in the same event replayed with the outcome being known. Therefore, in school science, we should want students to engage in the excitement of actually doing science (making observations, asking questions, and finding evidence) over cookbook type approaches (Zeeff, Palazzolo, & Dobson, 2007).
Much research has highlighted the positive impacts of inquiry-based approaches on student learning (Etkina, Karelina, Ruibal-Villasenor, Rosengrant, Jordan, & Hmelo-Silver, 2010; Ketelhut, Nelson, Clarke, & Dede, 2010; Liu, Lee, & Linn, 2010; van der Valk & de Jong, 2009; Wilson, Taylor, Kowalski, & Carlson, 2010). Colburn (2000) conducted a literature review of many studies that illustrated greater or at least equal student learning through inquiry-based instruction. Blanchard et al. (2010) found that students who operated at a Level 2 (guided) inquiry, as opposed to Level 0 (verification) inquiry, tended to show stronger gains in various knowledge areas and generally over time had better retention of the material. Kanter and Konstantopoulos (2010) noted the frequency with which teachers used specific inquiry-based approaches did correlate with improvements in students’ science attitudes and plans. Kali and Linn (2008) highlight that inquiry approaches can ideally facilitate students in the development of coherent and integrated understanding of science, rather than primarily memorizing random facts about science.

Research also exists to argue against the value of inquiry-based approaches over other methodologies. In a study by Klahr and Nigam (2004), the relative effectiveness of discovery learning and direct instruction was measured for 112 third and fourth grade students. Their findings found that more children learned from direct instruction than discovery learning, in relation to ‘control of variables strategy’ (CVS) i.e. designing and interpreting simple experiments, and being able to transfer this to more authentic reasoning. Kirschner, Sweller, and Clark (2006) argues that there is no body of research to support minimally guided instruction and notes that the continuing popularity of ‘a failed approach are unclear’ (p.84). Kirschner et al. (ibid) highlighted studies that showed discovery based approaches with little guidance can cause students to become lost and frustrated and in turn, lead to student misconceptions (Brown & Campione, 1994; Hardiman, Pollatsek, & Weil, 1986). This point by Kirschner et al. (ibid) implies that students’ being lost or frustrated is a bad thing. Also, misconceptions do not necessarily need to be viewed as a bad thing as they can be instructive to teacher practice. Hmelo-Silver, Duncan, and Chinn (2007) contested these views in that they distinguish inquiry learning as distinct from discovery learning in that inquiry is highly scaffolded, whereas Kirschner et al. (ibid) conflated the two. Wilson et al. (2010) note that the studies indicated by Kirschner et al. (ibid)
highlighted inquiry at Level 3 (open) where students are left with ‘minimal guidance during instruction’.

It is no surprise that these issues would emerge for students as it would be potentially beyond many students’ Zone of Proximal Development (ZPD) (Vygotsky, 1978). Abrams et al. (2007) also notes that Level 3 inquiries would normally require some prior experience of inquiries and certain skills, and hence are only applicable to certain content. Sandoval (2005: 635) points to this emerging issue within inquiry instruction in that ‘simply engaging in inquiry is insufficient to change most students’ ideas about the nature of science’ (Khishfe & Abd-El-Khalick, 2002; Meichtry, 1992; Sandoval & Morrison, 2003).

Many issues arise in how inquiry is being understood and thus each aspect of inquiry needs ample consideration, as the average student inquiry experience can be described as focusing on certain aspects of inquiry over others (Asay & Orgill, 2010). Dolan and Grady (2010) note that students often spend more time ‘collecting data or completing procedures, rather than discussing data analysis, generating conclusions, or synthesizing new findings with previous findings’ (Kuhn, 1993; Moss, Abrams, & Kull, 1998; Watson, Swain, & McRobbie, 2004). In a study by Asay and Orgill (2010), students were seldom ‘asked to grapple with scientifically oriented questions, create evidence-based explanations, connect explanations to accepted scientific concepts, or justify the results of their investigations to a larger group of peers’. This point is reinforced by Hume and Coll (2010) who found that students had limited understanding of the finer points of experimental design for example repetition and appreciation of in-depth forward planning.

A greater inclusion of inquiry-based instruction is not just a case of what ‘we’ want, but also what students themselves would like in their lessons. When asked about important features of lessons in school science, younger students explain that they like to be made to think, they like variety in activity and they like to see how science relates to everyday life (Bennett & Hogarth, 2009). These findings have been echoed in other research (Barmby, Kind, & Jones, 2008; Hassan, 2008; Osborne, Simon, & Collins, 2003). However, the line between ‘being made to think’ and ‘hard’ content is difficult to draw for older students whose focus is on external examination grades.
This in turn leads to implications in how material is approached in the classroom as science education ‘becomes the transmission of content knowledge’ (Chen, 2010). Also, Cheung (2009) argues that inquiry-based laboratory work in science would more greatly engage males, while a more humanistic approach to curriculum design would appeal to females. These points highlight the need to examine subject content in science curricula and how state exams are graded (Bennett & Hogarth, 2009).

There have been many arguments that support why inquiry should be an important feature of any curriculum and assessment change. Some reasons given are that students enjoy learning through inquiry-based approaches (Crawford, Krajcik, & Marx, 1999; Gibson & Chase, 2002), students do not just ask more questions (Hofstein, Shore, & Kipnis, 2004; Roth, 1994), but they ask better questions too (Crawford et al., 1999) and there are also the social aspects that inquiry promotes from students working together (Akerson, Morrison, & McDuffie, 2006; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Zion et al. (2004) argue that teaching through the right type of inquiry (dynamic) will develop students’ critical thinking and not just the practical aspect of learning (hands-on).

In terms of teachers, inquiry-based methods have also shown to have positive impacts. Teachers, just like the older students, focus on content coverage due to a mandated curriculum and seek to prepare students for the final examinations (Sorienta & Jimoyiannis, 2008). In a study by Hashweh (1996), he found that teachers with more constructivist beliefs (which fall in line with the inquiry approach) were more likely to detect alternative student conceptions, have a greater repertoire of teaching strategies, use greater methods in bringing about student conceptual change, and highly value their teaching strategies compared to teachers with empiricist beliefs. Liu et al. (2010: 1) also found that teachers who value inquiry teaching strategies have ‘significantly higher levels of knowledge integration understanding’ than teachers who believe in traditional teaching methods.

This section has explained rationales for the inquiry approach. Important points from this literature are:
• The distinction between differing levels of inquiry from verification (level 0) to open (level 3). In inquiry-based lessons it is important to note what types of inquiry are occurring.
• Certain features of inquiry are emphasised more than others during lessons and the reasons for this are important to uncover.
• Students have been shown to favour inquiry over other approaches, and have better gains in knowledge areas and knowledge retention. However, students’ desire for inquiry becomes blurred in light of the assessment structure in place.

The next section will move beyond the rationale for using inquiry-based approaches to how the use of these approaches takes shape within the classroom.

2.4.3 The reality: Placing scientific inquiry within the classroom

Students posing their own questions, designing their own experiments, collecting data, and drawing their own conclusions have been ‘almost universally appealing and at the same time difficult to implement in real classrooms’ (Wallace & Kang, 2004: 939). The idea of scientific inquiry is espoused by science educators, but is not carried out in practice (Bybee, 2000: 20). The changes involved in the roles of teachers and students present major challenges (Boud & Feletti, 1997). There are barriers to inquiry including safety issues, lack of equipment, management difficulties, and the need to teach a mandated curriculum (Smithenry, 2010; Welch, Klopfer, & Aikenhead, 1981). Other issues include time, resources, professional development, science topic or content, and mandatory assessments (Gejda & LaRocco, 2006: 9). However, Jackson and Bobac (2008) state that there will always be barriers in using inquiry-based instruction, but that ‘creative’ and ‘resourceful’ teachers can carry out inquiry-based lessons in even the most unlikely situations. They offer a plethora of strategies to help alleviate issues in inquiry-based lessons relating to time, learning environment constraints, student motivation, and safety.

Despite the aforementioned issues associated with teachers carrying out inquiry in their classrooms a salient issue commonly cited in research is that of teachers’ philosophy and their lack of understanding of the nature of science (see Wong & Day, 2009 for examples). Crawford (2007: 636) highlights the key significance of this
issue in that ‘the most critical factor influencing a prospective teacher’s intentions and abilities to teach science as inquiry, is the prospective teachers’ complex set of personal beliefs about teaching and views of science.’ Science is perceived by many teachers ‘as an established body of knowledge and techniques which require minimal justification’ (Bartholomew, Osborne, & Ratcliffe, 2010: 659). Teachers continue to support the belief in a common scientific method despite scientists strongly advocating that the choosing of a method of inquiry resides in contextual factors (Wong & Day, 2009). Even when teachers assert an interest in teaching through inquiry, they still favour the transmission of facts (Tobin & McRobbie, 1996) and view it as the most important student outcomes (Cronin-Jones, 1991). Gyllenpalm, Wickman, and Holmgren (2010: 1166) reinforce this stating that teachers ‘appear to focus almost exclusively on knowledge goals in terms of learning the products of science and the use of this knowledge’, as opposed to understanding scientific inquiry as conceptual knowledge. In an analysis of essential features of inquiry in articles published in The Science Teacher from 1998 to 2007, Asay and Orgill (2010: 68) argue the evidence of their analysis points to teacher views of ‘inquiry more as a process to be learned about and physically experienced than as a vehicle for teaching specific scientific content’ as features of inquiry, such as explaining, connecting, and justifying results, were poorly represented in articles analysed.

It is clear from the above examples that there are conflicting attitudes towards the current capacity of teachers to support inquiry-based forms of instruction. Smithenry (2010: 1690) notes that chemistry teachers in the United States continue to be ‘entrenched in traditional practice’ of instructional strategies relating to lecture/discussion with practice using the textbook/worksheets and with lab work occasionally (Smith, 2002). In many instances of inquiry efforts by researchers with teachers, the teachers modify the researchers’ enactments of inquiry approaches so much that the researchers no longer view them as inquiry (Hewson, 2007). Falk and Drayton (2004) argue that in the competing forces of inquiry and preparing students for high-stakes content focused assessments, test preparation wins out in science classrooms.

Even with the increasing affordances offered by computers (Webb, 2005) towards inquiry, a case study on professional development towards computer-enhanced
learning showed that only three out of ten science teachers integrated computer activities with inquiry-based pedagogy (Valanides & Angeli, 2008). The other seven teachers used the computer activities to support traditional teacher-centred approaches. In many instances these teachers found constructing lessons on constructivist principles as ‘difficult, demanding and daunting’ (p.10). In a study by Waight and Abd-El-Khalick (2011), a web-based tool used by practising scientists was adopted to Post-Primary Schools in the vision of supporting authentic inquiry. Despite this intended aim teachers used the technology in a teacher-centred manner with activities that encouraged a following of instructions by students and a focus on science content. The researchers noted ‘two extremes that reflected the disparity between scientists’ and educators’ views on science, inquiry science teaching, and the related roles of technological tools.’ (p.37). In attempting to explain the possible reasons for the lack of integration they noted (i) a need to look more closely at the role each person plays in integration including scientists, science educators, and researchers, (ii) the relation between technology enactment and levels of expertise, and (iii) efficiency versus the pace of technological progress.

These studies point to another implicit factor related to inquiry integration into practice in that teaching by inquiry has to be ‘feasible and viable in the mind of the teacher’ (Crawford, 2007: 638). Hence, the exemplification of inquiry activities is needed and chances afforded for teachers to practice implementing it (Asay & Orgill, 2010). Alongside this implementation continuous support is needed for teachers at varying stages of implementation (Liu et al., 2010). In an attempt to sum up these issues, Bartholomew et al. (2004) point more clearly to the necessity for the culture of science teaching and its curricular knowledge to significantly change.

It will clearly take time for the culture of science teaching to change towards a greater inclusion of inquiry-based approaches. Teachers are still learning how to give students space as well as structure through inquiry-based activities as the inquiry approach necessitates that both teachers and students have ‘new roles and responsibilities’ (van der Valk & de Jong, 2009) as distinct from the current *habitus* (Bourdieu, 1979) of expected teacher-led classroom activities. Habitus is influenced by the totality of life conditions (childhood experiences, type of schooling, parenting, community, etc.) and causes people to appreciate or do certain things (Bourdieu,
1979). Habitus is unique to each person, but through shared life experiences, some people can have similar habitus and thus, similar proclivities. It is habitus that generates ‘schema, which in turn leads to certain actions’ (Belland, 2009: 357). If inquiry habitus is to be developed in teachers, that moves beyond ‘ritualized routines’ (Nuthall, 2005), the schema of teachers must be firstly addressed, i.e. ways of knowing how to act (Korthagen, 2010).

Dolan and Grady (2010) note that ‘student-directedness and scientific meaning are two sides of the inquiry coin that teachers must learn to balance’. Findings from a study by Fogleman, McNeill, and Krajcik (2010: 1) also suggest that even with an inquiry curriculum, certain teachers need time ‘to effectively use innovative science curriculum’. Many of the new roles and responsibilities also centre on group work with an inquiry focus (Parr, 2007; Sampson & Clark, 2009; Voreis, Crawley, Tucker, Blanton, & Adams, 2008) that complicate things for teachers. It is important that the ways teachers adapt curriculum reform efforts are studied carefully as this can have a significant impact on the student learning experience (Fogleman et al., 2010). These studies illustrate the need to address current teacher schema (influenced by habitus), before desired changes can be espoused. As noted by Bourdieu and Passerson (1990), messages attempting to instill dispositions not present in the recipient’s habitus is often resisted. Again, teachers must see that change is ‘viable’ (Crawford, 2007: 638).

Rushton, Lotter, and Singer (2011) carried out a study of seven practising science teachers implementing a professional development programme related to a guided inquiry approach for teachers. It was noted in terms of teacher beliefs that (i) six of the seven teachers came to the programme with ‘naïve conceptions about inquiry based-teaching’ (p.32), (ii) the teachers had no model for how they would change despite five out of seven of them having student learning beliefs that aligned with the programme’s constructivist framework (need for exemplification), and (c) all seven teachers expressed dissatisfaction with their current teaching practice (bias for action). The findings of this professional development programme noted greater teacher conceptions of inquiry after the study, that teachers preferred a ‘phenomena first approach to get their students thinking about the content’ (p.34), and overall teachers had a greater integration of inquiry into their practice. In assessing the reasons for
this success, teachers noted the challenging of their own content knowledge in the workshops, the use of a POE (Predict-Observe-Explain) model of inquiry provided to them, and the chance to incorporate it into their practice and critically reflect on this practice with other teachers.

However, as touched on earlier, in most cases current assessment methods do not align with these approaches. Myers-Kelson (2000) notes that the development of proactive lifelong learners requires a congruent assessment system which reinforces and models the approach to problems that is required of them. As highlighted in previous discussion current assessment places a premium on regurgitation of information despite science education as the transmission of knowledge being long criticized (Chen, 2010).

Even when inquiry is attempted by teachers in their practice (Freedman, 2005; Lucas et al., 2005) the inquiry efforts are based largely on linear and cyclical processes. Hodson (1998) criticizes much scientific inquiry in school as being misled by myths, such as the following: scientific inquiry starts with only observation and is conducted through a simple and algorithmic procedure; scientific knowledge, obtained through induction, indicates the truth of nature; experiments are decisive to test scientific knowledge, and so on. There is an expectation that newly qualified science teachers leave college ready to implement inquiry-based lessons, even though college science lessons are rarely taught this way (Phelps & Lee, 2003). These findings highlight a need for teacher educators to not just teach about inquiry, but also to incorporate inquiry-based lessons more into their own practice.

This section has discussed some of the contemporary issues revolving around teacher adoption of scientific inquiry into their practice. Key findings of note from this literature are:

- There are many barriers to inquiry, but the biggest challenges are that of teachers’ philosophy, their conceptions of science, and the types of assessment in place. These issues must be taken account of in inquiry-based research.
• Teachers tend to modify inquiry approaches to such an extent that the approaches no longer resemble inquiry. It is important to be mindful of this in research on teachers’ practice.

The next section focuses in how a change in assessment through ICT may bring about greater opportunities in to authentically assess inquiry-based activities in class.

2.4.4 Moving towards the assessment of scientific inquiry using ICT

Traditional types of written assessment have been critiqued from the point of view that they do not capture students' ability to develop and carry out independent investigations, nor do they measure the development of student conceptual understanding (Ruiz-Primo & Shavelson, 1996). Further to this, Ketelhut et al. (2010: 67) argue that the use of high-stakes assessment in isolation can ‘erroneously categorise students’ understanding’. Also, in relation to teachers, high stakes testing motivate changes to teachers’ practices, but the changes tend to focus on ‘content coverage’ and ‘test preparation activities’, rather than on more meaningful improvements in their instructional practice (Supovitz, 2009: 211).

In a study of pre-service Physics teachers’ attitudes towards assessment (Ogan-Bekiroglu, 2009), it was found that two things affected ‘teachers’ predispositions for action’, knowledge of the subject matter and the university entrance exam. Even though these teachers had constructivist attitudes towards assessment they preferred not to use varied assessment for areas they had insufficient knowledge. Teachers are judged on the final examinations and if this is not addressed they become unwilling to use alternative forms of assessment (Bell, 2003). Despite all the research support for inquiry-based methods, as discussed in previous sections, the integration of authentic assessment of inquiry into curriculums has been lacking and thus not reflected as would be hoped by teachers in their practice. However, this is a substantial challenge because even though inquiry-based learning is highly adaptable the assessment of it can be problematic (Deignan, 2009: 18).

If the assessment is problematic then it must be asked, in terms of educational change, who is the assessment problematic for? From previous arguments it is clear why
teacher assessment of inquiry is difficult. In terms of students, they need assistance in reframing the culture of the classroom in terms of what is expected of them as successful learners (Crawford et al., 1999). This in itself provides another challenge for teachers. In Ireland, the National Council for Curriculum and Assessment (NCCA) noted in their ‘Towards Learning’ publication (2009) that what teachers, students, parents, and school management wanted was ‘more varied assessment arrangements’. Thus, NCCA have been working towards this end in trialling alternative forms of assessing practical work. In a Statement of Strategy Report (2008) by the State Exams Commission, who implement the final examinations as approved by the DES, they realise the need for change, but also recognise ‘the logistical challenge’ changes to assessment will bring and the need for equity, reliability, and validity. Therefore, any attempts at inquiry-based assessments on a national scale must meet these criteria.

Bybee (2000:39) gives examples of teaching activities and assessment types that support inquiry related outcomes that have the potential to satisfy various stakeholders’ criteria for assessment. In terms of understanding subject matter, the assessment types outlined by Bybee (2000) relate to performance assessment (laboratory work), open-response questions, and interviews. However, examples of detailed assessment rubrics are not provided, highlighting a need for them to be developed to the relevant context. Some current efforts at assessment rubrics for inquiry have revolved around concept-mapping (Chang & Chang, 2008; Ngec, 2009; Stoddart, Abrams, Gasper, & Canaday, 2000). An issue with concept-mapping is that although pre-service teachers have knowledge of concepts they find it difficult to establish relationships between these concepts (Ngec, 2009).

Williams and Wong (2009) explored how the use of technology could enhance the authenticity of student learning to final examinations and through this process, allow for a constructivist alignment of student learning with stated outcomes. They argue that the use of closed-book, pen and paper examinations present an anachronism as they are ‘incompatible with constructivist learning theory that facilitates deep learning’ (p.234). Students in their study favoured open-book, open-web examinations over invigilated, closed book type examinations. It is clear from this study that other forms of computer-mediated assessment should be explored.
This section has discussed some of the issues around moving towards the assessment of inquiry through ICT. Key findings for this research are:

- Closed book written assessments narrowly categorise student understanding and are incompatible with deep and meaningful learning. They also promote content coverage and test-preparation in teacher practice.

- Cultural issues are a major contributing factor to lack of change. The SEC state issues of reliability and validity as reasons for lack of change despite other feasible alternatives available, such as interviews and open-response questions.

The next chapter section focuses on the ICT tool by which some of these issues will be raised and possible ways they may be changed.

2.5 A virtual chemistry laboratory as the ICT catalyst to scientific inquiry

2.5.1 Ins and outs of student experimentation

Good quality experimentation in classrooms is often acknowledged to engage students in science and develop their relevant knowledge, skills, and conceptual understanding (SCORE Report, 2010; Report and Recommendations of the Task Force on the Physical Sciences, 2002). Unfortunately, real practical work (herein called Real Experimentation (REx)) has restrictions associated with it that teachers can find

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1 The terms Real Experimentation (RE) and Virtual Experimentation (VE) are used by Zacharia (2007) to distinguish between real and virtual practical work. However, the author feels the use of VE as an acronym can lead to confusion with Virtual Environment (VE). Hence, the author will use the acronyms of REx and VEx to alleviate this potential confusion. Zacharia and Olimpiou (2011) introduce the terms Physical Manipulative Experimentation (PME) and Virtual Manipulative Experimentation (VME), thus highlighting the terms to distinguish real and virtual experimentation are still open to debate. It is pertinent to note the change of the term ‘real’ (Zacharia, 2007) to ‘physical’ (Zacharia & Olimpiou, 2011). Firstly, the author believes the addition of ‘manipulative’ is unnecessary, as manipulation is an inherent aspect of experimentation. Secondly, the author has chosen ‘real’ over ‘physical’, as virtual experimentation still involves the physical element of using a computer. However, from a philosophical perspective, virtual experimentation could be argued as a ‘real’ student experience (Zacharia & Olimpiou, personal communication, 07/09/2011). The author acknowledges this viewpoint, but confines their use of ‘real’ to experiences outside the sphere of artificial computer simulations.
difficult to overcome. Commonly cited difficulties with REx are curriculum content, resources and facilities, time, assessment, students’ behaviour, teacher’s inexperience, technical support, health and safety, class size, and lesson length (SCORE Report, 2010). These difficulties have also been cited in a report Looking at Junior Cycle Science (2008) by the Irish Inspectorate. These difficulties of REx have also been noted in other research. Sokoutis (2003) note difficulties associated with REx, such as safety factors, a shortage of proper infrastructure and equipment, and limitations in relation to time. Lindsay et al. (2007) explain that engineering laboratory classes are ‘resource intensive’ and also impose ‘significant logistical constraints upon the curriculum’. Koretsky, Amatore, Barnes, and Kimura (2008) reinforce this in that the real laboratory does give students a high quality experience, but they must be supervised and the equipment is expensive, not only to buy, but also to maintain.

The Report and Recommendations of the Task Force on the Physical Sciences (2002) highlight difficulties associated with resources and facilities for REx in Irish Post-Primary schools in that 10% of students report never working with apparatus or equipment. In Irish schools that had a high uptake of the Physical Sciences the report noted that these schools tended to have an emphasis on REx and higher level laboratory resources than the average school. These points serve to strengthen the importance of adequately supporting REx so as to maintain student interest in the Physical Sciences and further to this, REx is a good place to target improvements in students acquisition of appropriate science knowledge, skills, and conceptual understanding. It is clear that students enjoy REx and the report notes it can be a contributing factor in attracting students to do science subjects, as opposed to other subjects. As noted by Högström, Ottander and Benckett (2010) REx is ‘important for the purpose of doing science’. If this is the case it is important to be aware of how REx may be improved to further engage students in science. The purpose of this exercise is not to question the value of REx, but to determine where improvements may be made.

Many research studies have centred on answering to the exact role, effectiveness, and possible improvements of REx as a teaching, learning, and assessment tool in Post-Primary School Science over the past three decades (Adlong et al., 2003; Garnett, Garnett, & Hackling, 1995; Hodson, 1991; Hofstein & Lunetta, 2004; Solomon, Scott,
Abrahams and Millar (2008) investigated 25 science lessons involving practical work in English Post-Primary schools. They found overall an emphasis on ‘recipe’ type approaches where the focus was on real observables devoid of student thought. This reflects Level 0 inquiry. Abrahams and Millar (2008) highlight the need for teachers to divide REx time more equitably between ‘doing’ and ‘learning’ so that students have more time to develop ideas associated with a phenomenon, rather than measuring the success of an experiment by managing to produce the phenomenon. This resonates with Yaron et al. (2006) in that many notational tools in traditional chemistry courses are ‘taught in the absence of activities that show their underlying utility’. It is hoped that students learn the experimental design methodology as practised by experts, but the experience students have can be ‘dramatically different’ (Koretsky et al., 2008).

In a multiple case study, Hume and Coll (2008) offer insight into why these issues with REx have prevailed and continue to prevail. They investigated science classrooms for inquiry-based learning under a national curriculum attempting to promote authentic scientific inquiry in New Zealand. They found that students were presented with a narrow view of inquiry, with mostly didactic pedagogical approaches being used, and that this was the result of the emphasis placed at school and department level on students’ achieving success in their high stakes national qualification. This affected the content of classroom curricula and the methodologies adopted by teachers to deliver the content. One area suggested that would help allow for more authentic inquiry to occur would be to provide more support materials to teachers. As a result, teachers could greater meet the needs and interests of their students.

Despite the lack of uptake of inquiry-based approaches, Hofstein et al. (2004) argue the utility of inquiry-based REx in that they found that students in this type of setting asked better questions, better planning in considering the variables of an experiment, and made suggestions of more valid and reliable equipment to carry out the experiments. Students themselves reported that the inquiry approach was more interesting, challenging, and enjoyable. It gave the students opportunities in developing their scientific skills and greater command of their own learning. These comments relate to growing research that argue the utility of teaching through inquiry
to develop critical student thinking (minds-on) and not just the physical part of learning (hands-on) (Abrahams & Millar, 2008; Helmo-Silver et al., 2007; Zion et al., 2004). However, research exists to argue against the proposed advantage of teaching through inquiry. Cobern et al. (2010: 92) argue that that inquiry and direct methods both ‘led to comparable science conceptual understanding.’

Wong and Hodson (2008) critique science curriculum in that it is lagging behind contemporary science. They argue that the more regular and creative use of technology supported and enhanced laboratory work (e.g. collecting, manipulating, presenting or monitoring and controlling experiments using computers) would illustrate a much more accurate representation of modern-day science than many of the activities within the current curriculum. They strongly propose an inclusion of more inquiry-based and open-ended practical work, where it is feasible and acceptable to have different solutions for a given problem.

This section has discussed some of the issues associated with practical work. The key findings for this research are:

- A significant amount of REx is being done in a cookbook manner devoid of student thinking, due to varying restrictions, some of which are inherent in REx, such as safety.
- A worrying concern is that some students are not even getting to do REx.
- Inquiry-based REx has been found to be more interesting, challenging, and enjoyable to students.

The next section discusses simulations and explores the potential role of these in providing an overall greater student learning experience of experiments.

**2.5.2 Simulation in education**

Simulation is becoming more and more mainstream in many areas of education as their spectrum of intricacy continuously increases. Examples include simulations in engineering education (Agrawal & Cherner, 2008; Aküner & Kakilli, 2003; Mirabella, Brischetto, & Raucea, 2008), in medical education (Holzinger, Kickmeier-Rust, Wassertheurer, & Hessinger, 2009; Spinello & Fischbach, 2004; Tsai et al.,
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2008) and in science education (Dalgarno et al., 2009; Jara et al., 2009; Su, 2008;). These examples give a small view of the vastness and complexity of simulations being developed across various disciplines as educational tools. These examples have been predominantly developed for tertiary level, but some have potential applications within Post-Primary education.

Many arguments exist for the use of simulations in education. One such argument is that simulations allow users at all levels to practice and develop skills without the fear of penalties, or causing any harm to anyone else (Bradley, 2006: 259). Of course the most important debate for the use of simulations in terms of education would be to answer if simulations really aid learning. A Best Evidence Medical Education (BEME) systematic review was carried out to find out the features and use of high-fidelity medical simulations that lead to effective learning (Issenberg, McGaghie, Petrusa, Gordon, & Scalese, 2005). The focus of the review narrowed to 109 journals that demonstrated uses of these simulations (that lead to effective learning), such as providing feedback (47%), repetitive practice (39%), curriculum integration (25%), range of difficulty level (14%), multiple learning strategies (10%), controlled environment (9%), individualized learning (9%), defined outcomes (6%), and simulator validity (3%). The percentages show the proportion of the 109 articles that noted these uses. These findings show that many features of simulations contribute to effective learning. However, the majority of these features, such as feedback, repetitive practice, and range of difficulty level, do not need simulations in order to be done in traditional classrooms. One must then ask what simulations can offer over traditional methods beyond increased safety.

The argument in the use of simulations over traditional methods is commonly argued in terms of cognitive load (Sweller, 1988). Sweller explains the importance of reducing cognitive load in presenting instructional information by reducing the demands on the working memory. Koretsky et al. (2008: 78) expresses a similar idea in relation to cognitive capital which they define as ‘the finite amount of mental energy and time that a student has to invest in the completion of a laboratory or project’. Koretsky et al. (2008) contends that actually completing an experiment to get data consumes a majority of students’ cognitive capital. With this occurring little cognitive capital is left for the critical steps of experimental design and analysis of
data. In many cases the experimental design is determined by the instructor and simply carried out by the students. However, with the safety simulations provide students can maximise the use of their cognitive capital by engaging directly with the experimental design. Hence, it becomes clear that the increased safety aspect of a simulation has further consequences.

The overall reduction of cognitive load or as it could be considered, redistribution of cognitive load in experimental practice has been discussed at length (Mayer & Moreno, 2003; Paas, Renkl, & Sweller, 2003; Winberg & Berg, 2007) and provides a strong base to support the use of simulations in education. The affordances offered by computers for learning could re-focus their workload. Computers could take over some of the teachers’ responsibilities and allow for more direct exchange among students (Bell, Urhahne, Schanze, & Ploetzner, 2010). Bell et al. (2010: 357) explain further the value of computers in planning investigations or constructing knowledge as they assume ‘large parts of routine processes like calculating, acquiring, sorting, or visualising data, retrieving and saving information’ and that students can control things themselves, retrieve answers on their own initiative, and therefore do not have to rely on the teacher as much. This would free up time for the teacher that they could use to support students in other ways.

As discussed in a previous section technical barriers are often cited for teachers’ non-use of ICT. However, other issues around teachers’ non-use lie within how the simulation is perceived and thus used/misused. Salas, Bowers, and Rhodenizer (1998) highlighted three assumptions that characterized the current use of simulation in aviation training and in many ways these assumptions are pertinent to considering how simulations are developing in other fields. Thus, they are adapted here and discussed.

The first assumption was that ‘Simulation Is All You Need’. This assumption admits that simulation has many uses in learning, but ultimately it will only act as a tool for learning and not as a replacement. Recent research has shown an awareness of the faults with this assumption as it explains that the simulations are to complement certain activities, but not to replace them. One example is Yaron et al. (2006: 178) who indicate that the aim of their virtual chemistry laboratory is not to replace the real
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laboratory, but instead to allow students to connect their paper-and-pencil tasks to actual chemical phenomena. This type of view has been mirrored in other research (Koretsky et al., 2008, Rohrig & Jochheim, 1999; Sánchez, Morilla, Dormido, Aranda, & Ruiperez, 2002).

The second assumption was that ‘More Is Better’. This assumption highlighted the issue of the level of fidelity becoming more of a concern than the instructional features within the simulation to support learning. Much recent research argues both ways. Ziv, Ben-David, and Ziv (2005: 195) argued that the challenge of simulation based medical education was to create a simulated scenario in which trainees could immerse themselves ‘as if it were real, and consequently, to maximize their learning from the situation’. This can be argued as a false assumption. It has been argued that the degree of fidelity and user control of an environment will not necessarily facilitate the development of conceptual understanding, but that an appropriate set of learning tasks is needed alongside relevant task support for the development of understanding (Dalgarno, 2002).

The final assumption was that ‘If the Aviators Like It, It Is Good’. Indeed this assumption can be easily changed to ‘If the Students Like It, It Is Good’ as many simulations are evaluated simply by students’ reactions to them. Kneebone (2005) reiterates this idea as he advises against the technological enthrallment of simulations as many of them are accepted uncritically and concentration on theory-based design is neglected. Holzinger et al. (2009: 292) again reinforces the call that ‘many questions still remain as to their [simulations] effective design’. A clear illustration of this assumption would stem from Issenberg et al.’s (2005) work. They highlighted a need for the improvement of research in terms of rigour and quality.

In explaining the final assumption they made, Salas et al. (1998) highlighted four levels at which training should be evaluated: reaction, learning, behaviour, and results (Kirkpatrick, 1959). These levels can easily be adopted and adapted to how effective learning from a simulation should be assessed.

- The first level: This refers to students’ and teachers’ reactions to the software. This level essentially addresses the quality of the design of the simulation in
terms of its intended expectations and reveals improvements that are needed for the simulation.

- The second level: This refers to progress in learning from the outcomes of initial learning objectives. This level gives more of a firm representation of what learning the simulation has evoked.
- The third level: This can be related to how students transfer what they have learned from the simulation to a real setting.
- The fourth level: This refers to how this behaviour results in changes to the organisational aspects of the classroom. The teacher could judge the simulation very effective and look to alter their practice in some shape or form. This stage could occur throughout the other three levels and could be considered as an overarching stage.

Many engineering journals invariably only justify their simulation software from positive reactions from users and fail to move on to level two (Dormido, Martin, Pastor, Sanchez, & Esquembre, 2004; Hernandez-Martinez & Garcia-Matias, 2007; Ko et al., 2000). Albeit the studies may not have been intended for such research, but to ensure quality and rigour, as argued by Issenberg et al. (2007), all four levels should be addressed.

From the current research discussed it is clear that these three assumptions outlined by Salas et al. (1998) still remain important factors in the current development, use, and evaluation of simulations in education. The key findings of the literature for this project are:

- Simulations can aid learning, in particular through providing increased and immediate feedback to students, and opportunities for repetitive practice.
- Simulations can remove elements of an experiment or take over routine processes. This thus reduces cognitive load on students and allows them to more quickly focus on other elements of an experiment, in particular experimental design and analysis of findings.
- Simulations can result in changes outside the sphere of simulation usage in relation to students’ and teachers’ practice.
The next section will focus on simulations in terms of virtual experimentation.

2.5.3 Perceptions of the utility of virtual experimentation

In discussing the potential uses of Virtual Laboratories (VLs) important research to consider is that of Winn and Jackson (1999) who gave 14 propositions about educational uses of virtual reality to act as a framework in which they hoped virtual reality could begin to play a small role in education. They use the term virtual environments (VEs) which is a broader term for a VL. Some examples of these propositions are that:

- VEs are cheaper than high-end simulators
- VEs are safer than real-world training
- Students can learn in VEs
- VEs are most useful when they embody concepts and principles that are not normally accessible to the senses
- Collaboration is possible, and beneficial, in VEs.

Winn and Jackson never claimed any of these propositions to be true or false, but felt more thorough research, based on empirical studies, would show findings relating to these propositions. From examples given in previous sections, many of these propositions for virtual environments have already been employed to explain the uses of the particular software. Indeed, even before Winn and Jackson, Pantelidis (1997) highlighted reasons to adopt virtual reality in education. Some of these reasons were that it is motivating, it gives the opportunity for insights based on new perspectives and it encourages active participation instead of passivity. However, with all types of virtual environments the ‘goodness’ of any technology depends on the purpose for which it was created (Salomon, 1993). The following examples give a context on which to base these propositions.

Georgiou et al. (2007) developed a Web-based virtual chemistry laboratory for volumetric analysis experiments. Some of the advantages they highlighted for Web-based distance education was that it gave space and time independency, it was low cost and easy to access, and overall it shifts the centre of learning from the teachers to the students. Another use they suggested was that the application allowed non-
experienced students to become familiar with the equipment of a laboratory without the need of a teacher. However, these findings were not based on empirical studies of students’ use of the virtual laboratory.

Dalgarno, Bishop, Bedgood, and Adlong (2004) have developed a 3D VL that is used to familiarise students, in particular distant learners, with the real laboratory before entering it. 55 of their students completed a questionnaire and 16 of them were interviewed. Their findings were that students were generally positive about the virtual laboratory in that it increased their confidence and reduced their anxiety about doing practical work. Of particular interest was that they noted differences in the perception of the virtual laboratory in terms of student age. Older students (>35 years) were less likely to perceive more benefits from the virtual laboratory than younger students and were less likely to use it. A reason given for this was that older students value personal interaction more. This links to the proposition that collaboration is possible and beneficial, but based on Dalgarno et al.’s (2004) study, the perceived benefits of collaboration relate to the participants’ ages.

This idea of collaboration has developed beyond the original preposition as seen with Yaron et al. (2006: 181) who have added an authoring tool to their virtual chemistry laboratory creating the ability for instructors/teachers to modify and create new materials. The development of these new materials has developed a community of practice around them as many adopters look to develop their teaching approaches. This reduces the length of curriculum development by actively engaging the community in the process itself. Other uses of their virtual laboratory from observations of 30-35 students showed that students found an experimental design problem more difficult than the text problem. This demonstrated a use of the laboratory in that there was additional learning in making a connection between an equation and the physical process. This point reinforces the proposition that students can learn in VEs. On a more general note, Baggott and Nichol (1998) describe how simulations allow ‘what if’ questions to be asked, which can be pursued to the answer through immediate feedback.

In relation to chemistry, advantages noted in a review of a VL software called Crocodile Chemistry are that the VL allows students to repeatedly perform reactions
while variables are changed, students have a greater access to a bigger variety of materials and chemicals, and dangerous reactions can still be manipulated (Keith-Lucas, 2000). Also, the review noted that simulations can be seen to bridge the gap between textbook and hands-on laboratory experiments, or as a means to expand student experiences into areas not possible in a normal lab environment. Chang and Wang (2009:170) reinforce this point further as they argue that technologies, including simulations, provide the possibilities of building learning environments that make students and ‘even real scientists’ able to view abstract phenomena that cannot normally be seen. VLs also provide use in special needs education (Neale, Brown, Cobb, & Wilson, 1999).

Zacharia (2007) carried out an empirical study to investigate the value of combining Virtual Experimentation (VEx) with REx in terms of students’ conceptual understanding of electric circuits. The students in the study were conceptually tested before, during, and after the teaching intervention. It was found that a combination of REx and VEx enhanced students’ conceptual understanding more than REx on its own. For part of the curriculum some students were only taught using REx, while other students were only taught through VEx. It was found that the group of students using only VEx had a more enhanced conceptual understanding of that part of the curriculum than students who only did REx. This is a very interesting finding as Zacharia (2007: 129) notes that ‘it is manipulation, rather than physicality, as such, that may be the important aspect of instruction’. In looking to explain why VEx aided students more conceptually than REx, Zacharia (2007: 129) suggested possible reasons, such as VEx:

(i) made phenomena more visible to learners (e.g. charge flow);  
(ii) allowed students to perform and repeat an experiment more easily, and thus experience it more;  
(iii) enabled easier and faster manipulation of variables than RE; and  
(iv) provided immediate feedback (e.g., about errors) throughout the process of construction of any circuit by the students.

In a study by Ketelhut and Nelson (2010) it was found that for some cases in using VEx for science classes that higher learning outcomes prevailed compared to REx, in particular for students who scored at or below the average of the scientific inquiry
pre-test. This enforces the importance of combining REx and VEx so as to offer students variety in their preferred learning approach. Khan (2011) also notes the value of combining simulation technology with appropriate teaching pedagogy to enhance student conceptual understanding.

In a review of 53 empirically based research articles from 1999 to 2009 on the educational applications of virtual environments, Mikropoulos and Natsis (2011) note that the majority of articles relate to science and mathematics and that the commonly cited features of Virtual Reality (VR) that are utilized for particular educational contexts and content are ‘first order experiences [student-centred learning], natural semantics, size, transduction, reification, autonomy and presence’ (p.769). They also note that the theoretical model underpinning most research on virtual environments is constructivism in that students are presented with real world tasks that support ‘context and content dependent knowledge construction’ (p.769). This knowledge construction can also be collaborative in nature and virtual environments also ‘foster reflective practice’ (p.778) in students.

This section highlights the varying uses of virtual experimentation. The key findings from the literature for this research are:

- VEx encourages active participation over passivity, gives space and time independency, and can facilitate experiences beyond that of normal student experiences.
- Within the VCL teachers have the potential to develop their own problems and thus become curriculum makers.
- VEx has been shown to provide students with greater conceptual understanding than REx alone.

The following section will provide a chapter summary of the literature review.

### 2.6 Chapter summary

This chapter has discussed a wide variety of issues in current research that have important implications for this research project in areas relating to educational change, ICT integration, PCK, IBSE, and virtual experimentation. The key
theoretical points from the research literature that can offer insight into the findings of this research project are:

- The key role teachers play in the outcome of any school-based project (Fullan, 2007).
- The three level model to explain teacher decision-making: gestalt, schema and theory (Korthagen, 2010).
- The differing levels of engagement in ICT use by teachers in practice (Sorienta & Jimoyiannis, 2008) and the many factors influencing this engagement (Cuban, 1986; Ertmer, 1999; Zhao et al., 2002).
- The utility of PCK to describe and in turn, explain teacher practice (Abell, 2008; Loughran et al., 2001).
- The many barriers to IBSE, particularly teachers’ philosophy, their conceptions of science and the types of assessment in schools (Crawford, 2007; Hodson, 1998; Waight & Abd-El-Khalick, 2011).
- The need for exemplification of IBSE for teachers with continuous support as they implement this teaching methodology (Asay & Orgill, 2010; Penuel et al., 2009; Rushton et al., 2011).
- The utility of VEx to support and enhance REx (Ketelhut & Nelson, 2010; Zacharia, 2011).

These key findings from the literature will be used to illuminate the findings of this research in the discussion chapter (Chapter 5). The following section will discuss the research methodology.
Chapter 3: Research methodology

3.1 Overview of the chapter

This chapter consists of ten sections detailing

- a review of the research questions (Section 3.2),
- the research strategy (Section 3.3),
- the research design (Section 3.4),
- the research methods (Section 3.5),
- the research procedure (Section 3.6),
- the research participants and timeline (Section 3.7),
- an explanation of two problems on the VCL (Section 3.8),
- analysis of the findings (Section 3.9),
- ethical considerations (Section 3.10), and
- a chapter summary (Section 3.11).

3.2 Review of the research questions

As noted in the introduction, a project of this nature affords many potential angles of investigation. In giving advice on choosing studies of research, Bogdan and Biklen (1992: 59) explain that the exact decisions a researcher makes are not always crucial, but it is crucial that the decisions are made. This section will consider why the research questions were chosen. As was visible from the literature review, educational change involves many stakeholders, from teachers to policy makers and other external bodies. For meaningful change it is important to have an understanding of the interactions between these stakeholders and how it relates to the school environment (Fullan, 2007). This project is focused on the use of a VCL to support changes towards IBSE, but attempts at this change must first consider the school culture in which it is looking to take shape, and how this culture may react to such change. These considerations led to the first research question:

1. What are stakeholders' views of the current science culture in Irish schools and how does this relate to the integration of a VCL to support educational change in chemistry?
This research question is novel in that the use of a VCL has not been considered in how it may impact on school culture. The literature review highlights considerations of VLs specific to teaching and learning in the classroom, but not how they may have a further reaching impact to mediate change between teachers and other educational stakeholders in impacting school culture. Ultimately, this question is geared towards understanding the current landscape of Post-Primary chemistry education in Ireland as expressed by teachers and other stakeholders, and their views on how a VCL may fit within or change the current landscape of teaching, learning, and assessment.

Having described the current culture in schools from the first research question and how this relates to the use of a VCL, a second research question can begin to look more closely at how this culture may be supported to move towards IBSE, through the context of teachers use of a VCL in their classroom practice. This would necessitate a strong focus on teachers’ ZPD, particularly in relation to their current decision-making, roles, and habitus, and how much this aligns with IBSE. This leads to the second research question:

2. How can the VCL act as an enabling infrastructure for IBSE in teachers’ classroom practice?

Although this research question is more specific in terms of the classroom, it encompasses a broad range of factors related to habitus within teacher schema and associated roles for teachers and students. Some of these factors relate to teachers’ integration of ICT into their practice, teachers’ knowledge in effectively utilising a VCL, teachers’ articulation of IBSE through VCL practice, and teachers and students views of the VCL in relation to teaching, learning, and assessment. The second question is novel in that the current literature highlights research focused on the use of virtual environments to align with more constructivist approaches (that fall in line with inquiry), but no research has been carried out specific to the use of this VCL in an inquiry manner, in the Post-Primary School sector, and focusing on addressing and challenging existing teacher schema. Instead, many studies start outside teachers’ ZPD and introduce conceptions of IBSE far beyond teachers’ existing schema e.g. open ended inquiry and oftentimes, guided inquiry may be a step too far. Such approaches fail to be cognizant of teachers’ existing schema and as such, are ‘doomed
to tinkering’ (Stoll & Fink, 1995: 80). For example, in implementing state curriculum materials, Penuel et al. (2009) found that professional development and the provision of all necessary resources had little impact on teachers’ implementation as desired by the state. In explaining this poor level of implementation, it was noted that state strategies fail to recognise the ‘particular needs of teachers and schools’ (p.672). An important awareness for this research is that it must first relate to teachers’ existing practice, before greater IBSE may be scaffolded, i.e. working stepwise within teachers’ ZPD.

Other lines of investigation could be taken, but it is felt that the second research question could be readily answered based on an understanding of the above factors. Towards this end, the second research question has been broken down into four sub-questions:

a) How do teachers’ knowledge of the teaching of particular content relate to how they adopt a VCL within their classroom practice?

A significant factor in how teachers’ shape their use of a new ICT resource is dependent on their ‘knowledge base’ (Shulman, 1986) of teaching, namely their PCK. It would be expected that teachers with a higher PCK would be in a better position to utilise the affordances of ICT-based resources, given the flexibility and degrees of freedom within the resources. This would also be suggestive of such teachers having well-developed schema. In answering this question, facets of teachers’ existing schema would be illustrated.

b) In what ways do teachers integrate an ICT resource into their practice?

This is an important question to consider as it highlights preferred teaching approaches in the use of a new ICT resource. This can also be reflective of many of their beliefs and in turn, gives good insight into what ways a VCL would be used. For example, Sorienta and Jimoyiannis (2008) noted three discrete groups of teachers in how they used ICT within their classes (traditional, undecided, and non-traditional) and it would be interesting to see how this takes shape in relation to teachers’ use of the VCL, as it would be reflective of existing teacher schema, similar to the previous question (a).
c) In what ways does the teachers’ use of the VCL support inquiry-based approaches?

This question is the central focus of the second research question. However, teacher adoption of ICT resources and their knowledge for teaching need consideration beforehand, as they strongly point to existing teacher schema and how this may influence the possibility and types of inquiry being demonstrated in class through the use of the VCL. Here, teachers’ schema can now be challenged through the scaffold of the VCL. With the two previous questions addressed, teachers are within their ZPD, but the VCL can facilitate progression towards greater IBSE e.g. moving from ‘verification’ to ‘structured’ inquiry, or from ‘structured’ to ‘guided’ inquiry, depending on the teacher’s existing schema.

d) What are teachers’ and students’ reflections on the use of the VCL as a potential teaching, learning, and assessment tool?

This research question is focused on overall comments by teachers and students after having used the VCL, where they believe the VCL fits within their current activities, and what its future role may be. These views would offer insight into the potential of the VCL to aid in students’ and teachers’ movement towards greater IBSE, and what teacher and student habitus may impinge on the use of a VCL in such a way.

The next section will give an explanation of the research strategy utilised in attempting to answer the above research questions. The rationale behind the research strategy will also be explicated in the context of this research.

3.3 Research strategy

Research strategy generally involves the distinction between quantitative and qualitative research. Quantitative research entails measuring, ‘using scientific techniques that are likely to produce quantified and, if possible, generalizable conclusions’ (Bell, 1993: 5). Qualitative research, on the other hand, is more concerned in understanding ‘individuals’ perceptions of the world’ (Bell, 1993: 6),
seeking insight instead of statistical analysis. Some writers have debated the utility of such a distinction as qualitative and quantitative research (de Vaus, 2001; Layder, 1993; Yin, 2009). Dillon and Wals (2006) for example, highlight the meaninglessness of a questionnaire to be considered in relation to qualitative or quantitative, as it can contain closed and open elements. Bryman (2008: 21) also acknowledges the ‘ambiguous’ nature of the qualitative and quantitative distinction, but explains the distinction’s utility as a ‘useful means of classifying different methods of social research’ and as a ‘helpful umbrella for a range of issues concerned with the practice of social research’ (p.21).

Important criteria in choosing qualitative or quantitative techniques generally relate to issues of reliability and validity. Firstly, reliability relates to ‘whether the results of a study are repeatable’ (Bryman, 2008: 31) and is of particular concern to quantitative research e.g. if a test would have the same result if taken twice. In social research, reliability can be explained as ‘the consistency and trustworthiness of a research account’ (Kvale & Brinkmann, 2009: 327). Secondly, validity refers to ‘the integrity of the conclusions that are generated from a piece of research’ (Bryman, 2008: 32). This integrity can relate to four areas (Bryman, 2008: 32):

- ‘whether a measure that is devised of a concept really does reflect the concept that it is supposed to be denoting’ (Measurement validity),
- ‘whether a conclusion that incorporates a causal relationship between two or more variables holds water’ (Internal validity),
- ‘whether the results of a study can be generalized beyond the specific research context’ (External validity) and
- ‘whether social scientific findings are applicable to people’s everyday, natural social settings’ (Ecological validity).

Bryman (ibid) explains that measurement validity and internal validity are particularly related to quantitative research, while external validity can have some connection with qualitative, but is more readily applicable to quantitative, and that ecological validity has relevance to both qualitative and quantitative research. Qualitative research holds very well in relation to ecological validity, as it is focused on natural settings. The ‘unnaturalness of the fact of having to answer a questionnaire may mean that the findings have limited ecological validity’ (Bryman, 2008: 33) and thus, would be
limited in its use. This point can be valid for both quantitative and qualitative questionnaires. A greater discussion of validity and reliability will occur in the next section on how they relate to the research methods for this project. Due to the strengths and weaknesses of quantitative and qualitative research, some researchers draw on both techniques in an attempt to enhance the overall quality of their research. This is referred to as mixed methods research. Importantly, qualitative research is not competitive with quantitative work (Silverman, 2006: 351) with both giving potential areas of insight.

Dillon and Wals (2006: 558) note the importance of researchers considering ‘the ontological, epistemological and axiological ramifications’ of the research strategy chosen. It is based on these considerations where a researcher will position themselves in the use of quantitative, qualitative, or mixed methods research. Dillon & Wals (2006: 550) explain each consideration: ontology ‘looks at what we’re dealing with (the what) – the nature of reality’, epistemology relates ‘to how we make knowledge (the how)’ and axiology refers ‘to ethical considerations and our own philosophical viewpoints (the why)’. Bryman (2008) explains these considerations under similar headings (Orientation to the role of theory, epistemology, and ontology) but encompasses different meanings under these headings. There is agreement in ontology as Bryman (2008: 4) describes it as referring to ‘whether the social world is regarded as something external to social actors [objectivism] or as something that people are in the process of fashioning [constructionism]’. However, there is disagreement in the use of epistemology, as Bryman (2008) relates it to ‘whether or not a natural science model of the research process is suitable for the study of the social world [Positivism and Interpretivism]’ (Bryman, 2008: 4). Dillon and Wals (2006) restrict their explanation of epistemology to deduction (testing of theory) and induction (generating theory), and encompass positivism and interpretivism under axiological considerations. The researcher will make use of Dillon and Wals (2006)’s terminology and associated meaning with this terminology, to explicate their choice of research strategy.

So what, how and why? Firstly, the ‘what’ of this research is primarily focused on the development of teacher schema for IBSE through the use of a VCL. As noted in the literature, IBSE is open to differing and dynamic conceptions and interpretations.
Hence, having a predetermined means of capturing teachers’ IBSE conceptions would be an incredibly difficult task. Thus, an ontological position of constructionism (emphasis on interactions between people) would be more readily applicable to this research context. Secondly, the ‘how’ of this research relates to understanding teachers’ habitus in practice and how their existing schema can be developed and extended towards IBSE, i.e. how teachers perceive IBSE and how they enact it through their classroom practice in the affordances derived from the VCL. This focus on teachers’ practice falls in line with an epistemological focus on induction (theory from research). Finally, the ‘why’ of this research relates to the overall philosophical considerations of the researcher. These considerations focus on the research context of school-based research using a new ICT resource to develop IBSE. It is felt a qualitative approach would be more suitable, as it places a greater stress on understanding the social world through an examination of the interpretation of the world by its participants (interpretivist), as opposed to a natural scientific model in quantitative research (Bryman, 2008: 366). Some quantitative instruments could also be used, but in a qualitative way due to the difficulty in getting access to a large enough number of inservice teachers. Thus, though primarily focused on qualitative methods, the researcher also has utilized quantitative instruments to give insight into some common practices across the teachers and feedback from the students. The overall methodological approach would therefore be mixed methods.

Given the multi-faceted nature of the research questions, it is felt a research strategy of mixed-methods through triangulation would be most effective as triangulation is ‘the use of two or more methods of data collection in the study of some aspect of human behaviour’ (Cohen, Manion & Morrison, 2000: 112). The assumption is that if the findings from each method correspond then similar conclusions can be drawn, thus the validity of the findings can be established (Silverman, 2006: 291). Validity and reliability for each research method will be discussed in more detail in a subsequent section. The research design for the project will now be discussed.


3.4 Research design

In explaining research design, de Vaus (2001) uses the analogy of constructing a building. When planning a building, it is a bad idea to order materials, buy particular tools or set certain dates, until a person knows what the type of building is going to be, e.g. school, house, offices, etc., and until this is decided, a plan cannot be effectively considered. Inherent considerations within this analogy are also the uses of this building and the needs of its occupants. In the context of social research, de Vaus (ibid) notes the necessity of a design before data collection or analysis can occur, and that far too often, researchers design questionnaires or start interviews ‘before thinking through what information they require to answer their research questions’ (de Vaus, 2001:9). Dillon and Wals (2006: 558) also echo this in that ‘inquiry should be driven by questions, not by preferred methods or even methodologies’. This quote also points to the importance of distinguishing methods and methodologies. Wilson and Stutchbury (2009: 57) explain this distinction in that methods relate to the particular approaches used to collect evidence for the research question, the data to collect and from whom, whereas methodology ‘consists of the overarching ideas about how a research study is designed’. More specifically, methodology ‘informs and links the methods used to collect and analyse data to answer the original research question’ (Wilson and Stutchbury, 2009: 58). Further to this, both methods and methodologies are distinct from the research design in that the research design ‘integrates the different components of the research project in a cohesive and coherent way’ (Wilson & Stutchbury, 2009: 57), in order to answer the research questions.

To refer back to the building analogy, research design would be considered the overall plan for the type of building and the rationale behind it, determined by the research questions. The methods would relate to the possible means by which to build the house. The methodology then involves considering the process used to build the house and what can be drawn from this process. Methods and methodologies for this research will be considered in subsequent sections. This discussion will now return to the research design.
This research design is driven by the two core research questions (noted in a previous section). The overall focus of this project is on research question two, i.e. how a VCL may effect educational change in classroom practice in the direction of IBSE. However, before considering this, an understanding of the current school science culture is needed and how this culture relates to the use of a VCL (research question one). Certain contextual factors related to Irish schools impinged on determining an appropriate research design to answer these questions. Firstly, Irish schools can be very difficult to get access to, as teachers are not usually paid, or required as part of their job to participate in research. It is totally voluntary. Hence, there is an issue of participation and thus, large numbers of participants would be difficult to encompass in the research design. This project was unable to pay teachers for their participation and thus, needed teachers that were willing to volunteer. The issue of participation also impinged on piloting the research methods. If piloting was used, it would reduce the number of teachers available and willing to participate in the actual core research. Hence, piloting would most likely limit the overall data obtained from the research, rather than enhancing it. Also, many of the research instruments used in this research (explained in subsequent sections) have been developed and used in other research. Hence, piloting the research instruments was unnecessary in many instances. If inservice teachers were more easily accessible, piloting would have been considered.

Secondly, an important aspect of school based research relates to logistical and organisational aspects of classroom visits, in that cancelled classes, school events, school trips, etc., are a common occurrence militating against classroom research. This aspect of schools points to the need for a research design that is flexible enough to incorporate ‘the reality of educational practice on a day-to-day basis’ (Helsby, 1999: 30) in schools and in classrooms. Therefore, a rigid experimental design would not offer enough flexibility for school-based research. Thirdly, there are issues in determining teachers’ ICT usage and hence, their ability to give feedback on the use of ICT. This ability is further compounded by the fact that even teachers who regularly use ICT may never have seen the VCL for this research, not to mention use it. This unfamiliarity raises research design issues in relation to obtaining findings that can be compared across teachers. Finally, teachers’ understanding of IBSE is also an important factor and how it relates to their existing schema. As noted in the
literature, there are broad conceptions of IBSE and thus, a research design that captures how IBSE is interpreted and enacted by teachers is needed.

In considering the above issues in light of the research questions, case study design is deemed most appropriate for this research. Demetriou (2009: 203) highlights the value of the case study design in that it is ‘versatile’ and it facilitates researchers in understanding ‘a complex issue or object and brings with it a familiarity to the case that no other research approach is able to do’. These are important factors for this research project, in that understanding the school science culture and how a VCL may support and/or challenge teachers’ towards greater IBSE in this culture is a complex task. However, this task will be aided through the development of familiarity by the author through a case study design.

Bryman (2008: 53) describes the use of a ‘case’ as commonly being related to a location with the focus tending to be on ‘an intensive examination of the setting’. Flick (2006) describes the use of ‘case’ as having a broad interpretation from studying persons, social communities, organisations, and institutions as subjects for a case analysis. For the case studies in this research, the location relates to science classes in different schools, whether these are boys, girls or mixed sex schools. The examination relates to particular settings within these schools focused on teacher practice in terms of IBSE. Bryman (2008: 53) cites a common difficulty in discerning between a cross-sectional design over a case-study design and stresses the importance of the location being a crucial part to the ‘unit of analysis’ for a case-study research design. The multiple case studies in this research occur in different locations and hence, are accounted for in the analysis. However, the intensity with which each case has been examined in this research has not been as in-depth as possible in that the author also desired breadth by having multiple cases of study. As noted by Flick (2006: 131) there will always be fluctuation ‘between the aims of covering as wide a field as possible and of doing analyses, which are as deep as possible’. In approaching the case studies the author sought four to five teachers for participation that would be realistically manageable, but that could also provide distinctive and meaningful data between each case for some comparisons.
The use of multiple case studies for this research was not originally conceived as being longitudinal in nature. However, interesting findings emerged from the first stage of case studies (Stage 2 of the research) and a follow-up study was decided upon as a result (Stage 3 of the research), making the case studies longitudinal in nature. Bryman (2008: 52) notes this in that ‘it can happen that the idea of conducting a longitudinal study occurs to the researchers at a later date’ and in many instances may not be part of the original research plan. However, issues can emerge in comparing the two stages of data collection due to such factors as time elapsed, different people at the school, different educational issues, and the potential influence of the initial study itself (Burgess, 1983). The author kept these issues in mind for the second stage of case studies in that teachers already had experience of the VCL, hence reducing issues related to ease of use. However, the author was also wary that some teachers from the first case studies may not want to continue in the research. This would diminish the amount of comparison between the two stages of research, but is part of the difficulties associated with longitudinal research in schools. This is reflective of issues discussed in the literature, in particular that any form of change can be viewed as leading to an intensification of teachers’ work by adding burdens to a job that is already excessively demanding (Hargreaves & Evans, 1997). Also, teachers’ level of autonomy in their school (Gleeson, Clifford, Collison, O’Driscoll, Rooney, & Touhy, 2002) can affect their continued engagement in a research project, e.g. a principal not wanting them to participate or parental pressure to teach in a certain way. This issue of autonomy is particularly pertinent to the Irish context with a strong focus on preparing students for final examinations. Ultimately, teachers may not be willing to offer their time over an extended period needed for a longitudinal study for varying reasons. In this instance the author would have no choice but to source other teachers and acknowledge the consequences of this on the research design.

A common issue argued with the case study approach is that the findings cannot be generalised (Bryman, 2008). However, generalisability is not usually the purpose of a case study. Despite this, the use of multiple case studies could allow for possible areas of commonality to be identified across cases. The next section will explain the research methods adopted within the case study design of this project.
3.5 Research methods

The methods used in this research included the following:

- Interviews (Section 3.5.1) - Semi-structured interviews, focus group interviews and PCK descriptors: Content Representations (CoRes) and Pedagogical and Professional experience Repertoires (PaP-eRs),
- Observations (Section 3.5.2) – Unstructured observation, video observation and Reformed Teaching Observation Protocol (RTOP), and
- Questionnaires - Inquiry Science Implementation Scale (ISIS) and Student Self-Assessment (Section 3.5.3).

Some of the features around all of these research methods will now be discussed.

3.5.1 Interviews

Interviews, in one form or another, have been around for a very long time, with even the ancient Egyptians having conducted population censuses (Babbie, 1992). However, the use of term interview only came into use in the 17th century (Kvale & Brinkmann, 2009). In more recent times, interviewing has evolved based on two trends. The first trend related to clinical diagnosis and counselling, where the concern was on the quality of responses, and the second trend focused on psychological testing, particularly during World War I, where the emphasis was on measurement (Maccoby & Maccoby, 1954). The first trend has developed into qualitative types of interviewing in social research.

The purpose, applicability and utility of interviews in qualitative research is ‘to gather descriptive data in the subjects’ own words so that the researcher can develop insights on how these subjects interpret some piece of the world’ (Bogdan & Biklen, 1992: 96). There are varying structures to qualitative interviews. These include structured, semi-structured, open-ended, and focus group interviews (Silverman, 2006:110). Semi-structured interviews and focus group interviews are considered in relation to this research project.
Chapter 3: Research Methodology

**Semi-structured interviews**

Qualitative interviews have been used to varying degrees in the social sciences throughout the 20th century, with anthropologists and sociologists in particular having used informal interviews to obtain data from their participants (Kvale & Brinkermann, 2009). The interview structure that is most applicable for this project is semi-structured. The advantage of semi-structured interviews is that they offer considerable latitude to pursue a variety of topics (Bogdan & Biklen, 1992: 97), as opposed to structured interviews that are more quantitative in nature where all respondents are asked the same series of pre-established questions by the interviewer with a limited set of response categories (Denzin & Lincoln, 2005: 71). The semi-structured interview goes beyond this in that it allows for some probing, building rapport with the interviewee, and requires an understanding of the aims of the project from the interviewer (Silverman, 2006: 110). Other advantages of semi-structured interviews are that they provide rich data to paint a broad picture and may highlight issues previously unconsidered (Wilson & Fox, 2009).

Important considerations should be made about interviewing in relation to reliability and validity. Firstly, in relation to the reliability of interviews, the concern is whether the interviewees ‘will change their answers during an interview and whether they will give different replies to different interviewers’ (Kvale & Brinkmann, 2009: 245). This issue of reliability particularly relates to the researcher in that they may ask leading questions, which ‘may inadvertently influence the answers’ (ibid: 245). This issue of leading questions relates to Cohen et al. (2000: 267) who argue that ‘the interview is that of a transaction which inevitably has bias, which is to be recognized and controlled’. In avoiding leading questions and reducing bias, it is useful for a researcher to have a topic guide in minimising their influence on interviewees’ responses. Issues of reliability also relate to transcribing and analysing interviews. These issues relate to the agreement between the researcher and a second person on what is transcribed and the codes under which it is analysed. To enhance the reliability of the interviews the researcher utilised a critical friend during the research. The critical friend ‘served as an intellectual watchdog’ (Rossman & Rallis, 2003: 69) in ensuring the value of conclusions made from the interviews.
Secondly, in relation to validity of interviews, Kvale and Brinkmann (2009: 248) note that ‘validation does not belong to a separate stage of an investigation, but permeates the entire research process’. There are significant considerations needed throughout the process from thematizing, designing, interviewing, transcribing, analysing, validating and reporting (*ibid*). For example, interviewing refers to the trustworthiness of the interviewees’ reports and the quality of the interviewing, while analysing pertains to whether the logic behind the interpretations made is apt. Also, in interviewing, the presence of an audio-device ‘might be unobtrusive but might constrain the respondent’ (Cohen *et al.*, 2000: 281). Validity requires the researcher to continually check, question, and theoretically interpret the findings (*ibid*: p.249). This involves tactics such as checking for researcher effects, triangulating, following up on surprises, looking for negative evidence etc. (Miles & Huberman, 1994).

From the above explanation of semi-structured interviews, there are many reasons why semi-structured interviews would be useful in answering the research questions. Firstly, in terms of research question one, that is focused on teacher and stakeholder views of school science culture and how it relates to the integration of a VCL, a semi-structured interview would allow the researcher to explore important issues for the project with interviewees (the perceived role of ICT in schools, teachers’ use of ICT, reasons to use a VCL, and issues around student assessment). The responses of interviewees would provide rich data, highlight issues that the researcher may not have considered, and overall, allow the researcher to effectively answer the first question. Quantitative interviewing would not give the insight needed to effectively answer research question one and provide ecological validity. Interviewees may not have been familiar with the VCL, so answering closed questions about it would be difficult. Also, having interviewees of different background (teachers and other stakeholders), the response items may not be suitable for each stakeholder and thus, would not adequately reflect their true interpretation. To this end, a qualitative approach was decided in the form of semi-structured interviews. Semi-structured interviews would aid in giving a picture of the landscape in which the multiple case study design is to be utilised.

Secondly, in terms of research question two on how a VCL could support teachers’ IBSE in classroom practice, semi-structured interviews would not directly illustrate
classroom practice. However, interviews would be a useful means for teachers to share their reflections, having taught these lessons. It would facilitate teachers in articulating their practice, thus highlighting important issues associated with elements of research question two i.e. teacher knowledge, attitudes towards integrating ICT and teacher IBSE schema. Hence, semi-structured interviews have been utilised as a means in answering research question two. The placement of semi-structured interviews throughout the research will be explained in a subsequent section.

**Focus group interviews**

Focus groups have been used for a variety of purposes over the past century. Social researchers conducted group interviews in the 1920s, but more widespread use of group interviews took place in the 1950s, with market researchers coining the term ‘focused group interviews’ which they used to ‘investigate consumer motives and product preferences’ (Kvale & Brinkmann, 2009: 150). The focus group method is a form of group interview in which there are several participants including the researcher who takes the role of the facilitator. There is generally a focus in the questioning on a particularly tightly defined topic where there is expected interaction within the group and a joint construction of meaning (Bryman, 2008: 474). Bryman (2008: 475) highlights the uses of the focus group for research in that it allows the researcher to examine the ways in which people in combination with one another interpret the general topics in which the researcher is interested in. He continues in that the focus group allows people to probe each other’s reasons for a certain viewpoint, it allows people greater time to formulate their responses and also offers them other considerations they may not have thought of in a one-to-one interview, but would like to comment on. On the flip side, people may only be comfortable sharing certain information in a one-to-one interview and not with their peers (Cohen et al., 2000: 288).

Many considerations of reliability and validity that were discussed in the previous section, in relation to interviews, apply to focus groups, as it is another form of interviewing. However, focus groups are distinctly different, as they entail a group dynamic. Issues in reliability relate to the researcher leading participants to agree with their views, some participants can dominate the group and in turn push a false consensus, and also issues emerge when transcribing in distinguishing between
individuals in the group (Wilson & Fox, 2009: 92). As in the previous section, a critical friend can aid in this process. An issue in relation to the external validity of focus groups is that it is difficult to generalise findings if the group is small or not representative of the wider population (ibid: 92)

The use of the focus groups could be of particular value in helping to answer certain parts of the research questions. However, there are too many practical difficulties in organising focus groups for this project. The reasons for this relate to many schools only having one chemistry teacher, thus there is an issue in the numbers participating. Also, even if a school had more than one chemistry teacher, the likelihood that both would be free at the same time to participate in a focus group is limited. These issues also relate to organising groups of educational stakeholders. In terms of the research questions, there would also be an issue with focus groups of teachers, as the research questions are more interested in individual teacher practice, highlighting their existing schema and how this may be facilitated towards greater IBSE. The elements of the research questions, which relate to interviewing teachers and stakeholders, can be sufficiently provided insight through one-to-one interviewing, so it does not justify attempting focus groups.

Focus groups, however, would be useful in answering research question (d) in relation to students’ perceptions of the VCL. Unlike teachers and stakeholders, groups of students would be much more accessible and focus groups could provide a number of viewpoints, as opposed to only interviewing one student. The use of a focus group with students in particular is that ‘it may increase the comfort level of participants’ (Wilson & Fox, 2009: 92) and thus, encourage greater responses to the questions of the researcher. The placement of focus groups in the methodology will be explained in a subsequent section.

**Descriptive tools of PCK**

Since the inception of PCK in 1986 by Lee Shulman, various methods have been used in describing teacher PCK, but little agreement has prevailed on a standard model for describing PCK in science education. Both earlier and more recent research on PCK have used case studies as the dominant research approach (Appleton, 2008; Geddis &
Wood, 1997; Jones & Moreland, 2005). This is not surprising as PCK is seen as the experiential knowledge and skills that are obtained through classroom experience (Lee & Luft, 2008). As with this it is important to make note again that how researchers define PCK has a direct impact on the measurement methods they employ. Seymour and Lehrer (2006: 550) for example characterized growth in PCK as the interanimation of two discourses between teacher talk and student talk. Thus they used video-stimulated structured interviews, field notes, and teachers’ journals to capture the ‘dynamic’ nature of PCK. This section will detail two particular approaches to describing PCK, which are applicable to this research: Content Representation (CoRe) and Professional and Pedagogical experience Repertoires (PaP-eRs) (Loughran et al., 2001).

Loughran et al. (2001) felt the case study method was not comprehensive enough for describing PCK and sought to overcome this with the proposed use of CoRe and PaP-eRs (See Figure 5), as means to illustrate how teachers structure what they see as important within lessons. The CoRe requires groups of teachers to decide the ‘big ideas’ related to teaching particular content and they must then answer eight prompts under each of the big ideas in relation to teaching that content. The PaP-eRs provides a complementary framework to the CoRe that take into account the specific nature of the individual classroom experience with a teacher narrative, e.g. teaching in a boys, girls or mixed school. As can be seen in Figure 5, each PaP-eR relates to a specific aspect of the CoRe. The usefulness of these tools is that the CoRe provides quite a general framework that allows a multitude of teachers to be compared in how they represent their content and PaP-eRs provide context. CoRe and PaP-eRs are useful as research tools in offering insight into teachers’ practice, particularly PCK, but the representations created by CoRes and PaP-eRs also have a professional development value in that they are useful in helping other teachers ‘recognise and develop their own PCK of particular content’ (Loughran et al., ibid: 289). Loughran et al. (ibid: 304) developed CoRe and PaP-eRs through working with experienced science teachers, and ‘teachers have been involved…both individually, and as groups helping to develop the CoRe’. These teachers ‘recognised important insights into their own practice and experienced a genuine sense of professional development’ (ibid: 304).
Rollnick et al. (2008) used CoRes and PaP-eRs in a case study of South African teachers teaching the amount of substance and chemical equilibrium. They found the use of these tools helpful in making visible teachers’ use of representations, their strategies for specific topics, and their curricular saliency. Lee and Luft (2008) argued that CoRes have a topic-specific orientation. However, though this may be true, other types of teacher knowledge can be highlighted from the CoRes, independent of the specific topic. As is clear from Sanders et al. (1993), teachers teaching outside of their area of certification would be influenced by PCK for general science topics while teaching a specific-topic. Also, when lacking content knowledge, these teachers would rely more on their general pedagogical knowledge to help them through and not let the lessons ‘shut down or stop’ like novices. Therefore, CoRes not just solely demonstrates topic-specific PCK, but also certain forms of both subject-specific and general PCK, and also some knowledge types in isolation. The knowledge types in isolation would be expected because as explained in the literature review they must be developed before the ‘synthesis’ that is PCK can be made.
In relation to reliability and validity, similar issues as related to semi-structured interviews and focus groups apply, as CoRe entails collective aspects while the PaP-eRs involves individual aspects. However, the impact of the researcher is reduced in that teachers are provided with an empty CoRe and must complete it following the prompts. The researcher only aids the process as needed. Loughran et al. (2001: 306) argue the validity of the CoRe and PaP-eRs in that they supply ‘sufficient context for the reader to develop an understanding of the complex nature of the teaching and learning tied to that particular content’, an important aspect of naturalistic inquiry (Guba, 1981). In terms of validity, Rohaan, Taconis, and Jochems (2009) have critiqued the CoRe and PaP-eRs from the point of view that it is cost and labour intensive and in turn, the sample sizes are forced to be small. This raises questions of the external validity of CoRe and PaP-eRs. However, the intention of these research tools is on ecological validity, and the reader can determine the external validity.

The use of CoRe and PaP-eRs is grounded in PCK, which is focused on classroom practice. In considering this in light of the research questions, CoRe and PaP-eRs would be most applicable to research question two, in particular (a): how teachers knowledge of teaching particular content relates to their adoption of a VCL, but may also provide insight into other elements of research question two i.e. how teachers integrate technology and their schema related to IBSE. The specific use of CoRe and PaP-eRs in this research will be detailed in the methodology section.

3.5.2 Observations

Observation has a long history, but a more scientific approach to observation developed in the 17th century, particularly by Galileo Galilei who advocated it as part of a scientific method to experimentation (Gribbin, 2002). Observation has since spread into other fields of research and not surprisingly, in the social and behavioural sciences, observation has been described as ‘the fundamental base of all research methods’ (Adler & Adler, 1994: 389). Observations in social research can be structured in various ways including systematic, participant, non-participant, unstructured, and simple observations (Bryman, 2008: 257). This research has used unstructured observations, and structured observations. The positioning of these
research methods in the research methodology will be explained in a subsequent section.

**Unstructured Observation**

Unstructured observation does not involve the use of an observation schedule, but instead looks to record in as much detail as possible the behaviour of the participants with an aim of creating a narrative account of that behaviour (Bryman, 2008: 257). There are various concerns of reliability and validity with using unstructured observations. Jones (1996: 15) explains that the influence of pre-existing beliefs presents a serious obstacle to accurate observation and that ‘under certain conditions, people see and remember only what they expect to see’. Wilson and Fox (2009: 86) echo this concern in that the ‘observer must make immediate decisions about what to record, so [it] may be [a] superficial or unreliable account’. Also, an issue with the reliability and validity of observational data is the effect the observer can have on what is being observed (Patton, 2002: 269) i.e. the reactive effect (Bryman, 2008: 265) where people may change their behaviour because they know they are being observed. Cohen *et al.* (2000: 129) highlight an additional issue affecting validity and reliability of observations in that the researcher, in exploring the present, may be unaware of important antecedent events. This lack of awareness points to the importance of using observations in conjunction with other research methods.

Despite the particular concerns of unstructured observations, there are also advantages to such an approach. These advantages relate to having an immediate account available, the researcher can actually see what is happening, the account can be available for discussion immediately after the observation, and there is a full view of the classroom available to the researcher at the time of observation (Wilson & Fox, 2009). The use of observations in this research would be helpful in answering research question two in particular as a central part of the question is based around classroom practice. Research methods such as interviews or focus groups would not solely suffice to answer research question two effectively. As noted by Nisbet and Watt (1980: 13), interviews provide important data, but they only illustrate what
people perceive happens, not necessarily what actually happens. Hence, direct observation may be more reliable.

**Video observation**

The use of video as a form of observation is becoming increasingly utilised over the last three decades, especially due to a greater availability of recording devices. Bell (1993: 112) describes the use of video and audio recording in relation to ‘a well-financed project’ and explains that ‘in a small project there is unlikely to be the money or the time to deal with audio recordings or video tapes’. This perception of the use of audio and video recording has certainly changed in the last 15 years, with even personal mobile phone devices now having both audio and video functions. Also, with the availability of such software as Nvivo, audio and video recordings can be managed in a much more realistic manner, particularly for small projects.

The use of video observations requires particular considerations in relation to reliability and validity, some of which interact with the considerations of unstructured observations discussed in the previous section. Video observations can be better than simple observations of classroom activities in relation to reliability in that there is ‘a better chance of picking up on cues that would…be otherwise missed’ (Coombes, 2001: 59). Despite picking up on certain cues, events outside the camera shot can be missed and the camera only provides one perspective (Wilson & Cox, 2009). This highlights the importance of the researcher to be clear if their interest is ‘in the content or process of a lesson or meeting, in interaction between individuals, in the nature of contributions or in some specific aspect such as the effectiveness of questioning techniques’ (Bell, 1993: 111). This relates to measurement validity in that a video recording reflects what it is supposed to. Also, as noted by Bryman (2008) in the previous section, there is an issue of the ‘reactive effect’ of the observer in observations, but this can be even further magnified by ‘the presence of the equipment’ (Coombes, 2001: 59). Loizos (2000: 106) highlights that it can take a long time for people to ‘act naturally’ when being recorded and thus, the ecological validity of using video observations needs consideration.

In relation to the practical aspects of video recording, Loizos (ibid) highlights difficulties in obtaining good quality sound from video-recordings and the need for a
researcher to have knowledge of microphones and how they can be effectively used so as to avoid issues of poor sound quality. Also, video analysis can be considerably time-consuming (Wilson & Cox, 2009) so a researcher needs to consider if there is sufficient value to answering the research questions in recording lessons.

**Reformed Teaching Observation Protocol (RTOP)**

The Reformed Teaching Observation Protocol (RTOP) research instrument (See Appendix M) was developed by Piburn et al. (2000; see also Sawada et al., 2002) and focuses on the implementation of inquiry and other various features of a teacher’s practice within a class. The RTOP instrument was developed to align with the principles of constructivism that framed United States (US) standards documents e.g. American Association for the Advancement of Science, 1989; National Research Council, 1996. The RTOP uses a Likert-type scale that ranges from 0 (never occurred) to 4 (very descriptive). The RTOP consists of 25 statements that span a range of US standards while having a priority that focuses on ‘Inquiry-Orientation’ within a lesson. The 25 RTOP statements relate to five subscales of teachers’ practice in terms of lesson design and implementation, content (including propositional and procedural knowledge) and classroom culture (including communicative interactions and student/teacher relationships). The RTOP also consists of teacher background information, contextual background and activities, and a description of events throughout the lesson.

Piburn et al. (2000: 12) carried out a correlational analysis on the five subscales of the RTOP to ‘test the hypothesis that “Inquiry-Orientation” is a powerful integrating force in the structure of the RTOP’. The five subscales of the RTOP had R-square values (Subscales 1 to 5) of 0.956, 0.769, 0.971, 0.967 and 0.941 (ibid). The high values indicate the strong measurement validity of the RTOP subscales and hence, that it measures “inquiry-orientation” to a strong degree. In order to test the reliability of the RTOP, observers were paired together to do a subset of observations on the same classes (ibid: 9). There were 16 pairs of observers, 32 in all. The instructor was the same for three of the paired observations, but the observations were carried out on different days. The students were the same. This may have led to an underestimation of the reliability. A best-fit linear regression was carried out on one set of
observations on the other, in order to obtain estimates of reliability (32 data points in all). This estimate of reliability was calculated at 0.954 (ibid: 10). Reliabilities were also carried out for the five subscales on the RTOP and the values (from Subscale 1 to 5) were 0.915, 0.670, 0.946, 0.907 and 0.872 (ibid: 10). As each subscale only consists of 5 items, the values were expected to be substantially lower than the total score, but this was not the case for 4 of the 5 items (ibid: 10).

This observation protocol has also been used in various research and shown to have many uses (Blanchard et al., 2010; Tolentino, Birchfield, Megowan-Romanowicz, Johnson-Glenberg, Kelliher, & Martinez, 2009; Wilson et al., 2010). Blanchard et al. (2010) found the RTOP useful in distinguishing between lessons that had a guided inquiry focus and lessons with a verification inquiry focus, and in turn, were able to highlight that high school students taught through a guided inquiry approach obtained higher results on standardised assessment than students taught through a verification inquiry approach.

The use of RTOP in this research would be useful in answering research question two, as it could point to the types of inquiry that are occurring in a lesson being taught with the VCL. From identifying if inquiry has occurred and what type of inquiry, it then allows the researcher to determine the important factors that caused this to occur.

3.5.3 Questionnaires

The history of questionnaires developed as an extension of interviewing, with a particular focus on psychological testing interested in measurement (as noted in Section 3.5.1, Maccoby & Maccoby, 1954). The use of the term ‘questionnaire’ tends to relate to ‘contexts in which a battery of usually closed questions is completed by respondents themselves’ (Bryman, 2008: 216). However, questionnaires can have both open and closed elements (Dillon & Wals, 2006). Hence, it is important that the use of open, closed or a mix of both is clarified in the use of questionnaires, so as to avoid confusion.

The reliability and validity of questionnaires depends on ‘the quality of the questions’ in it (Wilson & Cox, 2009: 89). It is possible for a researcher to develop their own questionnaire, but it is more sensible to use a recognised standardized test to
supplement other data (ibid: 88). Questionnaires can be of great use to researchers in that they are relatively easy to administer, are useful to collect information from large samples (external validity) and have an absence of interviewer effects (Bryman, 2008: 217/218). However, there are also many pitfalls of questionnaires that play importantly on concerns of reliability and validity. Participants may not find the questions salient to them (ecological validity), they may miss or skip particular questions (which can affect internal validity), and how participants interpret and thus answer questions may be incorrect (reliability) (ibid: 218/219).

Questionnaires could have particular use in answering the research questions for this study. In relation to research question one, a questionnaire could be useful in obtaining the views of teachers and stakeholders around particular issues. However, as noted previously, teachers may have no experience of the VCL, thus a questionnaire would struggle to capture this. Also, each stakeholder would find different factors more salient than others in relation to the current school science culture and the use of a VCL to impact it. Hence, the effort in developing a questionnaire suitable to each stakeholder would not be worthwhile in attempting to obtain meaningful data. Again, for research question two, a questionnaire could be useful to highlight particular aspects of teacher and student practice. As the research design is a case study, the use of a questionnaire would only be useful as a supplement to interviews and observations. This would point to the value in utilising existing questionnaires, as opposed to the researcher developing a questionnaire for a small number of participants. Two such previously developed questionnaires will now be discussed.

**Inquiry Science Implementation Scale (ISIS)**

The Inquiry Science Implementation Scale (ISIS) is a teacher self-report instrument used to highlight the extent to which inquiry is embedded within classroom practice (See Appendix E). The instrument was developed by Brandon, Young, Pottenger, and Taum (2009) and is based on a model of inquiry science from the Foundational Approaches in Science Teaching (FAST) program (Pottenger & Young, 1992a, 1992b, 1992c) which is based around the National Science Education Standards in the US. The ISIS is intended to address implementation of science investigations in three phases: the introduction phase, the preparation and conduction phase of the
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investigation, and the summary phase in which students consolidate their learning from the previous phases (Brandon et al., 2009). The researchers considered many variables that would be applicable to teacher behaviours during investigations and after various testing of the ISIS, 22 statements were selected for the final ISIS instrument that were deemed to be applicable to a broader range of inquiry programmes other than the FAST program.

To test the validity of the instrument, Brandon et al. (2009) created a teacher log (used for teachers to reflect on inquiry practices after each lesson) that consisted of a subset of five items from the ISIS and correlated this with results of a previous 26 item ISIS they had developed. 74 teachers completed the teacher log and a coefficient for the five log items was 0.72 (ibid). 64 of the 74 teachers also completed an ISIS. The correlation between the five log items and the five ISIS items was 0.63 (significance 0.01) and this was justified as evidence of measurement validity (ibid).

To test the reliability of the ISIS, internal consistency and test-retest analyses were conducted. An ISIS was sent twice to a group of 183 teachers, with 156 teachers completing the ISIS once and 111 teachers completing the ISIS a second time (ibid). The 111 teachers were used for the test-retest analysis. The coefficient for the first ISIS was 0.87 and the second ISIS was 0.89, with a Pearson correlation between the two ISISs of 0.76 (ibid). A generalisability theory analysis was also conducted and illustrated that the proportion of variance due to the items was 7%, due to the respondents was 10%, and due to occasion was 0% (ibid). These findings were adjudged to indicate that the ISIS data collected were ‘highly reliable’ (ibid: 1142).

The use of ISIS in this research would be useful in answering research question two, as it would highlight teachers’ perceptions of inquiry and how they support it in their classroom practice. It could also highlight how the VCL may change teachers’ practice. The use of the ISIS in a talk-aloud manner could also illustrate teacher’ decision making in their approaches to IBSE.

Student Self-Assessment (SSA)

The Student Self-Assessment (SSA) was developed by White and Frederiksen (1998) as a means to encourage students ‘to examine important aspects of their inquiry and modelling processes’ (p.9) in the classroom. Some examples of the items contained
in the SSA that students have to reflect on are ‘Being Systematic’, ‘Being Inventive’, and ‘Reasoning Carefully’. White and Frederiksen (*ibid*) believe that the use of a reflective process, such as the SSA, is essential to students developing an understanding of inquiry and being able to carry out inquiry effectively. White and Frederiksen (*ibid*) found that students who used SSA in their Mass projects (focused on IBSE) did significantly better than students who did not. The number of students for which data was collected was 120. The main effects of reflective assessment were found to be significant for statements relating to design, \( t(109) = 2.29, p = 0.01 \), reasoning \( t(106) = 2.21, p = 0.02 \) and teamwork \( t(69) = 2.42, p = 0.01 \) (*ibid*: 34).

As the SSA is essentially a reflective tool, it serves as an insight into student thought processes and how they interpret their science learning within the classroom. This would be useful in answering research question two, in allowing the researcher to consider the role students play in a teacher’s ability to support an inquiry focused lesson through the use of a VCL.

This section has looked at the various research methods being employed in this study to answer the research questions. The next section explains how the research methods were incorporated into the research procedure and will also explain the rationales behind the use of each research tool within the research procedure.

### 3.6 Research procedure

The research procedure consisted of four stages. The purpose of the first stage was to address research question one and entailed semi-structured interviews with teachers and stakeholders. The purpose of Stages 2 to 4 was to address the second research question, and case studies of teachers’ classroom practice using the VCL were utilised to answer this. *Figure 6* represents a block diagram of the four stages of research employed in the study and the research methods used in each stage. The number of participants in each stage will be explicated in the following section.
As can be seen from Figure 6, Stage 1 addresses research question one through semi-structured interviews of teachers and stakeholders. Stage 2 was seen as a natural progression from Stage 1, because as noted by Nisbet and Watt (1980: 13), interviews only illustrate what people perceive and not necessarily what actually happens. Hence, Stage 2 followed on from research question one and began to address research question two, highlighting how teachers in the current landscape of schools adopted a VCL in practice. This would also provide important insight on possible issues unconsidered by the researcher. With the completion of Stage 2, it set the scene for Stage 3 where teachers were to use the VCL in an explicitly inquiry directed manner. This would strongly answer to research question two in highlighting any issues that teachers would have with such an approach and how the VCL would facilitate this process. Stage 4 followed from Stage 3 in highlighting what teachers had taken from Stage 3 through problems they described for the VCL. A more detailed explanation of each stage will now be presented, alongside the research methods incorporated within each stage and how these related to answering the research questions.

Firstly, Stage 1 of the methodology involved interviewing teachers and other relevant educational stakeholders (See Appendix A for topic guide) including people from the
National Council for Curriculum and Assessment (NCCA), the State Exams Commission (SEC), the Inspectorate, the Second Level Support Service (SLSS), and teacher educators. These various stakeholders have differing roles in Irish Post-Primary education and impact on the current culture in Irish science classrooms in different ways. Teachers are responsible for implementing the curriculum as outlined by the NCCA. The NCCA is a statutory organisation that works in an advisory role to the Minister of Education and Skills on curriculum and assessment, and this advice is based on consultation and research in schools. The SEC, as noted previously, is responsible for implementation related to current Irish assessment and thus has a strong say on any changes to assessment. The Inspectorate is a division of the Department of Education and Skills (DES) that evaluates the quality of teaching in schools and thus advises on educational policy. The SLSS, as the name suggests, is a support service for teachers on integrating effective classroom practice and thus is astute to emerging technologies that can be used in schools to enhance curriculum. Finally, teacher educators play an important role in relation to pre-service teachers and the advisory role they play to the aforementioned organisations based on research related to current teacher practice.

The purpose of these interviews was to illuminate some of the issues in the current landscape of Irish science education early on in the project and how these related to the VCL, thus addressing research question one. As can be seen from the explanation of the various stakeholders’ roles above, there are some similar roles and thus potential for both agreement and disagreement on current educational issues between the stakeholders. The DES has the final say on any changes to curriculum and assessment, but other stakeholders have critical roles towards influencing these changes. Semi-structured interviews were viewed as the most effective research method in providing an opportunity to explore the current landscape of chemistry education in Ireland and where a VCL may fit within this. As noted previously, this related to the fact that teachers and stakeholders may not be familiar with the VCL, so a research method that allowed divergence was needed. The questions on the topic guide (Appendix A) for the semi-structured interviews were deemed important issues to be aware of based on the literature review related to teachers’ beliefs on the use of ICT and some questions were included to receive specific feedback on the use of the VCL. All interviews were recorded, where the participants gave permission. Only
one stakeholder (Stakeholder D) refused to be recorded. It is important as far as is possible to record interviews as it will not be possible for the interviewer to write down everything that is said, interviewers also may embellish what is said or misinterpret what was said by an interviewee (Bryman, 2008).

Secondly, Stage 2 involved a case study of practising chemistry teachers. The purpose of this case study was to begin to address the second research question of how the VCL may support IBSE, after having considered research question one. Stage 2 involved the exploratory use of the VCL with teachers, in order to highlight their decision-making in integrating a new ICT resource into their practice, and to gain insight into the teachers’ schema when given the opportunity to teach with an open, inquiry-based environment, such as the VCL. The author was interested to see if the teachers would utilise such an environment in an inquiry manner with their students, or if they would structure the use of VCL in such a way that it became part of a traditional, teacher-centred lesson. This may not be a conscious decision made by the teachers to use the VCL in such a way, but based on their previous experiences they may only know “how to act” in this manner. Hence, teachers may not see the innate value of the VCL to support student inquiry. The teachers were asked to use the VCL however they saw fit and without any direction from the author. The only stipulation was that they had to use the VCL within a class lesson.

The research methods used for Stage 2 (See Figure 7) needed to be broad enough so as to capture elements of teachers’ overall practice and allow for insights into teachers’ schema. The research methods deemed most suitable were interviews in the form of PCK measurement tools for teachers (CoRe and PaP-eRs) and focus groups for students. The purpose of CoRe is to make teacher practice and the decision-making behind it explicit. In doing this, it would open the door for research question two to consider how a VCL may impact on this practice towards IBSE. Observations were also used to highlight how teachers’ descriptions of their practice took shape in the classroom.
Teachers were interviewed before the lesson using a CoRe (See Appendix B). The CoRe was originally designed to be carried out with groups of teachers through discussion so that teachers could bounce their ideas off each other and improve the overall standard of the CoRe. However, due the nature of this study it was not possible to organise groups of in-service teachers and so the CoRes was used in a one-to-one interview manner. Also, as it was only one teacher completing the CoRe, they were not asked for big ideas related to the topic, but instead were just asked to answer the prompts on the CoRe protocol related to the topic they were teaching. The big ideas, as interpreted by the teacher, emerged from the response to these prompts. The advantages of using the CoRe with an individual teacher were that the responses were solely from that teacher and were not influenced by other teachers. Hence, the CoRe used in this way more clearly represented the particular teacher’s beliefs and schema, providing insights into typical practices by each teacher and indeed offering insight into teachers’ habitus. The disadvantages of this approach were that the CoRe was not as detailed and collaboration between teachers was not encouraged. The CoRe consists of eight prompts (Appendix B), but a ninth prompt was added in terms of asking teachers for advice they would give to a beginning teacher. The purpose of this question was to give additional insight into what teachers deemed as important in teaching the particular content for the first time.

After completing a CoRe, teachers were then observed teaching a lesson using the VCL. After the lesson a follow-up interview was carried out with the teachers (See Appendix D) and these were used to develop PaP-eRs. Focus groups were also
carried out with the students (See Appendix C) to get their feedback on the lesson. The content of the focus groups centred on the place of the VCL within their learning and also how they would feel about it being used in terms of an assessment. The author specified to the teacher that they were to select four to six students that they deemed to be a cross-section in terms of ability. The rationale behind having the teacher select students in terms of ability was so that potentially varying interpretations of the VCL would be obtained. This stage of the research would highlight important considerations for research question two in firstly, showing how a VCL may support IBSE and secondly, what type of teacher schema supported or impinged the use of the VCL for IBSE.

Stage 3 entailed an explicitly inquiry directed use of the VCL with teachers (See Figure 8), in order to explore how the VCL could support IBSE for all teachers, and the factors associated with its use towards this end. This approach would strongly answer to research question two in how the VCL could aid teachers in their engagement in IBSE. The author discussed an explanation of inquiry based on the current research literature with teachers and highlighted through a sample lesson what he hoped to explore in the study. Teachers were told that the lesson was only a sample and that they could use the sample lesson how they saw fit. The explanation of inquiry presented by the author was based around literature reviewed (Blanchard et al., 2010; Urhahne et al., 2010). Discussion also centred on how the VCL had been used by teachers and students in Stage 2, and potential difficulties students may encounter in completing the problems. The purpose of this was to make the author’s interpretation of inquiry as explicit as possible so that teachers were aware of what would be deemed as inquiry while teaching, from the author’s perspective.

Research methods included video observations (incorporating RTOP, Appendix M), interviews in the form of a final interview with teachers and student focus groups, and questionnaires in the form of ISIS (teachers) and SSA (students). The author used the ISIS in Stage 3 in a test-retest manner, but also modified the ISIS so that it could be applied after an individual lesson. This modification simply involved changing the beginning stem of the ISIS from ‘When teaching science how often do you...’ to ‘When teaching this lesson how often did you...’. For the ease of clarification the 3 stages of ISIS use will be described as Pre-ISIS, Lesson ISIS, and Final-ISIS.
Teachers completed a ‘Pre-ISIS’ before using the VCL, taught a lesson with the VCL and then completed the ‘Lesson ISIS’ immediately after the lesson and a few weeks later completed the ‘Final-ISIS’. The ISIS was used in this way to allow for pre and post comparisons of the teachers’ perception of their overall practice after having taught an inquiry lesson using the VCL. The ‘Lesson-ISIS’ also gave specific detail to the lesson in which the VCL was used and highlighted important aspects of the teachers’ practice when using a VCL to facilitate an inquiry-based approach.

Teachers were video recorded teaching the lesson. Teachers were given a mini-microphone to attach so that their audio was recorded. This also captured individual interaction between the teacher and the students. For one of the teachers, Susan, the mini-microphone did not work properly so only parts of the audio were captured. The probable cause was a loose connection between the microphone and the camera. However, the visual was captured and also comments to the whole class by Susan. The audio was captured perfectly for the other three teachers. Due to the small sample of lessons video recorded (four) the RTOP is being used as a lens to give certain insight into teachers’ practice, as opposed to being used to provide statistics around teachers’ practice.

On a later date, after the lesson, teachers completed a final interview (See Appendix F). Students were also asked to complete a Student Self-Assessment (SSA) sheet (See Appendix G) and a focus group (Appendix H) was carried out where possible. The SSA is being used in Stage 3 as a means to capture student feedback on a lesson that is taught through an inquiry manner. Many of the students may not have experienced such a lesson before so the SSA should highlight some key insights in terms of the student experience of inquiry. The SSA should also shed light on more common practices of the students if they are not used to an inquiry type approach. If students are familiar with an inquiry approach, it may lead as an example to how a VCL may facilitate further inquiry experiences for the students.
These research methods were useful in answering the second research question in a number of ways. Firstly, the ISIS illustrated teachers’ perceptions of their use of IBSE in their practice and schema related to this, and how this may change with the use of the VCL. Secondly, observations allowed a focus on teachers’ gestalt in a directed inquiry lesson, thus highlighting potential issues with IBSE in the class. Thirdly, the SSA and focus groups provided student feedback on the use of the VCL in an inquiry manner and factors they considered important in this classroom setting. Finally, a final interview with teachers allowed them to reflect on the lesson they had taught, thus illustrating their schema and pointing to how the VCL could support IBSE in future lessons.

Finally, Stage 4 involved the teachers making recommendations on problems they would like to see incorporated into the VCL. This was left open to teachers to illustrate their decision-making and in turn, highlight what they had taken on board over the course of their involvement in the project and also, to have problems that were teacher-designed for the VCL. In the following section the participants for each stage and the timeline will be explicated.

### 3.7 Research participants and timeline

This section details the participants and timeline for each stage of the research. Not all participants were involved in every stage of the research and it will be made clear for each stage who participated and why other participants withdrew from the
Chapter 3: Research Methodology

research at different stages. Stage 1, for example, involved seven teachers and six stakeholders, and only two of these teachers participated in further stages of the research. Table 4 summarises the stages of the research, the participants involved in each stage of the research (excluding participants who only took part in Stage 1), and the data collected. The length of each interview, observation, and focus group is noted to the nearest minute. Organisational details for each stage will now be discussed.

<table>
<thead>
<tr>
<th>Teachers (Case Studies)</th>
<th>Eric</th>
<th>Shane</th>
<th>Mark</th>
<th>Paul</th>
<th>Martina</th>
<th>Susan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 May 2009 - Oct 2009</td>
<td>Interviews (Length)</td>
<td>Yes (23)</td>
<td>Yes (26)</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Stage 2 Sept 2009 – May 2010</td>
<td>CoRe (Length)</td>
<td>Yes (37)</td>
<td>Yes (34)</td>
<td>Yes (24)</td>
<td>Yes (25)</td>
<td>Yes (19)</td>
</tr>
<tr>
<td></td>
<td>Observation (Length)</td>
<td>Yes (80)</td>
<td>Yes (80)</td>
<td>Yes (60)</td>
<td>Yes (70)</td>
<td>Yes (70)</td>
</tr>
<tr>
<td></td>
<td>Follow-Up Interview</td>
<td>Yes (40)</td>
<td>Yes (48)</td>
<td>Yes (36)</td>
<td>Yes (43)</td>
<td>Yes (34)</td>
</tr>
<tr>
<td></td>
<td>Student Focus Group (Length/No. of Students)</td>
<td>Yes (13/5)</td>
<td>Yes (11/5)</td>
<td>Yes (5/4)</td>
<td>Yes (7/5)</td>
<td>Yes (18/6)</td>
</tr>
<tr>
<td>Stage 3 Sept 2010 – Apr 2011</td>
<td>Pre-ISIS (Length)</td>
<td>Yes (14)</td>
<td>Yes (8)</td>
<td>Yes (10)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Observation (Length)</td>
<td>Yes (60)</td>
<td>Yes (60)</td>
<td>Yes (40)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Lesson-ISIS Length</td>
<td>Yes (21)</td>
<td>Yes (24)</td>
<td>Yes (7)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Post-ISIS (Length)</td>
<td>Yes (17)</td>
<td>Yes (14)</td>
<td>Yes (14)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Final Interview (Length)</td>
<td>Yes (24)</td>
<td>Yes (17)</td>
<td>Yes (13)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Student Focus Group (Length/No. of students)</td>
<td>Yes (42/5)</td>
<td>Yes (25/6)</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td></td>
<td>SSA sheets</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Stage 4 Apr 2011</td>
<td>Discussion</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 4 - Teachers' involvement in the research beyond Stage One
3.7.1 Stage 1

The semi-structured interviews were conducted with seven male science teachers (predominantly of chemistry background) from across the country including the counties Cavan, Clare, Donegal, Dublin, and Galway and six other people (four male and two female) from backgrounds including the NCCA, the SEC, the Inspectorate, the SLSS, and science teacher educators between March and November 2009. The teachers were chosen based on recommendations made by the SLSS. The SLSS recommended teachers who they felt would be willing to become involved in a research project and that they also determined as a fair cross-section of teachers in terms of their use of ICT. 12 teachers (eight male/four female) were then contacted by phone and those willing to participate were then interviewed. The research design had not planned on all male teachers, but many female teachers had either not responded to initial contact by the author for interviews or were not available for interview when contacted. It is important to note that contact was made in April/May which is a busy time of year for schools leading up to final examinations at the start of June. All interviews with the teachers took place at the school of the teacher, while interviews with the stakeholders took place at a location agreed between the author and the particular stakeholder. The selection criteria on which the stakeholders were chosen cannot be discussed in order to ensure anonymity. However, of note, two people within the DES refused the opportunity to be interviewed, hence their absence in the participants. The following pseudonyms are used for the seven teachers interviewed: Tom, Richard, Alex, Shane, David, John, and Eric. The six stakeholders are referred to as Stakeholder A to Stakeholder F, so as to distinguish their comments from the teachers. The average length of these interviews was 16.5 minutes for the seven teachers and 32.5 minutes for the six stakeholders.

3.7.2 Stage 2

Stage 2 of the research began in October 2009 and finished in May 2010. This stage involved five practising chemistry teachers, two of which had partaken in the Stage 1 interviews (Shane & Eric) and were willing to commit to continue in their
participation for the following year. Other teachers from Stage 1 were either not interested in continued participation, citing busy schedules or that the VCL was not applicable enough to the Irish context. Three additional teachers (two male/one female) recommended by the SLSS were contacted (in September 2009) in order to get participation from five teachers. It was felt five teachers would provide a good and manageable sample to explore the research questions with, in that the sample was large enough to provide variation, but small enough to allow more in-depth analysis. The three teachers who joined the research in Stage 2 were given the pseudonyms of Mark, Martina, and Paul. Overall the teachers came from the counties Cork, Dublin, Galway, Kilkenny, and Tipperary. For a quick reference guide to each teacher in the case studies see Appendix L. More detail is provided in the findings.

3.7.3 Stage 3

Stage 3 began in September 2010 and finished in March 2011. Stage 3 involved four practising chemistry teachers, three whom were involved in Stage 2 of the research: Eric, Mark, and Shane. Paul and Martina from Stage 2 of the research pulled out of the study. Paul pulled out due to pressures from his students that they did not want to use the VCL in their examination year. This highlights the influence of the assessment structure on student and teacher approaches to learning. The students obviously felt the VCL did not align with the current assessment and was thus a distraction to their overall goal of getting good grades in the final examination. Martina pulled out of the study due to personal reasons unrelated to the project. In seeking to find replacement teachers for the study, two other teachers, Nathan and Mary, initially agreed to participate in the project. However, both teachers later pulled out of the project. Nathan cited that he was under parental pressure as his use of ICT was being criticised. He felt if he was to use a VCL it would put him under greater parental pressure and in turn, school pressure. This pressure again appears to stem from the school environment the final examination has created. Mary explained that her work schedule had become too hectic and that she was unable to participate.

The fourth teacher to join the project for Stage 4 was Susan. A second teacher had been originally contacted in her school based from contacts provided by the SLSS.
However, this teacher cited a hectic schedule and recommended Susan. Susan was contacted, the project was explained to her, and she agreed to participate. It was not possible to get a fifth teacher for the research sample as Nathan and Mary pulled out too far into the school year. Hence, the final research sample for Stage 3 consisted of four teachers.

3.7.4 Stage 4

This stage of the research began in January 2011 and finished in April 2011. This stage focused on the four teachers involved in Stage 3, suggesting problems that they would like to see on the VCL. The purpose of this was to have problems that were specifically suggested by teachers and thus offer teachers ownership in what could be put on to a developed VCL. It could also give insight into the teachers’ focus in how they would like to use the VCL, in terms of the problems they wanted to see on it and potentially in relation to issues associated with their current practice. The next section details two problems on the VCL that the teachers used with their students.

3.8 Explanation of two problems on the VCL

In Stages 2 and 3 of the study teachers were asked to teach a lesson using the VCL. Teachers were allowed to choose how they wanted to use the VCL in Stage 2 and all the teachers either picked a titration problem related to vinegar samples or a density related problem. In Stage 3 of the research design teachers were asked to use the vinegar problem with their fifth year students (15-17 year olds) so that comparison could be more easily made across the teachers and on student responses to the lesson. The vinegar problem and density problems will now be explained with particular reference to how they can promote inquiry.

Firstly, in terms of the vinegar problem, students were presented with a problem description on the VCL that explained that customers were complaining that the vinegar in some of their local fastfood restaurants had no bite. Samples of vinegar had been taken from three local fastfood restaurants and were contained within the stockroom of the VCL. Students were also supplied with a sample of supermarket
vinegar. Additional items in the stockroom included a 0.1 M NaOH (sodium hydroxide) solution, water, phenolphthalein, and methyl orange indicators. The problem asked students to design and carry out an experiment to determine if any of the samples of the vinegar had been watered down. The problem asked students to make a plan of their investigation before doing anything on the VCL and asked them to adapt this plan as the experiment progressed.

This problem fits within a mandatory experiment on the Leaving Certificate Chemistry course of carrying out a titration of ethanoic acid and sodium hydroxide. In carrying out this experiment on the VCL students were expected to have a basic understanding of titrations, but teachers were asked by the author (in Stage 3) not to give students details relating to this particular experiment. It was expected that students would run into cognitive conflicts in the experiment in firstly determining what indicator to use. Both indicators would give different colour changes, with one colour change being more immediate than others (a sharp colour change within a fixed end point volume range, as opposed to a larger end point volume range). This would potentially lead to a great deal of questioning from the students in terms of what the purpose of an indicator is, how it works, and its suitability for different types of acid and base titrations. Secondly, students had to also realise that the acid would have to be diluted, as it was much more concentrated than the 0.1 M NaOH. Otherwise, students would get very low volumes for their endpoints of the titration. This too would potentially lead to many questions from the students in relation to why a colour change was occurring so quickly, was a small volume a sufficient end point, and what would be a suitable volume and why. This problem on the VCL constitutes ‘guided’ inquiry (Blanchard et al., 2010) in that students are provided the problem through the VCL and the necessary scaffolds for investigation within the VCL. However, students must decide their approach, interpret their findings, and draw conclusions by themselves. The author was interested in how students would inquire and manage to overcome the difficult aspects of these experiments, if at all and also how the teacher would react to the students in meeting these difficulties. Despite this problem having quite strong scaffolding through the VCL infrastructure it was still expected by the author that students would struggle with the problem as traditional school culture affords students limited opportunities to make decisions for themselves.
Secondly, another problem on the VCL was that of a density problem. The problem description on the VCL explained that the labels of three metals had been mixed up in a jewellery store. The students were told that given the three densities of the metal, they could work out a way to determine which metal was which based on its density. It was suggested to students that they may have to use a graduated cylinder. This problem was aimed at Junior Certificate Science so students from ages 12 to 15 years could attempt the problem. The students were again asked to pre-plan their experimental design and to change their experimental design as necessary throughout the experiment. This problem mirrored ‘guided’ inquiry (Blanchard et al., 2010), like the vinegar problem, as students were supplied with the problem and had to work out the rest through the scaffolding provided by the VCL. It was expected that students would run into cognitive conflict in determining what size graduated cylinder to use and what amounts of metal to add in their ability to use the ‘density’ construct. Questions could arise, such as why one sized graduated cylinder is better than another for a density experiment, is there a certain sized graduated cylinder that would be most effective, and how accurate should the readings be. Again, the author was interested in how the students would inquire and work out the experiment, and also the role the teacher would play in aiding students who run into difficulty in solving the problem. The author was interested in this in light of the fact that apparently obvious decisions, such as what graduated cylinder to use, may provide a cognitive conflict to students, particularly in the context of not being used to making such decisions.

3.9 Analysis of the findings

All of the research data (interviews, focus groups, video observations, ISIS ‘talk aloud’ interviews) was transcribed, and analysed as relevant through Nvivo 8 software. Nvivo is code-and-retrieve software allowing a researcher to code various texts on a computer under differing nodes and to retrieve texts related to a particular node as desired on the computer. The obvious utility of this software is that it ‘takes over the physical task of writing marginal codes, making photocopies of transcripts or field notes, cutting out all chunks of text relating to a code and pasting them together’ (Bryman, 2008: 565). The overall advantages to this software is that it speeds up the
code and retrieval process of data, it gives greater transparency to the conducting of qualitative data analysis, and encourages the researcher to think of codes in relation to ‘trees’ of interconnected ideas (Bryman, 2008). However, the use of such software has been critiqued in that qualitative research could be ‘colonized by the reliability and validity criteria of quantitative research’ (Hesse-Biber, 1995), textual materials could become fragmented (Weaver & Atkinson, 1994) thus losing the narrative flow of interview transcripts, and there are also issues of chunks of text being coded in that it could decontextualize data (Buston, 1997). Catterall and Maclaran (1997) critique the use of such software as Nvivo for focus groups, in that the code and retrieve process can result in the loss of the communication process that occurs.

It becomes clear that many important issues need to be considered in the use of such software as Nvivo 8 and that the researcher plays an important part in how the data is interpreted and thus portrayed. However, as noted Nvivo does allow this process to be made much more transparent. The interview transcripts (Stage 1) were initially coded inductively based around responses to the questions asked. These gave a number of nodes that were subsequently revised into a more coherent set of tree nodes for ease of analysis (See Appendix K for details). Additional analyses were carried out on Stage 1 and Stage 2 data using a theoretical framework to guide the analysis e.g. findings were coded under Ertmer (2001)’s second-order barriers. The focus groups with students from Stage 2 and 3 were only transcribed and not coded as the data was too fragmented and lost its meaning and context through attempts at coding. Stage 3 final interviews were also analysed inductively based around the questions, but were not coded due to there only being four teachers. The RTOP was used to analyse the video observations. The ISIS questionnaires were analysed across the various statements to find similarities and differences in the teachers’ responses. These are presented in the findings.

3.10 Ethical considerations of the research

At all times every participant was assured of total confidentiality with respect to the handling and use of the information they disclosed. Every participant received an information sheet on the project and signed a subsequent consent form agreeing to partake in the study. Teachers signed for their students in loco parentis, but were also
asked to inform the principal and the students’ parents of the project. The information sheet explained that participants were free to withdraw from the study at any time they wanted to, but it was asked that they would inform the author or the supervisors of the project. The project has been approved by the University of Limerick Research Ethics Committee (ULREC). The information sheet also contained contact information for a person in ULREC external to the project if the participants wanted to raise queries with them.

3.11 Chapter summary

This chapter has outlined the methodology to this research, the research tools underpinning it and the rationale behind this approach. How the research was conducted has also been detailed. The next section will discuss the findings from the four stages of the research.
Chapter 4: Findings

4.1 Overview of the chapter
This chapter contains eight sections explaining:

- Stage 1 Findings (Section 4.2),
- Case Study A: Eric (Section 4.3),
- Case Study B: Shane (Section 4.4),
- Case Study C: Mark (Section 4.5),
- Case Study D: Paul (Section 4.6),
- Case Study E: Martina (Section 4.7),
- Case Study F: Susan (Section 4.8), and
- A chapter summary (Section 4.9).

Firstly, the findings of Stage 1 will be presented (Section 4.2), as it relates to research question one, i.e. identifying the current landscape in Irish science classrooms and how a VCL may impact on this landscape. Secondly, the findings from Stages 2, 3 and 4 will be split into the six teachers who participated in the case studies of the research (Sections 4.3 to 4.8), as these findings relate to answering research question two, i.e. how a VCL can effect teacher schema towards greater IBSE in their classroom practice. This question is set within the context identified from research question one. For each stage a teacher participated in, the data from each of the research instruments will be described. Section 4.9 will summarise each stage of the research. Please refer to Table 5 (Section 3.7) as a guide to each teachers’ involvement in each stage of the case studies.

4.2 Stage 1: Initial interviews

The teachers and stakeholders were asked many questions during the initial interview (Appendix A) and the responses will be discussed under the following headings:

1. ICT’s Role In Meeting the Challenges of Science Education (Section 4.2.1),
2. Other Teachers’ Use of ICT (Section 4.2.2),
3. Personal Use of ICT (Section 4.2.3),
4. Reasons to use a VCL (Section 4.2.4),
5. Ideal Assessment (Section 4.2.5), and
6. Use of a VCL as an assessment (Section 4.2.6).

The findings that are presented here focus on contemporary science education issues and questions where ICT can meet any of these challenges, specifically in terms of the role a VCL may play. After revising the preliminary nodes for each question it was noted that the majority of answers related to either resources or students. These responses also linked with Ertmer (1999)’s first- and second-order barriers. The findings were then coded again with a focus on responses to resources and students. Other nodes were used but were more specific to particular questions. The teachers are referred to using pseudonyms (Mark, John, Tom, etc.), while the stakeholders are referred to with letters after each name (A, B, C, etc.). The six sections will now be discussed.

4.2.1 ICT’s role in meeting the challenges of science education

When asked what they viewed as ICT’s role in meeting the challenges of teaching science, teachers’ and stakeholders’ responses to this question centred on first-order barriers in terms of resources and students. In relation to resources, the role of ICT in meeting the challenges in teaching science highlighted were; the sharing of resources, better organisation, and time saving. Firstly, in terms of sharing of resources this refers to sharing between teachers and sharing between teachers and students. Teachers can save time preparing resources if other teachers already have the same resources. One teacher, David, noted that his use of Moodle allowed him to make resources available to students not just inside the classroom, but outside of the classroom as well. Another teacher, Richard, viewed ICT as a means to get notes to the students in a more efficient way:

We’d say as regards notes and that, we’d say the way I normally work it is that I’d normally, I’d give them all their notes on a disk. You know, we’d say they all, most of them have computers now at that so you just, you know, rather it saves a lot of paper work as well in that area like.

Also, teachers explained the value of ICT in how it let them better organise their classroom activities, and resulted in time saving that allowed them to cover additional activities in their classes. A teacher, Shane, explained the value of PowerPoint to his teaching:
The key stuff is up quickly, summarised easily and I can normally get all my theory stuff done in 15/20 minutes now so it gives me that extra 15/20 minutes maybe to be at something else. Maybe a bit more practical work or demonstration or getting the kids doing something. Now I wasn’t able to do that when I’d chalk and talk, and overheads and writing so it has, it definitely has speeded up.

In terms of students, the comments on the role of ICT in meeting the challenges in teaching science related to alternative transmission, better explanations, modernity, critical thought, and ICT overload. Firstly, ICT has a huge role in how it allows information to be provided to students in different ways as one teacher, Tom, argues:

There are huge possibilities for example using well-designed graphical PowerPoints as a form of active learning where what’s on the screen demands a response from the student, rather than just have the student sitting passively looking at it, and the other area in Science is the use of data-logging which is very useful both as a demonstration and as a method of they’re doing their practical, their own practical work.

Secondly, ICT allows for better explanations. This stakeholder (Stakeholder C) explained about ICT:

It has a very, very useful place in science teaching because some of the concepts can be explained so easily with the right animation. It, just, you know, you could be talking about global warming and until you can show an animation of the rays coming in from the sun and bouncing off the earth coming back. Two minutes and they can see it and that’s enough. You know, you could be talking about it and putting headings up on the board and trying to draw your diagrams and they’re looking at you, but you know, five minutes.

Thirdly, an important feature of ICT in terms of students is that it is viewed as modern and hence, more relevant to students. One teacher explained that teachers are responsible for providing an education, but that students like to be entertained also and there is no reason ICT cannot play a role in that. One stakeholder (Stakeholder A) points to the danger of not using ICT:

I think the very first thing to do is, to say, is that we must embrace it. It must be, it just has to be included as a day-to-day part of students’ lives as they go through school. It's an artificial, we create an artificial environment if we do not include ICT tools.

Fourthly, an issue highlighted by two stakeholders and none of the teachers in terms of ICT’s role is that it can be used to develop critical thought within students in that it can provide opportunities for more open-ended investigations. As one stakeholder (Stakeholder F) explained about the use of data-logging:

What we're trying to get out of this is to use appropriate equipment, appropriate tools to teach the appropriate material, and if you have, you
Chapter 4: Findings

...know, if you want to do the experiment that's in the textbook, well, fine, but that's not, that's just a recipe directing whereas if you want to make it open-ended and bring in say your data-loggers, bring in other tools that are available.

Finally, teacher Shane made the point that even though ICT has a role in classrooms it is important that teachers do no overload students with ICT related activities. For example, students going from history to geography to science lessons and all these lessons could have been taught through PowerPoint.

### 4.2.2 Other teachers’ use of ICT

When asked how they would describe other teachers’ practice there was discussion that related to both first-order barriers and to second-order barriers. In terms of first-order barriers teachers again discussed issues around resources and these related to greater resources and more training. Two teacher comments highlighted these:

*The science department, as I said earlier, is totally ICT dedicated, as you would expect I think. Other departments are now taking it on quite, quite strongly, but the, the biggest thing of course is the expense.*

David

*Skill level of most teachers is fairly low at ICT. They're not ICT suave. Okay they can do their e-mail and book a flight with Ryanair and they can type Word and maybe do an Excel, but they're not good at computers. They're not, they're not computer people. They haven't grown up with it and then they don't have many resources, and they've had very little or no training on how you could do stuff, do a class plan and do, teach a course with IT [Information Technology]. They have no idea how you could, you could take a topic and use IT to teach it. They've never seen it done. They've no model. None of their teachers in their time ever had this so they've never seen any of them do it.*

Shane

In terms of second-order barriers issues that emerged related to assessment and teachers’ willingness to engage in the critical use of ICT. Firstly, in terms of assessment Shane highlighted the effect of assessment in guiding teacher attitudes towards ICT usage:

*They, they have limited IT skills and they feel they haven't got the resources and they have everything they need at the moment to get the kids the results. They've all the notes and the handouts, paper, chalk and talk that's successful in getting the kids points in exams so again it's the exam, it's the exam that's killing it. They know they don't have to, why change your teaching methodology when at the end of the day you can turn out the results? And*
they're measured in September by the results. The parents come in, how many points, did the kids get the points? That's all they're measured on, not the methodology, so unless the exam changes I can't see too many teachers in this school changing their methodology.

Secondly, in terms of teachers’ willingness to engage in the critical use of ICT many teacher comments related to teachers not engaging with the ICT resources in the school, and even when the teachers did, the ICT may not be used very critically. Two teacher comments highlighted how they felt other teachers were using and view ICT:

*I would also feel that a lot of the stuff that is being done is not really very, well I don't think it's very well thought out in as much as a number of people would see a PowerPoint some place and they like it, and they'd take it, but they don't make it their own. They don't adapt it to their circumstances.*

---

Tom

*I think it would be quite representative of the, of schools throughout the country. You have some people who use it very, very well, very, very effectively. Other people who don't use it at all. Other people who don't use it and don't even want to know about it. And I think that in any school, in any system we're going to have to reflect and we're going to have to respect that, that you know we cannot force people to use ICT in the same way as you cannot force them to use any other classroom resource, but I think it beholds us to encourage those who do want to, you know to make it as easy as possible and to provide as much support and resources as possible for those people.*

---

Eric

4.2.3 Teachers’ personal use of ICT

When teachers were asked about their own personal use of ICT their comments linked directly to second-order barriers, particularly in terms of the beliefs they held on the use of ICT to their practice. All teachers were mostly positive in describing the amount of ICT they used in their practice, but the ways in which they described their uses of the ICT tended to reflect certain teaching methodologies. Two teacher quotes highlighted this:

*An alternative to write-ups I'd say they could take photographs of all the stages of their experiment and put it into sort of a PowerPoint presentation so they enjoy that. That was great, but again it's time consuming and you'd never be able to do it for every class so.*

---

John

*I’ve spent a lot of time now putting a lot of notes, etc., all on PowerPoint. We’d say finding applets. That’s from my own, we’d say, presentation of work. As I said already I give out notes, cut a disk of notes, you know we’d say, it saves a lot of paperwork. Possibly it could be more student interactive.*
Chapter 4: Findings

You know we’d say, I tried it out a bit with transition year. They like do a project and say they’d have to use ICT as well like to research the project and also to present the project, but, you know we’d say, having access and again trying to get the kids interested in the whole thing, that’s the biggest challenge really like, you know...but again it’s like everything else. If you see it being done it makes it easier to learn it.

Richard

4.2.4 Reasons to use a VCL

Different reasons were given for using a VCL and these reasons mostly centred on aspects relating to resources and students. In terms of resources, interviewees noted factors, such as time, equipment, and cost. Firstly, in relation to time it was mentioned that students get bogged down on the physicality of an experiment and lose sight of the key theory of the experiment and experimental design. Students end up wasting time, setting up equipment, and trying to add chemicals together safely. It was felt that these manipulative skills are important, but actually become a hindrance time wise once they are mastered. The VCL saves time in allowing students to move past this physicality and thus allow them to get to the finer details of experimental design more quickly. As one stakeholder (Stakeholder C) made clear:

They do have to know how to physically do a titration or how to physically set up apparatus, but this [VCL] allows them to focus more on the experiment than on the practical side of the actual physical setting up of the experiment which seems to be the norm at the moment anyway. You know, because you can understand the teacher can only go around, so everything, issuing the orders, you know, make sure this isn’t. Johnny turn off that tap. Don’t be lighting the Bunsen Burner until I tell you to...so everything is controlled and very confined so you know the student expression is limited. They must only concentrate on what they’re doing, but I think with virtual they can actually explore all the possibilities.

Also, in terms of equipment and cost the VCL stands out on its own. Something that stood out in particular though is that teacher Richard suggested that with the equipment aspect of the VCL he would use a more inquiry-based approach with his students:

If I’d get access to computers, then let them work away themselves at it...just to give them the hands on and let them mess around with various different options and what’d happen if you change, do you know we’d say, change concentration or change...various different options, you know, carry out various different experiments, you know, without having to go through the whole process of getting down glassware, etc., you know.
Items mentioned by interviewees relating to students in the use of a VCL revolved around strengthening didactic methods, allowing more inquiry-based approaches or comparisons of a VCL with a physical laboratory. Firstly, in terms of strengthening didactic methods some interviewees discussed how they would use the VCL for demonstration purposes or to reinforce key points about the physical practical. As teacher Alex explained:

*It allows me as I said earlier to repeat the experiment and repeat the experiment and repeat the experiment, as opposed to doing a demonstration once.*

Secondly, some interviewees explained why they would use the VCL through inquiry-based reasons, such as student control, problem-solving, and critical thought. Students would be able to work away on a computer themselves and the infrastructure of the VCL provides problem based questions that demand a critical thought process from students in what they are doing. The comments below express some of these views:

*Yes. Quicker. Kids can do it in their own time. They can do it at home. They can do it at weekends. They can spend more time at it. They can park it halfway through maybe.*

Shane

*(VCL) almost better than practically as it involves thinking, more investigative.*

Stakeholder D

*One of the selling points of this would be that students are taking more responsibility for their learning and students are more active in learning and when that happens students learn better.*

Stakeholder B

Finally, many reasons given for why a VCL would be used in terms of students related to factors associated with physical laboratories. Some interviewees said they would like a mixture of both. Also, if teachers lacked resources for physical experiments the VCL would be better than the students doing no practical at all. Certain interviewees also expressed the concern that the VCL might be viewed as a replacement for practical work. Two examples of comments were:

*I’ve mixed views – there should be a mixture of cookbook and thinking techniques...it’s better introduced through a textbook...helps understanding why and what they’re doing different things.*

Stakeholder D

*I found in my experience the kids get tied up in the mechanics of the thing, rather
than the theory that you're trying to get across and in some ways, because of that, practical work can be counter-productive which it shouldn't be, but it is because they get, they concentrate on the wrong things. This [VCL] seems to have, to me to have the potential that kids can use it afterwards to go back over the thing and try it again and try it again, and try it again, and it seems to pick out the important points.

David

4.2.5 Ideal assessment

When stakeholders and teachers were asked what they thought the ideal assessment would be there were a lot of comments made about the current assessment system, the majority of which were negative. Shane said the current assessment was a brilliant exam, but he meant this in terms of what the people in charge of the current assessment wanted:

_They get the outcome they want. They get the bell curve, the bell curve of distribution results. It's a brilliant exam. It's very well written and it manages to separate out the kids to get you the 20 percent As._

There were many criticisms of the current assessment system. It was described as prescriptive and thus lacked creativity. As a result, this leads to the final assessment becoming predictable:

_We teach within the spirit of the curriculum, but have to assess within the letter of it...immediately puts a limit on creativity of what can be assessed if to stay within the syllabus. There's very few things left to ask after examining a syllabus five times._

Stakeholder D

The final assessment was explained as assessing students’ ability to organise, integrate, and store knowledge which one teacher felt favoured girls. It was explained by some that the final assessment assessed the ability to regurgitate information. One teacher vented frustration at what the final examination assessed, as he felt the assessment was not relevant to any everyday life situation. Some interviewees felt the final assessment did not assess any higher order skills, problem-solving, critical thinking or co-operative skills that would be relevant to the workplace. Some interviewees also felt practical skills were not evident in the assessment and as a result, some teachers may abuse it by not doing practical work at all. Another issue with some teachers was that the final grade all depended on one final examination which was not fair to students. One stakeholder highlighted that many of these issues become evident at third level where
students who may have got an A in Leaving Certificate Chemistry struggle with practical work.

Finally, a key concern relating to the current assessment was its strong influence on teachers’ pedagogy. As can be seen from the two quotes below these teachers note pressures created from the final assessment:

*Our exam system is a load of rubbish, but it's strangling everything. If I wanted higher grades in Leaving Cert I'd dump this IT and I'd get the kids grinding out the definitions and grinding through the exam papers, spend all my time getting them good at doing the exam. Now I'm not going to do that because I can still get most of them what they need in a nicer, modern way, but I know most of our teachers won't do that so change is going to be slow.*

Shane

*The real world is that students are going to be assessed based on how they write out the answers, so all of that, so I have to try and help them make that transition from their preferred way and the way that works best for them into a way which will help say optimize their marks.*

Eric

In terms of comments relating to students the ideal assessment was seen as being relevant, not rote-learning, and giving them the chance to demonstrate their knowledge in novel situations. The two teacher comments below highlight these factors:

*Honestly, if I had my way I would have no memorised exams. Sorry I shouldn't be saying this, but I would have no memorised exams. I would have all my exams in, with a book. There is no position in life really where you're expected to rail, roll stuff off the top of your head. You as an adult, I as an adult, I can go and open a book so why do we insist on children learning stuff by rote so I would put them into the laboratory...the most important thing that they need is an understanding of the theory, not to know what is added to what in what particular percentage. I don't know that stuff. Why would I expect my children to know that stuff?*

Alex

*By challenging them to think of novel ideas or simply by giving them a simple titration. Give them different compounds. Ones that they haven't come across. The process is the same. The, the thoughts are the same, but move it across and there are many other ways that it can be done to.*

David

The methods that teachers and stakeholders included in their ideal assessment related to mixed methods, practical, teachers assessing their own students, interview, VCL, and student teaching. In terms of mixed methods of assessment Eric argues:

*Well because you have a myriad of learning styles I think that you have to reflect that in your assessment and you have to try to assess you know that if people, for example, are virtual learners, can they draw a concept map. If they can draw a*
concept map of something or if they can, you know, draw diagrams, labelled diagrams that should be acceptable as a way, as a form of assessment. Other people however are much more comfortable in writing things down, writing lists.

Some teachers espoused ideas of having a practical exam, an interview or teachers assessing their own students. However, one stakeholder felt this was not feasible:

*I don’t think we’re going to get a proper practical examination… would like to see it, but I’d be the first to admit it’s unlikely to happen…where would you do it, not technical support there…teachers would have to do it, but teachers won’t assess their own students in the current climate. Logistics…when do you do it during the school year? Factors such as when/logistics/teacher release/technical support/cost…tie them altogether and then with the recession.*

Stakeholder D

This stakeholder went on to explain that the other extreme was a written assessment of practical work, but that this had issues in terms of knowing if students had completed the work themselves. They felt a VCL may have potential to fit somewhere in between. Some teachers noted the same issues as this stakeholder and also acknowledged the potential of a VCL to fit between a paper and practical assessment:

*I wouldn't see anything wrong with having a complete virtual assessment. I see all sorts of difficulties with having a practical assessment here in the lab. Without any, without any technicians to help you, to try and have everything.*

Shane

*I think in a perfect world we would have something like that where a person would come in and supervise a particular experiment and the results of that would be noted by the external examiner. That's not going to happen. I think that the alternative to that, to have a virtual approach to it is imminently feasible as well as desirable.*

Eric

### 4.2.6 Use of a VCL as assessment

When teachers and stakeholders were asked about the use of a VCL as an assessment, comments relating to resources and to students were again noted. Firstly, the use of a VCL as an assessment tool was commented on under resources, in terms of cost and time. In terms of cost, the VCL provides all chemicals and equipment within its infrastructure, so there is no issue of supply once the VCL is in place. As Alex noted using ICT can save a lot in terms of logistics:

*Apart from anything else just, sometimes I wonder if you think about how much money it would save the Department if every student sat down, logged in, and did their exams over the net…just think about how much money that would save the Department. You could even, if you were clever enough, have*
the corrections over the net.

In terms of time, it was explained that an issue in a practical assessment was that if a student smashed glass and spilled chemicals, then the whole assessment could grind to a halt. However, that would not be an issue in a VCL as the student could quickly restart their experiment. David also highlighted the time advantage in terms of students not being fixed to a particular time to have to do an assessment using the VCL:

*If you get a Virtual Lab, providing it's been tested properly, you've no such problem. You're not limited to a physical place to do it. You can do it anywhere. You're not limited to a physical time to do it, whereas if you got a lab you're limited to a time and a place, and you've got the expense of providing all the equipment and all the materials, most of which would be dumped at the end. There's a lot, a lot to be said for doing it virtually.*

Secondly, in terms of students using a VCL as an assessment, factors noted were safety, ICT versus chemistry knowledge, and thought process. Firstly, the VCL obviously provides an advantage in the assessment of practical work over real practical work due to its safety aspects. As teachers made clear, the practicalities of a real practical assessment are too messy and a VCL suits much more. Secondly, some interviewees made the point that there is a danger of a VCL assessing students on their ICT skills and not their chemistry knowledge. This highlights the need for the focus on what is being assessed to be kept very clear.

Finally, in terms of thought process, the VCL can give teachers a greater insight into where students may have difficulties with practical work. With the VCL, the process a student has followed in doing an experiment can be seen, so a teacher will have a greater insight into possible misconceptions that a student may have. As one stakeholder explained:

*The Virtual Laboratory allows us to actually see the thought process that's going on behind the actual doing of the practical, so I would say that there's a huge gap at the moment where the link between the practical and the written report of the practical and any measurement of thought process that goes into that is missing.*

Stakeholder C

Some interviewees were unsure about the use of a VCL as an assessment tool. The interviewees were not against the use of a VCL as an assessment tool, but were unsure
how exactly it might be incorporated into the broader assessment of practical work. The two quotes below illustrate some of the interviewees’ thoughts:

> It [VCL] would, well, in one sense it would and another sense it wouldn’t. It’s not practical work, but it’s an analogy of practical work and can test a number of the skills of practical work. The problem solving type skills can certainly be tested using it. The...There’s a whole lot of skills that can be done, but not every skill in practical work, but then you ask the question then as of now we don’t test any skills of practical work, except using a pen and paper, so I think it would be a big advance over the pen and paper method being used now.

**Stakeholder B**

> I know that the NCCA at the moment is, has a number of, is running with a number of models of assessment at senior level. The component other than a written exam and that will probably involve some type of practical assessment or well, at the moment the NCCA is thinking about maybe poster type presentations, not necessarily a physical poster. Now it's possible that a student could use something like a Virtual Laboratory to save a file and have that as the electronic poster, so to speak, or incorporate it maybe into a broader presentation style poster, so yes, there are possibilities there I'm sure.

**Tom**

This first stage of the research has presented important teacher and stakeholder views around the current culture in Irish science classrooms and how a VCL may fit within this culture, thus answering to research question one. Following on from an understanding of the science culture in schools from research question one, the second research question can be focused on. The second part of the research presents case studies of teachers’ practice in the use of a VCL. The first case study presented is Eric.

### 4.3 Case study A: Eric

Eric teaches in a mixed sex school in a city suburban school, has over 15 years experience teaching chemistry, and also spent six years as an ICT advisor to schools. He also has a range of experience teaching other school subjects. He expresses positive views towards the use of computers from the affordances that they offer for different types of learning to occur in the classroom. Eric was involved in all four stages of the research. The findings for Stage 2, 3, and 4 will now be presented.
4.3.1 Stage 2 - Eric

Eric picked the topic of titrations, in terms of acids and bases, in particular the titration of ethanoic acid and sodium hydroxide, to teach his fifth year students (15-17 year olds). The findings for the CoRe, the observation of him teaching this lesson, his follow-up interview and a focus group from his students will now be presented.

Content Representation (CoRe) - Eric

When asked the first question on the CoRe (for a combined CoRe of Eric, Shane, and Paul from Stage 2 see Appendix I), what he intended students to learn, Eric highlighted many aspects of the topic. These aspects included students’ development of manual skills, their ability to transfer their knowledge of volumetric analysis of acids and bases to volumetric analysis involving oxidation and reduction, and students’ understanding of the links between concentrations of solutions, amount of solutions, and molarity. Eric also stressed the attitudinal aspect in that students should not fear titrations. In explaining the importance for students to know this, Eric noted that for a practical knowledge of chemistry, students need to know how the theoretical knowledge of moles and molarity can be used practically, and that for effective learning it has to be embedded in real life problems. Eric also remarked that it is fundamental in terms of students’ understanding of chemistry, and developing a love and knowledge of chemistry.

Eric highlighted that he would not tend to hold back any information from the students and that if something was remotely of interest it would be included somewhere. Things would only be left out if the effort in doing them would not be worth the payback. When asked about difficulties and limitations connected with teaching the idea of acids and bases, Eric made note of the lack of laboratory experience students have from previous years doing science. Eric also remarked on difficulties in terms of students’ understanding of what is meant by a mole and also, he commented that there is a broad range of student understanding in terms of mathematics that has to be addressed.
In articulating his knowledge of students’ thinking that influences his teaching of the idea, Eric explained:

*Different learning styles depending on the desired theory, Myers-Briggs or talk about Howard Gardiner, that people will have different ways of taking in the information, different ways of representing this information within their own brain and different ways of kind of learning and making it their own, and what a teacher has to be very conscious of is that they don't limit the way in which they deliver the material, the way which makes sense to them, because of their preferred learning style.*

When asked to explain his teaching procedures, Eric notes that he starts the lesson by introducing the concept to be covered and very often places it in a historical context, so that the students see where the idea of a mole started from. This followed by addressing student prior knowledge through further discussion in that Eric’s students have already covered atomic mass and molecular mass. From making this connection with their previous knowledge Eric then leads students to Avagadro’s number, and from there, on to the concept of a mole:

*They have this idea of going back to molecular mass which they did. Get them as an exercise to work out what is the molecular mass of these objects in grams. They come up with this absolutely miniscule number. So it is clear it is not very useful, to talk in terms of that? So then ask them how much would a 100, how much would 200, how many would 300 molecules or whatever amounts. So then [the teacher] would say well actually there is a particular number where it does, for historical reasons, and the teacher would talk a little about Avagadro and the work that would have been done, back in the 18th century and that and a figure was came up with that is named after Avagadro called Avagadro's number. From that move to the concept of the mole and do stepwise by stepwise, and when they've got an idea that it's a number, then start comparing right how much would a mole of this weigh? How much would a mole of that weigh?*

Eric states that he would have a strong focus on a guided discovery approach. The reasoning behind this focus is that Eric feels it is better to draw the ideas from the students and in turn, the students would better understand it, as they feel more ownership of the material. Eric highlighted that this approach would then pay off much more when doing more complicated questions. Eric also explained that he preferred to teach the theory of an experiment first before doing practical work:

*You know, that there is already a theoretical framework where they can hang these experiences on to, rather than I think a lot of people start with the experiences and then try to hammer a theoretical framework out of these.*
In explaining how he ascertained students’ understanding of the material, Eric highlighted varied approaches. Eric organised lunch-time sessions, if needed, as a chance for students to have specific problems addressed. Eric highlighted the importance of talking and listening to students:

*Talk to them a lot, is the second most important thing. Most important thing is to listen to the answers, and kids will tell a teacher. They may not tell a teacher straight out ‘I don’t fully understand this’, although something a teacher should insist, keep on telling the class that a sign of real intelligence, a real mark of intelligence is to admit they don’t understand anything.*

Eric also made note of past exam questions and class tests as a means of ascertaining students’ understanding, and these were also accompanied with feedback.

Eric explained the advice he would give to a beginning teacher. He noted the importance of teachers always trying to look at material from new angles, that kids should be given more opportunity to contribute to the school environment and to let students do things for themselves when it comes to practical work. Eric goes on to highlight difficulties associated with teaching from the textbook and stresses that no teacher should do it:

*Nobody should teach from the textbook. Use if for scaffolding, but the kids have the textbook that they can bring home. A teacher is there to add value to it, to add meaning.*

**Observation of classroom practice – Eric**

Eric carried out his lesson in the school computer room with 13 students (10 male/three female). Before explaining what he wanted the students to do, Eric asked them to turn off the computer monitors and listen to his instructions. Eric explained that there was a problem description on the VCL related to the titration of ethanoic acid and sodium hydroxide, and that students had to solve it. Eric then spent the rest of the lesson moving around the classroom, observing students as they attempted the problem, clarifying issues for the students as needed, or questioning them to consider other approaches. The students were very engaged in the problem and there were no issues of classroom management. At one point in the observation, Eric joked to the researcher that he felt like one of most underworked educationalists in the country at the moment, as the students were so engrossed in solving the problem themselves.
Other observations noted were that four students brought all the samples out on to the workbench of the VCL before doing anything, two students tried to use their textbook to help them, and five students carried out three titrations very quickly while other students were still working on their first titration. Two students queried each others procedure in how they got their final volume. One student in the class renamed his conical flasks with the concentrations as he worked them out. Two students continued to play around on the VCL, even though they were finished the problem assigned.

**Follow-up interview - Eric**

This section will present findings on Eric’s comments on questions related to the VCL as a learning tool, its use to facilitate inquiry, the teacher’s role while using the VCL, and the VCL as an assessment tool (Appendix D). Firstly, Eric was asked how he found the VCL as a learning tool. He commented that the VCL was a ‘superb learning tool’, but felt it was limited in its current state compared to what it could potentially do. Eric commented:

*It [VCL] gives students an opportunity to learn or to study or to play around with concepts any time in any place. That the learning is not being limited to the classroom. Learning is not being limited to the school and not only that it allows them to replicate what they would be doing in a real world. So it is not just reading about how a titration can be carried out. It allows them to carry out the titration so therefore they're in a position to make mistakes.*

Eric also highlighted the value of the VCL in that two of his students were unsure of a concept after the lesson and could not articulate what it was that was confusing them. They used the VCL at home that evening and came back to Eric the next day with a clearer understanding of what it was that was confusing them.

Secondly, Eric commented that the VCL could support inquiry ‘very, very easily’. He noted a common issue with inquiry is the ‘lack of time’, but felt that if the digital divide was bridged for all students, inquiry could be supported more effectively online. He gave the example of students using the VCL through Moodle and being able to collaborate together in working out a problem.
Thirdly, Eric was asked about what he perceived his role to be when students were using the VCL. He commented:

Facilitator. Essentially you hover around and you, if people have specific questions or specific problems you try and facilitate them. Otherwise then you butt out and let them get on with their learning.

Finally, when asked about the VCL as an assessment, Eric commented:

I think it could certainly be modified to be used as an assessment tool. I can certainly see no reason why not. I think that the biggest obstacle to it being used is a cultural one for people who don't understand how it works. You know, in the past I've certainly seen that the use of ICT in terms of assessment has been obstructed mainly by people who, whatever about their understanding of assessments, have no understanding of ICT.

**Student focus group – Eric**

This focus group had five students, three male and two female. The focus group centred on positive and negative aspects of the VCL, and the VCL as an assessment (Appendix C). Firstly, in terms of aspects of the VCL, the students commented that the VCL was easy to use and had increased safety. One female student highlighted the utility of the VCL to allow a lot of mistakes and for experiments to be easily repeated:

You can get good practice if you make mistakes it doesn't take ages...You'd be so frustrated when you make mistakes in the real thing that you'd probably be put off, but it's not hard when you make a mistake on the virtual.

A male student also followed up on this comment:

Yes, you can learn, 'cause learning from your mistakes is like you learn it best that way. You make loads of them on the computer so you learn loads more like, but it's better for the first time learning so if you've never done the experiment before, the virtual lab the first time would be best.

Students noted that they would feel more confident doing a physical lab if they had used the VCL first. They also noted that they would like to see more experiments supported on the VCL, as it would allow them to practice without needing to use up physical resources.

Secondly, these students expressed certain hesitations about using the VCL as an assessment for their Leaving Certificate. Comments were made relating to their knowledge of safety procedures not being assessed and that students might some how
be able to cheat. They noted that if these issues were addressed then they would be happy with using the VCL as an assessment. One female student remarked:

> No I suppose it's more issues with the software. If they had it so it was really realistic and you had to go by all the safety procedures, maybe it would actually be more practical in terms of them monitoring it and for actually using for the Leaving Cert. it might be more practical to do it, it would be easier for the examiners. I think it would be kind of messy if we all were doing our experiments on a certain day. You'd have to have various examiners watching that and it seems kind of messy.

A male student also commented:

> I think that the Virtual Lab would be quite good because you can't bring home experiments and practice them at home. You can practice on the virtual lab so I think that the virtual lab would be a very good idea if you could work out a way so that people can't cheat on it.

4.3.2 Stage 3 - Eric

In Stage 3, Eric taught his fifth year students the topic of titrations, using the vinegar related problem. He completed a Pre1, Lesson1 and Final1 ISIS (Appendix E), his lesson was video-recorded, he completed a final interview and his students did a focus group and completed SSA sheets. The findings for each research tool will now be detailed.

**Inquiry Science Implementation Scale (ISIS) – Eric**

In the Pre-ISIS and Final-ISIS, Eric had the same response for 14 out of the 22 items. All the other items only differed by one on the Likert scale, except Item 2. Eric marked Item 2 (have students write the problem before doing an experiment) ‘sometimes’ in the Pre-ISIS and Item 2 ‘always’ in the Final-ISIS. When marking Item 2 in the Pre-ISIS he commented:

> I would say sometimes depending on the experiment. They should do it all the time. It's like how often do students do their homework, you know. They do it sometimes, but you know that again would be something I would certainly look at.

In the Final-ISIS, Eric marked Item 2 as ‘always’:
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Again I tend to always get that. Again, particularly with a problem as I said I try to break, I try to get them, to train them to break it down into what information is given, what's required and where do I go from there.

Eric marked Items 4 - 22 (see Appendix E) as either ‘often’ or ‘always’ in the Pre-ISIS and Post-ISIS. When answering Item 16 (challenge the students to consider the effects of errors on group results) Eric noted that students’ findings would be different and that it would be an integral part of an experiment to discuss it:

Well again I see that as a direct part to getting them to discuss their readings, you know, I would see that as an integral part that if I got students, if they are going to do a result, if they're going to do an experiment, if I get them to share their findings. Obviously their findings are going to vary and there's going to be errors, but as a class then why do you think these figures are considerably low? Is there anything that might have, you know, cause that to happen? So say I would see something like 13, 14, 15, really, it's the one activity. Probably there's smaller subsets to it, but I would see that as one in the same activity.

Eric followed with a similar comment for Item 17 (compare and contrast students’ explanations of findings), noting that he would view statements relating to findings as a part of one activity when doing experimental work:

Again this is part of the dynamic of the classroom so that obviously if different people have different readings this is going to be shared. They're going to try and kind of challenge them to consider why there are variations in readings and then this is again I think a part, a standard part of the one activity.

For Item 18 (question students as they conduct their experiments), Eric highlighted a focus that moved beyond simply ensuring that students were completing an experiment, but were also trying to understand it:

Again I think this seems to go back to the one where you're circulating and interacting with the students [referring to Item 12], the interaction. Obviously the best type of interaction is in the form of questions, rather than going around and telling them what they're doing. You know that the interaction should be why are you doing it this way or you think this is the best possible way. Now that, okay it's a loaded question, but you're not saying no, no, no, you should have this setting or something like that.

Video observation and Reformed Teaching Observation Protocol (RTOP) – Eric

As in the observation from Stage 2, Eric instructed the students (14 students: 10 male/four female) that there was a problem on the VCL they had to solve. He spent the rest of the lesson circulating the classroom, helping students as he was called
upon. As expected from the problem design on the VCL, students ran into challenges in determining what indicator to use and in understanding why the colour change was occurring at a small volume. The extract below is from this observation. The student has figured out that there is an issue with the concentration and is trying to decide how to overcome it:

Teacher: How's it going [student's name removed]?
Student: Is there anyway you can increase the molarity of the NaOH?
Teacher: No.
Student: 'Cause everytime I try it, I end up using an entire burette.
Teacher: An entire burette of base? Why are you putting base into your burette? Traditionally you put acid into your burette, don't you? Would there be another way? But even if you were doing it another way is it that, okay, you cannot, let's have a look at the solutions that you have there. You cannot make your base more concentrated. Is there any other way around it?
Student: Weakening the acid?
Teacher: I don't know. How would you do that?
Student: Putting in water.
Teacher: Okay but if you're going to do that you should document that. Document that you've got a problem and then document how you might go about it.

This conversation gives an example of the type of teacher and student interaction in the class, where Eric encouraged students to think the problem through themselves and sought explanations from students on what they were doing and why.

In terms of the RTOP, Eric scored 3 or 4 (occurred often to always) on 20 of the 25 items. The items that scored less were mostly outside of Eric’s control (Items 2, 7, 10, 11, and 16, See Appendix M for statements) due the lesson design asked for by the researcher. For examples, Items 11 and 16 related to students using a variety of means (models, drawings, graphs, concrete materials, etc.) to represent and communicate ideas, when the VCL lesson did not facilitate enough time for these. Item 7 (promote coherent conceptual understanding) was marked 2 (occurred sometimes), as there were instances of student confusion throughout the lesson. However, many students did move in the direction of solving the problem on the VCL, but still had questions at the end of the lesson. Hence, it could be argued both ways that the lesson promoted coherent conceptual understanding. Item 2 (engaging students as members of a learning community) was marked 1 (occurred rarely) as the teacher instructed students to work individually. However, students still communicated with each other during the lesson.
Final interview – Eric

In the final interview, Eric was asked questions relating to his views; on how the lesson went (strengths and weaknesses), on the use of the VCL as a learning tool, on his role in the classroom, and on the use of the VCL as an assessment. Firstly, Eric expressed disappointment in how he felt a number of students took to the problem that caused him to move to a more structured inquiry approach with some students. In explaining why he felt some of the students did not take to the approach so well he commented:

_They, again, maybe it's expecting too much of them that you know that they've gone through, this is their fifth year in secondary school and for their entire experience of primary school, for most of their experience in secondary school, the teacher has chopped everything down into these very easily digested nuggets of information or whatever and everything has been set up for them and now essentially what we've done is we've done the equivalent of giving them a fully stocked laboratory, given them a problem and told them to go figure and okay, maybe I'm expecting too much to think that the first time we do that they take to it like ducks to water, but I would hope that with a little bit more practice that they would respond and they would become better at this._

Eric highlighted the utility of the VCL to cater for mixed ability in that nearly all the students were making an effort to solve the problem and thinking of different approaches. He also felt the inquiry approach was a good movement away from simply having students recall content. He commented:

_I would, certainly some of the brighter students would kind of go ahead and they just get stuck in. The ones, by brighter, the ones that are probably more confident as well as bright. For the ones that would be struggling what I also felt with some of them, they didn't give up. They would keep on trying and they would try this, they'd try that, they'd look at it again and you could see that they were actually thinking and working on it so I think that certainly there are plenty of strengths to this. We have to get away from this whole system of trying, absorbing, soaking in a certain number of facts into our short term memory and then regurgitating them, in the worst meaning of the word, on to an exam script and then promptly forgetting most of it, you know, two weeks later. That is not education and I think we have to get away from that and anything which helps us get away from that cannot be but good._

Eric noted weakness in students’ ‘ability to try and tease out what the problems are’. He felt if students are given a lot of information that they find it difficult to filter it to
find the clear information given that will help them solve the problem. He explained the main reason for this student weakness was a ‘lack of practice’ in that:

They've [Students] gone through an entire primary curriculum probably with very, very little opportunity to solve or you know, to learn in this way. They're now in their fifth year of secondary school with precious few chances to do the same.

Secondly, Eric felt the VCL was excellent as a learning tool, but noted he would like to see it developed further to encompass more experiments. He commented:

I think learning is something which we have to do ourselves...I think that if it was properly developed a VCL could allow students to carry experiments, scientific experiments or lab experiments any time, anywhere and that certainly would be very, very useful.

Thirdly, Eric described his role in the following way:

If somebody is stuck on something, to get them out of that particular kind of state or whatever and just to get them moving on or whatever and hopefully that once they get out of that particular problem or whatever, that it'll be, they'll be able to work out the rest of it themselves.

Finally, Eric responded that it would be a good idea to use the VCL as an assessment, but exercised caution in that it would take time for the culture of schools to change:

What I would suggest however is that you would probably have to in the short term not use it for assessment of investigations, probably maybe more the assessment of laboratory technique for doing let's say particular mandatory experiments. I think that it would be quite unfair given the fact that most students don't get an opportunity to practice open ended investigations, that something like the Leaving Cert. is viewed as being way too important that if you got an investigation and you didn't happen to understand or see the trick that was involved. I think short-term use the VCL as a method of measuring scientific technique or laboratory technique, certainly would be the first stage. Long term I think it would be great if we could have a particular system where it would be possible for students to carry out investigations.

**Student Self-Assessment (SSA) and focus group– Eric**

11 (nine male/two female) of Eric’s students (out of 14) completed the SSA. The responses were for the most part positive by the students. For ‘understanding the processes of inquiry’, three of the 11 students marked ‘bad’, six marked ‘adequate’, one marked ‘good’, and one marked ‘very good’. One of the students who marked ‘bad’ commented:
I think I can do it better because I sometimes get into troubles but I must do it better.

There were two male students in this class who did not have English as their first language. In marking themselves on ‘reasoning carefully’ one student marked ‘very bad’, three marked ‘adequate’, five marked ‘good’, and two marked ‘very good’. Also, for ‘being inventive’ two students marked ‘bad’, four marked ‘adequate’, four marked ‘good’, and one student did not tick any box. Some of the students’ comments on ‘being inventive’ were:

I’ve never needed to be inventive outside of the virtual lab (Male student).

I have a good imagination and I like to solve things so I think I’m okay at this (Male Student).

I can be very creative and imaginative in science (Male student).

In relation to the focus group (four male/two female), students were asked questions relating to the role of the teacher, their role in the class, the use of the VCL as a learning tool, and the use of the VCL as an assessment tool. Firstly, many of the students expressed expectations of the teacher that related to teaching towards the final assessment. One female student commented on the role of the teacher:

To give notes as well. I like, it’s easier like to study off notes instead of just what you remember from class so.

A male student also followed up with a similar expectation of the teacher and explained his reasoning for this:

Yes, notes are great. They’re the best. But like you’re not expected to remember every single thing of the forty minutes in that class, you know, but if you forget, you can always go back to the notes and it’ll be there if you’re stuck so yes, notes are great.

Secondly, students discussed issues relating to interaction within the class when asked about their role. A male student commented how he liked feeling he could ask questions in class:

I like that the way that if you don’t understand something you just put up your hand and you know he’ll try and explain it to you.

Other students also commented that they liked the small size of their class and that it allowed them to interact more with each other. One student felt their role in the class
would be different if it was a bigger class, as they would not be given the freedom to interact more.

Thirdly, all students in the group commented very positively on the use of the VCL as a learning tool and expressed interest in more experiments being included on the VCL that they could use. However, despite these positive comments, the discussion moved towards a concern by the students as to whether they would have enough time to cover all the mandatory experiments on the Leaving Certificate, if they were using the VCL also.

Finally, the students all responded positively to the use of the VCL as an assessment tool. One student highlighted the importance of students to have sufficient practice on the VCL so that their ability to use the VCL was not a factor in the assessment. One male student commented:

*Definitely. Yes 'cause I think in the Leaving Cert. paper there're two sections and section A is just experiments questions, experimental questions so yes that'd be good if you like took that off and did a virtual lab test, like assessment because it is, chemistry is a very practical subject. I don't think it should all be just based on one big written test, you know, change it about.*

A second male student also made a comment, following the previous comment noted, in relation to having a choice in assessment:

*Yes. I think it'd be a good idea. It would make sense if we had a choice, either doing it in a test or in the lab because some people just can't do tests. It doesn't make any sense you know you could ruin their life over something silly, but if you can actually do it fine so.*

### 4.3.3 Stage 4 - Eric

Eric explained two types of problems that he would like to see on the VCL. The first problem he suggested was an oxidation and reduction problem where students would have to determine the amount of iron in iron tablets. He also gave the example of iron being poured onto cornflakes and a magnet working on cornflakes. The second problem he explained was an iodine and thiosulphate titration. He said the problem could be phrased in such a way that it relates to seaweed, which contains iodine. Students could be given samples which were taken from seaweed and have to determine the amount of iron in them. The two examples he gave are two
experiments that are currently in the Irish chemistry syllabus, but he looked to relate to them to everyday situations and possible problems.

4.4 Case study B: Shane

Shane teaches in a mixed school in a rural town, has over 30 years experience of teaching chemistry and estimates that he has been teaching for about 10 years with computers. Shane expressed very positive views towards technology in that he feels it is where students are at now and it gives a teacher who uses technology a lot of credibility with the students. He also highlighted technology’s role in presenting the material in new ways. Shane participated in all four stages of the research. Findings from Stages 2 to 4 will now be detailed.

4.4.1 Stage 2 - Shane

For Stage 2 Shane picked the topic of titrations, in particular the titration of ethanoic acid and sodium hydroxide, to teach his fifth year students. He completed a CoRe (for full CoRe see Appendix I) on this topic, had the lesson observed, completed a follow-up interview and some of his students also participated in a focus group. The findings for each research tool will now be presented.

Content Representation (CoRe) - Shane

When asked the first question on the CoRe, in terms of what he intended students to learn, Shane’s focus was on the procedural knowledge of setting up the equipment correctly and ensuring that the students get accurate results. Shane argued that the importance of students knowing this was that good laboratory technique is important to other areas of life in the fact that students need to be able to work logically, in an organised method, and be able to keep records. He also stressed the importance of students being able to plan so as not to waste time having to correct mistakes. Shane highlighted the influence of assessment in the importance for students to know the material:
It is rigourously examined and if the procedure is slightly out in the exam they'll lose a lot of marks.

When asked about things he did not want his students to know yet Shane argued that when doing titrations students do not need to know the theory of acids and bases to actually do the titrations. He stated that the theory would be filled in afterwards and that he felt students are more accepting of the theory having done the physical experiment and he re-iterated this in the PaP-eRs (Appendix J):

I think they get bored if you give them a whole pile of theory. They cannot possibly see the relevance of it...and you see this will be useful when we come to the practical work. I would prefer to do the practical work first and then say to get a full understanding you need this little plug-in, you need this little bit and then I find they take the theory in their stride and as a natural part of the practical work.

In relation to difficulties in teaching the idea Shane asserted, in both the CoRe and the PaP-eRs, that students tend to have little chemistry background from previous years doing science, as other teachers tend to avoid chemistry as it is not their forte. Hence, students need to be brought up to speed on things like formulas and balanced equations. Shane feels that it is important to do the titrations with the students as the ‘kids get a good kick out of the titrations’. However, Shane noted again how students’ chemistry background can be an issue:

You write down a formula, \( \text{Na}_2\text{CO}_3 \), sometimes it is too abstract for them. Not to mind bringing that into a chemical equation, not to mind bringing in moles and molar. But they can all do it by rote. They are almighty at that. \( V_1 \) over \( M_1 \) and blah blah blah their method, the formula method they will get it down...except the calculations flummoxes them a bit.

Shane explained differing teaching procedures in how he looked to get the material across to the students. He would start off with a demonstration and the purpose of this was argued in terms of safety precaution, breakages, and getting injured. Once students started doing the experiment he would again stop the students and show them a video clip of someone else explaining some of the technique of the experiment. After that he would then spend the rest of the experiment observing students, probing their approach, and giving more one-to-one demonstrations. Shane recaps the lesson through use of summaries on PowerPoint slides. Shane explained that he would ascertain students’ understanding through observation, talking to the students, getting them to do calculations, and through homework. Shane noted how fretful students can become doing practical work, but that using the VCL gave the students much
more confidence and a greater focus when actually in the physical laboratory. Shane commented:

*You have too many distractions to distract you from what you are trying to do when you are going around the lab, ‘Where is this glassware? Where are the beakers? Where is the acid? How do I fit the filler on to the pipette without breaking it? There are too many physical things to be done that distracts them. I felt that the Virtual Lab goes straight on to the doing of it and not having all those distractions, and safety as well.*

Finally, when asked about advice he would give a beginning teacher, Shane stressed the importance of a teacher demonstrating the experiment first themselves to see where issues may arise as this would give a young teacher confidence in knowing potential ‘snags’ in the experiment. However, Shane also stressed the importance of letting students do the experiments themselves and not for beginning teachers to be afraid of letting students do the experiments.

**Observation – Shane**

Shane brought his fifth year students into the computer room (11 students: five male, six female) and explained to the students that there was a titration problem on the VCL they had to solve. He went around the room ensuring all the students had opened up the correct problem. Once all the students had the VCL problem in front of them, Shane moved around the classroom observing students as they completed the problem, helping students as needed and also questioning students on their procedures and results. The classroom was very quiet (possible reactive effect of the researcher), but all the students were engaged in attempting to solve the problem.

In relation to the students attempting the problem, a few observations were noted. Six of the students brought all the equipment on to the workbench before adequately reading the problem description. Various students had a discussion on the concentration of the solutions and how this related to carrying out the experiment. Three students also discussed how many times they should do the titration and the importance of this.
Follow-up interview - Shane

In the follow-up interview Shane was asked about the VCL as a learning tool, how the VCL could support inquiry, his role in the classroom and the use of the VCL as an assessment tool. Firstly, Shane commented the following when asked about the VCL as a learning tool:

Very happy with it and I'd love more time to be able to bring more classes down to it. The kids have enjoyed it. It's, the kids have enjoyed it. They can work very quickly with it. It's very safe. The only thing I'll say about it is that they can be, they're are techniques they can't learn with it. You just draw the pipette over the conical flask and it empties. There's a lot of practical things there from putting on the filler and using the filler and then letting it empty by gravity and the rinsing out of the pipette. There's a lot of things, they could leave gaps in their knowledge so I wouldn't like to use it as the tool to teach the topic fully because they'd be asked questions in Leaving Cert. that they wouldn't be able to answer.

Secondly, when asked about the use the VCL to support inquiry, Shane commented:

Definitely, because it eliminates all... the nitty-gritty things you have to do in the lab if you're doing a practical. So if I'm assessing their ability to solve a problem, if I'm doing it here in the lab, just bogged down with glassware being broken or using the equipment properly. They've no time to think because they've a hundred other tasks, physical tasks they have to do. Now I find when we did, I've done the vinegar one, the chip shop vinegar ones here in class, practical-wise and it has taken us two or three classes to do it because we'd so much hands-on stuff to do so we spent most of our time doing physical stuff and less of our time doing thinking. It actually became one of the smaller parts for it whereas we went to the virtual lab. We seemed to spend most of the time figuring out, thinking about how to do it so much higher level and we hadn't hardly any physical things to do at all.

Thirdly, when asked about how he perceived his role in the classroom using a VCL, Shane explained his role at two levels. The first level entailed making sure ‘the computers are running properly’ and that students can work through the menus. He explained that once this is done he could move to the next level of ‘teasing out stuff’ with the students. Shane noted that he was surprised at how little he had to do at the first level, as the students had ‘been so quick at it’, i.e. figuring out the VCL interface.

Finally, when asked about the VCL as an assessment, Shane highlighted a concern in that he found it difficult to figure out what exactly each student had done on the VCL. He noted that students could all have figures at the end of the lesson, but he would not
be sure if they had got them all from doing the experiments properly on the VCL. He highlighted that some form of a save function on the VCL would be useful, so that he could see some of the steps the students had completed in doing the experiment. Shane noted that other than this issue he would be happy with the VCL as an assessment. He explained that it would be much more feasible than a REx assessment where a student could get injured or a serious spillage could occur.

**Student focus group – Shane**

This focus group had five students, three female and two male. The focus group centred on pros and cons of the VCL, and the VCL as an assessment. Firstly, students commented positively on the VCL. One female student noted the VCL aided in remembering the names of apparatus:

> And you get to know the names more because like, like the options are there, you have to decide yourself whereas in the lab they're left out there for you.

A male student commented on the use of the VCL as a pre-REx exercise:

> Maybe on the virtual lab trying to get familiar with the experiments and then getting a bit of understanding about what you're trying to do and how you should go about it.

One female student expressed that she got more satisfaction from doing the experiment physically, yet still expressed value in the VCL outside of school. This student and another female student noted the value of the VCL to be used at home:

> Girl 3: And even at home y'know like after doing the physical experiment (Girl 2 interjects: Yes) it is hard to get it into your head.
> Girl 2: and even reading the book.
> Girl 3: Yes and in the book. The book doesn't, you can't really picture it so like if you went on that[VCL] that'd be brilliant at home like.

Secondly, in relation to assessment, the students explained that they would like a mixture of practical and virtual assessment. A male student remarked:

> I suppose I'd say a mixture of both because maybe like not everyone is skilled with the practicals as they are on a computer and people might have like more confidence using a computer than they would using chemicals with their own hands so I suppose a mixture would be fair.
4.4.2 Stage 3 - Shane

In Stage 3, Shane taught his fifth year students the topic of titrations, using the vinegar related problem. He completed a Pre-, Lesson- and Final-ISIS (Appendix E), his lesson was video-recorded, he completed a final interview and his students did a focus group and completed SSA sheets. The findings for each research tool will now be detailed.

**Inquiry Science Implementation Scale (ISIS) – Shane**

In the Pre-ISIS and Post-ISIS, Shane had eight of the same responses out of the 22 statements (1, 6, 10-13, 17 & 22, see Appendix E for statements). Shane’s other 14 statements only differed by one on the Likert scale. In terms of the introduction phase of an experiment, Shane marked Item 2 (have students write the problem before doing an experiment) as ‘rarely’ in the Pre-ISIS and ‘sometimes’ in the Final-ISIS, while he marked Item 3 (review relevant concepts that were learned in previous lessons) as ‘sometimes’ in the Pre-ISIS and ‘often’ in the Final-ISIS. Shane simply commented on Item 3 in the Final-ISIS:

> Often. I wouldn't always need to do that. I would often do it.

Shane marked Item 2 as ‘always’ for the VCL lesson. Shane commented:

> Yes, they did that today even though they were reluctant to do it. They wanted to go straight into it. We had to get them to do a little bit of writing. There wasn't enough time actually to do a full plan.

Shane marked Item 3 as ‘sometimes’ for the Lesson-ISIS:

> I had to sometimes do that today. I had to just mention little bits about how much indicator to add and that type of stuff.

In responding to Item 9 (check students’ designs for safety before conducting experiments) on the Post-ISIS Shane commented:

> Often. Sometimes I'm careless about that. I presume they know how to do it.

In relation to the conduction stage of the experiment, Shane marked most of the Items 13 to 17 (discuss variations in data collected (13), have students share their predictions with the class (14), have students share their data with the class (15),
challenge students to consider the effects of errors (16), and compare and contrast students’ explanations of findings (17)) as ‘sometimes’ in the Pre-ISIS and Post-ISIS. He did not elaborate on the reasons for his decisions while completing the Pre-ISIS and Final-ISIS, except to comment that there was a time constraint. When Shane was discussing the Final-ISIS upon completion, he noted:

*Discussing variations in data. You know, there often isn't time for it and I don't do enough of that. It'd be great from a scientific method that I'd be able to pull everybody's results and share stuff around, but the clock is ticking so you've to go along to the next thing.*

When Shane was then asked what he viewed as the biggest constraints in changing his practice he responded:

*I would say time. It's the biggest one. The syllabus is overloaded with just getting content covered for the purposes of the exam so there isn't time. I see 'cause I've a little bit of experience of some of the schools in America, the high schools and a lot less volume so they've time for discussion, sit around talking, go off and do a further bit of research on it and come back. So we're just overloading them with volume so it's time would be the main thing here for me. It wouldn't be lack of knowledge or lack of resources or material. It would simply be time.*

Shane favours the Items 13 to 17 on the ISIS, but feels that the current ‘overloaded’ syllabus and focus on the final examination does not allow for more time to be spent on these areas.

**Video observation and RTOP - Shane**

Shane explained to students (10 students: six male/four female) that they had to open up a problem on the VCL related to vinegar. He spent the start of the lesson ensuring the students had opened up the correct problem on the VCL. Shane then explained the problem to the students and what was expected of them. Shane spent the rest of the lesson circulating the classroom observing, and questioning students and probing students’ answers. Many students in the lesson used methyl orange as an indicator and despite finding the colour change difficult to determine, many students persisted in using it as an indicator. Many of these students did not consider testing the use of phenolphthalein as an indicator. Three students noted towards the end of the lesson that they should dilute the acid in order to obtain larger values for the titration values, but were still trying to figure out how much they should dilute the acid by at the end
of the lesson. The dialogue below is an example of a student who persisted in using
the methyl orange indicator:

Teacher: [Student's name removed] Did you get the colour change?
Student: Yes, I'm on my third one now.
Teacher: And how much did it take?
Student: Point two (0.2) and point six (0.6).
Teacher: Hmm, see they're really small. It's very hard to be accurate.
Second Student: We put in three drops of the methyl orange and I'm getting
one point two (1.2), one point seven (1.7). He's getting something the same
[pointing to other student].
Teacher: What colour change are you getting?
Second Student: Just going from the first colour change. It's going from like
kind of yellow to just off yellow. Amber-ish.
Teacher: But is that, is it a distinct colour change, you see...
Second Student: Well I can tell from back here it's gone.
Teacher: 'Cause you need a distinct colour change when you add a drop at the
end point of the titration.
Second Student: Oh like with primary colours is it?
Teacher: Well there's a definite colour change on a drop. Are you happy that
there's a colour change in the methyl orange?
Third Student: Yes.
Second Student: There is but a slight change. I'm going on the same change
for the first two.
Teacher: Would you say it's only a slight change?
Second Student: Yes. Well like you can see the difference.
Teacher: You can see the difference okay. So you'd be happy enough if
there's a colour change that you can see when you've added just a drop or two
of the...
Second Student: Yes.
Teacher: Okay.

Shane has not told the student what to do, but has looked for the student to explain
what they are doing. The student is happy with their approach so Shane has left the
student to continue on with the experiment.

In terms of the RTOP, Shane scored 3 or 4 (occurred often to always) on 21 of the 25
items. The items that scored less were similar to Eric’s items (Items 7, 10, 11, and 16:
the lesson promoted coherent conceptual understanding (7), connections with other
content disciplines (10), students used a variety of means (11), and student
communicated through a variety of means (16)). However, Shane asked his students
to work in pairs so the lesson scored 3 (occurred often) on Item 2 for the engagement
of students as a learning community. However, whole class learning did not occur as
findings were not shared across students over the course of the lesson. Item 7
(promote coherent conceptual understanding) was marked 2 (sometimes) for Shane, as students were provided as many answers as they were questions, and many of these questions were still not answered for many students at the end of the lesson. However, students did develop and extend their experimental designs throughout the lesson.

**Final interview - Shane**

In the final interview, Shane was asked questions relating to his views; on how the lesson went (strengths and weaknesses), on the use of the VCL as a learning tool, on his role in the classroom, and on the use of the VCL as an assessment. Firstly, Shane felt the approach fell in line with a guided approach where students were given a problem and left to solve it, with some guidance from the teacher. However, Shane also expressed surprise at having to aid some students more than he expected:

> Now, sometimes, I had to step in. I didn't think I would have to step in as much. I had to step in to point out sometimes that there was a problem. Some of the better kids recognised the problem. Some of the kids maybe didn't recognise. I had to pull them back a little bit just to make sure they realised there was something more happening here, but a lot of them did recognise the problem and some of them only did help when they recognised the problem and all I had to do was to give them a bit of clarification or just verify what they were doing was right in a really small way.

Shane noted that the lesson was much more student-centred than teacher-centred and that students were able to work away at their own pace. Shane also noted that much more problem-solving was occurring throughout the lesson than students simply following a procedure. He highlighted that students can get bogged down on procedure in the physical laboratory in terms of rinsing glassware, getting things out of cupboards, and setting up. However, the VCL allowed students to move beyond this and allow students to get to the ‘core problem’ of the experiment much more quickly.

Shane highlighted a weakness of the lesson in that students did not get ‘hands-on’ practical skills. However, he questioned the value of it as a weakness depending on whether the aim was to teach a lab technician or a problem-solver:

> They got no skills in actually really diluting solutions, handling glassware, making up chemicals and doing all the necessary things if you were to do a
real experiment. So that's a weakness, but that's only a weakness if you were training lab technicians. I think that weakness was far overridden by the fact that the people doing chemistry are generally higher level ones that are going to be going on to laboratory management, rather than laboratory technician, more problem-solving than lab technician.

Secondly, Shane commented positively on the VCL as a learning tool in allowing students to move away from being given instructions to follow:

I thought they were spending a lot more time, now we didn't do a lot of it, but you know in the limited number of runs we had at it [VCL] I thought they were spending a lot more time on the key, trying to solve the problem, the key problem, rather than on the bucket and spade stuff so isn't that what we're suppose to be doing isn't it? Teaching them how to think logically, to problem solve, how to work through difficulties and a scientific method in an investigative approach so I thought it was a great tool for that.

Thirdly, when asked about his role in the classroom, Shane explained his role was to ‘guide’ the students and to ‘let them work away on their own’. He would monitor the students and intervene if necessary.

Finally, Shane argued favourably in terms of the VCL as an assessment and felt it would be much more suitable than a physical assessment:

Well I thought it was very good for the scientific method where you have certain observations and you come up with a suggestion that you test, you design your experiment. It can be designed quickly and you get your data very quickly. The getting of the data quickly was wonderful, that once you'd the experiment designed, the experiment basically worked in the virtual lab, you got your data whereas I find if you were doing a hands-on experiment a million things could go wrong. You might have everything set up and be working properly, you might have the correct idea and get totally bogged down because suddenly the tip of the burette is clogged.

Student Self-Assessment (SSA) and focus group – Shane

Eight of Shane’s students (four male/four female) completed the SSA (out of 10). Responses by the students on the SSA were mostly positive. When asked about ‘understanding the processes of inquiry’, one student marked ‘bad’, three marked ‘adequate’, and four marked ‘good’. The female student who marked ‘bad’ had marked ‘adequate’ for the previous statement on ‘understanding the science’. Her comment on each statement was:
I felt that would be better to work in the lab as you would be able to experience the experiment first hand.

Again I feel that in a lab environment I would be a lot more inquisitive than just sitting in front of a computer screen.

In terms of ‘reasoning carefully’, three students marked ‘adequate’, while five students marked ‘good’. One female student, who marked herself as ‘adequate’, commented:

It wasn’t really necessary to be too careful because it was easy to cancel what was done and start over.

The female student who had a preference for practical work also commented under ‘reasoning carefully’:

Handy enough because you can repeat experiments several times to reason why you got such a result.

In terms of ‘being inventive’, two female students marked themselves ‘bad’, two students marked themselves ‘adequate’, one student marked ‘good’, and three marked ‘very good’. A female student who marked herself ‘bad’ commented:

I find it difficult to be inventive as I find it all right or wrong.

Another female student, who marked themselves ‘adequate’, commented:

In an experiment, I don’t like to be inventive. I follow instructions.

A third female student marked herself ‘very good’ at being inventive and commented the following:

I thought it was excellent in this way because you could do as many experiments as you like as many times as you want and it only took two minutes to set up.

In relation to the focus group (four male/two female), students were asked questions relating to the role of the teacher, their role in the class, the use of the VCL as a learning tool, and the use of the VCL as an assessment tool. Firstly, in relation to the teacher’s role in the class, the students expressed many expectations. Students desired guidance from the teacher, but not to the extent that the teacher would give them the answer. Many of the students in the focus group expressed the desire to think things through for themselves, as they felt it helped them remember the material much better. One male student commented on the teacher’s role:
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To guide you through your learning and to help you along in the practicals. If you don't know just to help you, not just telling you how to do it, but they're helping you understand it. Say if you're just told how to do it you don't really understand how you've done it so if, it's just my view, if a teacher's going to teach you something they should make sure that you understand it.

Another male student also highlighted the desire to have more ownership in their learning:

The role of the teacher I suppose giving us a foundation in the subject like and even you could do a little bit yourself 'cause you remember it better if you sort of research it yourself, but just being able to understand it first of all is the role of the teacher.

A female student focused her comment on the teacher’s role in relation to the final assessment:

Yes, just understanding of the course like altogether but, and then for the exam as well being able to do the exam like if it's how you answer questions and stuff, like the exam could be different from the course. You wouldn't expect it the questions the way they come up.

Secondly, in relation to students’ own role in the classroom, students expressed varying ideas. One male student commented on his role in the classroom:

Just to follow what I'm told and to just try and understand things. If I can't, obviously ask and try and get my head around it. Just do what I'm told really.

A female student followed the previous comment with her interpretation of her role in the school:

Pretty much just prepare for the exam and once get the information on it just use it in the exam and that's it, but like to help my friends out as well if I can.

A second male student also mirrored the previous two comments:

I suppose just learning the stuff, going home, reading about it after the class. That's about it. Make sure you know it.

Thirdly, students responded positively to the VCL as a learning tool. Some of the comments were that the VCL made it easier to set up experiments, it removes the fear of breaking things, and when mistakes are made it is easy to start over. One female student commented the following on why she liked the VCL:

Yes, I think it's good, like I'd rather the practicals as well, but it's good to get an understanding of them before you do it just to make sure you know what you're doing instead of going into a practical without having a clue like, if you missed anything.
Other students also noted advantages to the VCL, but were clear to highlight that they would favour practical work. These students explained the use of the VCL as a preparation tool in allowing them to better understand the experiment before doing it. In explaining this use of the VCL, some of the students made note of not fully knowing what they were doing in practical work. One male student commented:

*I still prefer the practical, but you know for preparation work and sort of just to know what you're doing before you walk into the lab, you've a clear idea of what you're going to do.*

Students in this focus group also noted the use of the VCL as something to follow up on practical work, as it is available online and thus gives greater freedom in its use. One female student commented:

*I think it's very good 'cause you've actually got all the stuff there in front of you. It's much easier to understand. You've got all the labels, numbers, figures and you're not there going oh god what's this, what's that? You've got all the units there in front of you as well so it's easier to use.*

A male student also commented:

*It's definitely a great learning tool 'cause in contrast to an ordinary practical where everything is out in front of you, all over the place, it's very hard to remember which is which, especially if you're getting ready to label something whereas the virtual lab everything is there, labelled, you can see it and you can take it out, one at a time if you need to and it's just great like that.*

Finally, students were asked about the use of the VCL as an assessment tool. All students, except one, responded positively to the use of the VCL as an assessment. The students who commented positively noted how students may get flustered while doing an experiment physically, how writing about experiments does not really show if a student understands an experiment, and that a student should remember it better by doing it. They noted the utility of the VCL to overcome these issues. One female student comment for example was:

*Yes I think it would be good for that like, anybody can write down an experiment straight from the book into their lab book so i like if that could show that they understand it by doing it themselves.*

The student who commented negatively on the VCL expressed issues in what the VCL would exactly assess:

*I don't think it'd be great because it would depend on the students' skill at using the computer as well as their chemical, their understanding of chemistry like so you might be good at computers, but not so great at chemistry or vice*
versa and it'd all come into the mix then like, rather than just your knowledge of chemistry.

4.4.3 Stage 4 - Shane

Shane suggested three problems for the VCL. The first problem related to a bleach problem where students buy two leading brands of bleach from the supermarket and have to determine which one is better value for money based on their concentration. The second problem related to students determining the amount of oxygen in water and the Biological Oxygen Demand (BOD) of water from river samples. He said the problem could be framed in such a way that fish were found to be dying at a certain point in the river. Students would then have to argue various factors as to where the pollution was occurring if different farmers owned land on various parts of the river. The third problem described by Shane related to anion tests. In explaining this problem he expressed frustration at the level of preparation these tests took for students to simply note colour changes. He said if the VCL could support anion tests it would be a much more efficient and effective approach.

4.5 Case study C: Mark

Mark teaches in a single-sex boys school in a large town, has 27 years of experience teaching science and mathematics, and estimates he has been teaching with computers for 23 years. He also has previous experience teaching in a mixed school. He explains that he has a pretty favourable attitude towards computers, but only so far as if he sees it has an advantage to his teaching in using it. Mark participated in every stage of the research, except Stage 1. The findings for Stages 2, 3, and 4 will now be detailed.

4.5.1 Stage 2 - Mark

For Stage 2 Mark picked the topic of density to teach with his second years (13-14 year olds). Mark completed a CoRe, his lesson was observed, he completed a follow-up interview and a short focus group was carried out with his students.
Content Representation (CoRe) – Mark

When asked about what he would like students to learn about density, Mark highlighted issues of misconceptions and the need to remove these. He also highlighted the practical applications of density to everyday life and hence, the importance of students to know it for future use. When discussing the difficulties in teaching the idea, he highlighted how students can have difficulty with the mathematics element and how it was abstract for students. Mark said he would try as many ways as possible to overcome these student difficulties.

Mark explained that in teaching the topic he would firstly get students engaged through telling them a story that may relate to television, or a book that the students have read. Then he would give students as much practical work as possible and as many problems to solve along the way in terms of density, and that students would ‘figure it out for themselves’. When Mark was asked about advice he would give a beginning teacher he noted the importance of not following the textbook as it would lead to student confusion in teaching density before other material was covered first. He highlighted the importance of new teachers relating the material to students’ lives:

So if I was telling a new teacher or a dip student you know, give them [students] something that, you know, they can relate to, the question, trying to figure out themselves why is that floating? Why is that sinking? You know, same mass...and work from there.

When Mark was asked how he found the CoRe as an exercise he commented:

As an exercise...well it's made me think really. I think what's the best way for getting them to understand this, you know. Would all students have a greater understanding if I just did all the problems on the board, you know. Calculate the volume, density of this and mass of that, or would they have a better understanding if they actually got their hands dirty and got those blocks of wood or metal or whatever, and got the instruments and measured volume, mass, do the calculations, you know. I think like this an area now that's kind of open ended really. There's a lot of stuff you can do with them, you know, that wouldn't be covered in most of the textbooks and would give them a better understanding, but of course part of the problem there is you need time. You don't want to spend too long on it either because you're tied to the syllabus and you have to have a certain amount covered at the end of first year, at the end of second year so yes...I think the method I would use is important but...at the same time I'm going to watch the timescale, you know.
Chapter 4: Findings

Observation – Mark

Mark originally had difficulty in deciding what way to use the VCL, firstly saying he would use the VCL with fifth years, but then changing his mind to second years. When Mark used the VCL with the students, he spent part of the first lesson showing the students how to use the VCL from a data projector, before letting them into the computer room to use the VCL in the second part of the lesson. Mark also explained a great deal in relation to how to solve the density problem while demonstrating the VCL in the first lesson. Classroom management was somewhat of an issue in the first part of the lesson, as many students were shouting out of turn at the teacher when he asked questions.

During the second part of the lesson, Mark moved around the classroom quite comfortably, but spent a lot of time with individual students, while other students sat at their computer, waiting for the teacher to come to them and answer their question(s). Some students played around on the VCL, looking at different features of it, before moving their attention to the problem the teacher was asking them to complete. Three different students asked the teacher how much they needed to weigh out and the teacher gave them an example figure. Another student asked the teacher what they had to do and the teacher began to explain the procedure to them. As the teacher did this, two other students began to play games on their computers. Out of 16 students, six students had worked out the problem at the end of the lesson, six were still trying to figure out the problem and four students had given up.

Follow-up interview – Mark

In the follow-up interview Mark was asked about the VCL as a learning tool, how the VCL could support inquiry, his role in the classroom and the use of the VCL as an assessment tool. Firstly, when asked about the VCL as a learning tool, Mark commented that the VCL ‘takes a bit of getting use to’, but not for smarter students, that the presentation of the VCL could be ‘jazzed up a small bit’, and that a help function in the VCL would be useful to guide students more. He noted the utility of the VCL to support trial and error by the students, but felt that a hint system would
make it more user-friendly. When questioned further about the use of the VCL to support learning Mark commented:

*I felt now that problem, they were jumping in at the deep end whereas maybe if they was a grading progression, start off with something simple and work your way up to the next step you know. Turn it more, we'll say, into an online lesson.*

Secondly, when asked if the VCL could support inquiry, Mark responded:

*I don't think it will replace a teacher who can, we'll say, tease the answers out or throw the right questions at a group, you know, to bring them onto the next stage, you know. I think it's kind of, it's very much dead in the water really as regards that, because the layout of the graphics, it's not enticing either, you know, so I wouldn't rate it too highly as regards an investigative method, alright grant it, it's a tool that can be used, we'll say, to backup your ideas, you know, help you out there as such, but as for getting the students to investigate off their own back I wouldn't rate it too highly.*

Thirdly, when asked about his role in the class, Mark commented on the importance of guiding the students along where necessary:

*I suppose really I'm there kind of looking over their shoulder making sure that they're doing the right thing or if they're in trouble I'm there to answer a question on it you know, not to give them the answer, but to guide them along you know. I'd say that's simply my role there really you know, just to guide them along. Make sure they're going to head towards the right answer at the end of the day you know.*

Finally, when asked about the use of the VCL as an assessment, Mark said that he ‘wouldn’t rate it as an assessment tool’, highlighting that the VCL would need to grade ‘each step along the way’ which would be a difficult process.

**Student focus group - Mark**

This focus group was cut short as the students had to leave for a school bus to get home. However, the students made certain comments about the use of the VCL in class and as an assessment. One student commented that he would prefer ‘to do the experiments in real life’. Two other students disagreed with him saying they would prefer to use the VCL. One of these students commented:

*It's a lot easier to do once you get use to it [VCL]. It's really easy to use.*
Chapter 4: Findings

The student who preferred REx then aligned his views more with the other students ‘you’d be faster I suppose’. One student highlighted that the VCL would be useful to help students have a better idea of what they are doing when it comes to REx. In terms of assessment, all students in the focus group said that they would like a mixture of both REx and VEx type assessments. They noted the value of the VCL in removing concerns relating to breakages or wasting equipment.

4.5.2 Stage 3 - Mark

In Stage 3, Mark taught his second year students the topic of density, using the density related problem on the VCL. He completed a Pre-, Lesson- and Final-ISIS (Appendix E), his lesson was video-recorded, he completed a final interview and some of his students completed SSA sheets. There was not time to complete a student focus group. The findings for each research tool will now be detailed.

Inquiry Science Implementation Scale (ISIS) – Mark

In the Pre-ISIS and Final-ISIS, Mark had the same response for 10 out of the 22 items. However, four of the items were different by one on the Likert scale, four were different by two (Items 17, 19, 20, 22: compare and contrast students’ explanations of findings (17), connect new information with students’ personal lives (19), connect current events with current science concepts (20), and have students ask questions about scientific phenomena (22)) and four were different by three (Items 1, 5, 8, 14: demonstrate the use of a new instrument (1), ask students to identify and define words (5), discuss how everyday situations relate to experiments (8), and have students share their predictions with the class (14)). For the introduction phase of the experiment on the ISIS, Mark ticked Item 2 (have students write the problem before doing an experiment) ‘rarely’ in both the Pre-ISIS and Final-ISIS. He commented in the Pre-ISIS:

*I’d say rarely because I try to keep the problem simple and discuss it with them so I wouldn’t ask them to write it down.*

Mark prefers to do this activity through a discussion with the students. For Item 3 (review relevant concepts that were learned in the previous lesson) he noted ‘often’ in
the Pre-ISIS and ‘always’ in the Final-ISIS. Mark simply commented that he would recap on material covered in the previous lesson.

For the conduction phase of the ISIS, Mark explained Item 10 (monitor small group progress during experiments) in the Pre-ISIS as following:

Yes I would always go around and check and see what they're doing and making sure that they're doing things right and asking questions about how they're getting on and so forth.

In the Final-ISIS Mark gave a similar response to Item 10:

Yes, yes, always, I have to go around and just make sure each group, they should be moving along, so forth.

Mark had mixed responses to Items 13 to 17 (discuss variations in data collected (13), have students share their predictions with the class (14), have students share their data with the class (15), challenge students to consider the effects of errors (16), and compare and contrast students’ explanations of findings (17)). He noted ‘often’ to ‘always’ for Items 13 to 15 (with the exception of Item 14 in the Final ISIS: ‘never’), but noted ‘rarely’ for Items 16 and 17. In terms of Items 13 to 15 in the Pre-ISIS he commented the following:

Item 13: Yes, I would do that quite often. On the board I'd make a table or maybe put up an Excel spreadsheet on the screen and compare the results and get averages and discuss you know results that are off the mark and so forth you know.

Item 14: Yes, as a whole class group, yes. Yes I would. I would discuss in advance what they would expect so I'd say very often.

Item 15: I'd say yes. Yes we'll say in the case of let's say titrations that we'd gather all the data at the end and discuss them so I would have them share their data and compare.

In the Final-ISIS Mark ticked Item 14 (have students share their predictions with the class) ‘never’ as compared with ‘often’ in the Pre-ISIS:

It'd be nice, but I'd have the fear there that, you know, some group might have some completely ridiculous prediction altogether and could be ridiculed, you know. So I've it down there for never so it would be along that lines, I'd try and avoid it, that they would make predictions, but within the group and they wouldn't share it openly beforehand, just to avoid any embarrassment later on, you know.

In relation to Items 16 and 17 (effects of errors and students’ explanation of findings), Mark made the following comments in the Pre-ISIS:
Item 16: Not too often because I would have them kind of told that by doing the experiment two, three, four times that they would be reducing the errors. So I wouldn't be challenging them later on that except that they would know that that we'd say if they'd one result totally off that I would have them told you know that.

Item 17: I'd say rarely. It's more compare results really, rather than explanations, and generally I find that the experiments get drawn out towards the end and you're generally kind of rushing towards the end to get them to finish up, clean up and so forth so it's mainly getting results and drawing a quick table on the blackboard or whatever, but explanations wouldn't be too drawn out.

Video observation and RTOP – Mark

As in the observation from Stage 2, Mark explained the features of the VCL to the students before bringing them to the computer room to use the VCL. He circulated the classroom in a relaxed manner and checked to see what each student was doing on the VCL and how far they were progressing. The extract below is from this observation. Mark is looking to see how the students are getting on at solving the density problem:

Teachr: How are we doing? Have you got there?
Student A: We put in 50 grams and it comes out as, it's different for each metal in each graduated cylinder. It's the same one. (Teacher observing as student works on computer screen)
Student A: I'm confused (puts hand on head).
Teacher: Are you confused?
Student A: You try it (to Student B).
Teacher: Okay, how do you calculate density?
Student B: Mass over volume.
Teacher: Mass over volume so you've got to get the mass of a certain volume or the volume of a mass. So how are you going to go about doing it? I can see you're using a graduated cylinder and what does that measure?
Student A: Volume.
Teacher: Volume. So you're putting metal 1 into the graduated cylinder. Now the balance there is saying 40.9. What's that the mass of?
Student B: The cylinder.
Teacher: Empty?
Student B: Yes.
Teacher: There's nothing in it, okay. So now what do you do?
Student A: If we tare it.
Teacher: Okay. We'll put it back to zero now, okay next?
Student B: Stick in the mass of metal.
Teacher: Okay. Do that so.
Student B: How much should I stick in?
Teacher: You decide.
Student B: A hundred is easy to divide by.
Teacher: A hundred, and how far does it go? Can you read it?
Student B: Nine point...
Teacher: Nine point? Would that be half way?
Student A: I don't know.
Teacher: It's not 9.6, 9.4, what do you think?
Student B: 9.5.
Teacher: 9.5, so you happy with that?
Student B: Yes.
Teacher: Okay, so that metal has a volume of 9.5 centimetres cubed and a mass of...
Student B: A hundred.
Teacher: Now you've volume, you've mass, can you find its density?
Student A: Yes.

In relation to the RTOP, Mark would have scored 3 or 4 (occurred often to always) on 22 of the 25 statements. Items that scored less were similar to other items that other teachers scored low on (Items 10, 11 and 16: connections with other content disciplines (10), students used a variety of means (11), and students communicated their ideas through a variety of means (16)). Mark would have scored 3 (occurred often) on Item 7 (promoting strongly coherent conceptual understanding) as he did not leave students to figure things out for themselves. Students were provided with the answers in many instances where they asked Mark questions. Mark worked more within structured inquiry than guided inquiry. Hence, at the end of the lesson, students did have an understanding of the experiment. However, how much ownership students took in the experiment was open to question.

**Final interview – Mark**

In the final interview, Mark was asked questions relating to his views; on how the lesson went (strengths and weaknesses), on the use of the VCL as a learning tool, on his role in the classroom, and on the use of the VCL as an assessment. Firstly, Mark saw strength in the lesson in that some of his students refined their approach to the experiment so as to get more accurate results, which was something he had not expected. He also commented:

> They had to think it out and there was a lot of collaboration within the groups themselves, that they talked their way through it, you know, they worked their way through the problem and I think they all came up with the correct results at the end of the day, but it was done through, you know, asking each other questions and trying out. So it wasn't a question of reading instructions of how to do it, you know, which is what they normally would do we'd say in
Mark commented on not so much a weakness of the lesson, but a difficulty in terms of classroom management while using computers. He felt some students can tend to get distracted by games on a computer for example, so it is important to ensure that they are monitored and are kept on task.

Secondly, when asked about the VCL as a learning tool, Mark remarked that initially he was not gone on the VCL, but after seeing it used he began to see advantages to it. He noted the use of the VCL to allow for quick demonstrations or to let students do out a problem on it on their own. He also noted that on days he is unable to get into the physical laboratory that the VCL would be much more convenient, as compared to doing nothing at all with the students.

Thirdly, when asked about his role when using the VCL, Mark commented:

I suppose really as a facilitator, rather than as an instructor, guide them along, get them to get the answer themselves and don't give them the answer, you know. Help them get there alright, get them discussing the problem, get them discussing how to solve it, you know, discuss any errors they made and so forth you know so it's facilitating really, rather than instructing.

Finally, in terms of the VCL as an assessment tool, Mark liked the idea of the VCL as an assessment, but felt it would be difficult in light of the current assessment structure that is in place:

It would be nice, but as it is at the moment I would see it difficult to use in the kind of the current meaning of assessment where you allocate so many marks for getting this skill right and that skill right, you know. It would be difficult that way.

Student Self-Assessment (SSA) - Mark

15 of Mark’s students completed the SSA (out of 16). All 15 students only ticked the responses ‘very bad’, ‘bad’, ‘adequate’, ‘good’ or ‘very good’. No students put comments to justify any of their responses. The boxes ticked by students were mostly positive. For ‘understanding the processes of inquiry’ one student marked ‘bad’, three marked ‘adequate’, eight marked ‘good’ and 3 marked ‘very good’. For ‘being
inventive’ one student marked ‘very bad’, four marked ‘bad’, five marked ‘adequate’, two marked ‘good’ and three marked ‘very good’. Finally, ‘for reasoning carefully’, one student marked ‘very bad’, two marked ‘bad’, three marked ‘adequate’, four marked ‘good’ and five marked ‘very good’.

Stage 4 - Mark

Mark explained that he would like to see experiments relating to the solubility of gases in polar and non-polar solvents on the VCL. His explanation for having problems of this nature on the VCL was that in doing these experiments it can only take maybe 10 minutes of class time yet it would have taken a teacher much longer in terms of preparation and tidy up. He felt doing the experiments were not worth the payback.

4.6 Case study D: Paul

Paul teaches in an all-girls school in a rural town, has over 30 years of experience teaching chemistry and estimates he has been teaching with computers for over five years. Paul also has experience teaching in a boys’ school and a mixed school. He argues that teachers are not at the stage yet where they are able to use computers in the classroom as not all students can afford them. He also noted that there are difficulties in attempting to get a timeslot to use the computer lab in the school. Paul participated in Stage 2 of the research.

4.6.1 Stage 2 – Paul

For Stage 2 Paul picked the topic of titrations, in terms of acids and bases, in particular the titration of ethanoic acid and sodium hydroxide, to teach his fifth year students. Paul completed a CoRe, his lesson was observed, he completed a follow-up interview, and some of his students completed a focus group. The findings of these will now be presented.
Content Representation (CoRe) – Paul

When asked about what he intended the students to learn Paul referred to the definitions of acids and bases, and the theory related to them. He viewed the importance of knowing this in terms of students getting an A in their final examinations and that it would also be useful if the students did a science degree in college. The difficulties and limitations Paul noted in teaching this idea were the boring nature of doing titrations:

After students do two of them they are wondering why they have to do another ten of them. Simply to solve the same problems, but they are there and they have to be done.

In explaining his knowledge of students’ thinking that influences his teaching of the idea Paul highlights the uncritical methodologies the students have developed:

Students get bored of doing titrations, repeating the same procedures and trying to understand that they have to get an accurate answer every time and that there is a precision involved in it is difficult to get over to them. They are quite happy to just do three titrations and get any sort of answer at all.

Paul also felt that titrations are not something students see as being done in the real world. When explaining his teaching methods Paul stated that he ‘unfortunately’ had to cover the theory through chalk and talk. Paul viewed new resources (VCL included) as a means to strengthen his existing practice, but not to change it:

I suppose in science teaching I am looking for some way all the time of reinforcing the chalk and talk. Okay and as a method of giving homework, rather than just here is a hand-written problem, the figures are all there, work it out. With the Vlab you are making them at least repeat the experiment from the chemistry lab okay. So it is extending their, their approach to the question. It is the exact same question that you would have given them had you written it out and said a student did something and here are their results. Now you are saying here are the chemicals, you get the results. So you are reinforcing the whole learning that way.

In doing the experiments Paul expressed a focus on reinforcement of safety procedures, the accuracy associated with doing experiments, and that he would have explanation throughout for the students.

Paul explained that he would ascertain students’ understanding through a written test and made note of the fact that the current assessment does not have a practical
assessment. Paul felt that the use of a VCL in assessment would be favourable in that:

*It should give a better idea of how they understand what they are at.*

**Observation – Paul**

Paul used the VCL as an assessment for his students. There were only five students in his class. At the start of the lesson, he explained the problem description on the VCL and that the students had to work out if the vinegar was being diluted. Paul then sat at his desk at the top of the classroom and let the students work on the problem on the VCL. This use of the VCL did not reflect much in the way of the Paul’s classroom practice. Paul spent a lot of time sitting down at his desk during the assessment using the VCL, but began to move around and observe students more as it became clear that two of the students were having difficulty in solving the problem on the VCL. Paul had to provide hints to the students in relation to how they carried out a titration, in particular what volumes to use and what indicator to use.

**Follow-up interview – Paul**

In the follow-up interview Paul was asked about the VCL as a learning tool, how the VCL could support inquiry, his role in the classroom and the use of the VCL as an assessment tool. Firstly, Paul commented that he liked the VCL as a learning tool, and that ‘it was very useful to let the students go and practice the titration problems’. However, he expressed frustration in not being able to add his own problems to the VCL as ‘in terms of the Irish curriculum it's not developed in that direction’.

Secondly, he felt the students would need support if the VCL were to be used for inquiry and noted it would also be difficult with the amount of material to be covered in the current curriculum. However, he did note that the VCL did make an addition to students’ understanding of the concepts:

*It does help them to get their head around the concept of the whole acid and base and the titrations in a different way than chalk and talk or the PowerPoint.*
Thirdly, Paul explained his role in terms of helping students to understand chemistry and as much as possible to make the subject more interesting for students. He commented:

*For the students learning chemistry is the same drudge as learning history or learning anything else. They're sitting on a hard chair and it can get tedious after a while.*

Finally, in terms of the VCL as an assessment, Paul said he felt ‘quite happy’ with his students’ approach to the problem. However, he noted that two students ran into difficulty while doing the experiment. He said he was unsure if it was to do with technical issues of using the VCL or issues with understanding the problem. He commented:

*They'd want to have far more practice with it [VCL] or else more time to do the particular assignment, that time, we gave them what was it, there were four sets of titrations to be done on it so it wouldn't have been possible to do it in a lab so as a means of assessment outside the lab it's brilliant...but the technical skills for them is sort of a limiting factor and again the availability of the hardware.*

Paul also makes note of the difficulty of having enough computer hardware. He only had five students in his class, but felt that using the VCL as an assessment would be much more difficult with a larger group of students.

**Student focus group – Paul**

This focus group had five students (all girls). The focus group centred on positive and negative aspects of the VCL, and the VCL as an assessment. Firstly, in terms of using the VCL, the students commented that the VCL was easier to use, it was faster than doing it physically (no cleaning and rinsing) and that the VCL allowed them to move past safety concerns in the experiments. Students highlighted that they would prefer a mix of both REx and VEx, as they still enjoyed seeing the real chemicals in front of them.

Secondly, the students commented positively in the use of a VCL as an assessment, noting that it would be much better than having to write up experiments as it involved a ‘doing’ element. One female student was asked if she would prefer a physical
laboratory examination or a virtual laboratory examination and she commented in favour of a virtual assessment:

When you're doing, this'll sound stupid, but in an exam you're going to be scared so there's probably going to be less room for error on a computer than there would be when you're trying to do it.

4.7 Case study E: Martina

Martina teaches in an all-girls school in a large town. She has 10 years experience of teaching science and explained that she would not have much experience or confidence in using computers in her class beyond the use of occasional PowerPoint or finding something on the internet. She expressed a strong focus in Post-Primary School in teaching towards the Leaving Certificate examination, which could easily be achieved without using computers. Martina participated in Stage 2 of the research.

4.7.1 Stage 2 – Martina

For Stage 2 Martina picked the topic of titrations and density with her Transition Year students (15-16 year olds). Martina completed two CoRes, two of her lessons were observed, she completed a follow-up interview, and some of her students completed a focus group. The findings of these will now be presented.

Content Representation (CoRe) – Martina

Martina completed two separate CoRe interviews on density and titrations, and hence was observed teaching twice. When she was asked about why it was important for her students to learn about titrations she commented:

Well of course because being a teacher Leaving Cert. chemistry is, you know, volumetric analysis is a huge part, question one so obviously that is for Leaving Cert. chemistry it's a big, mainly for chemistry.

She also made a similar comment when talking about what she intended students to learn about density:
When you're teaching in secondary school you're really teaching to the exam, okay, so what do you intend students to learn about this idea is to learn to be able to do a question and be able to answer questions on density, to understand it and answer the questions on density.

When answering what her knowledge of students’ thinking was that influenced her teaching of titrations she commented:

Well I know what they've learned from Junior Cert., you know, and sometimes again you know the weaker students, what you'd have drummed into them, you know the way, so from that you know usually have your base point where you're working from.

She makes reference to having knowledge of where her students’ starting point is based on the Junior Certificate requirements. When Martina was asked about her teaching procedures for titrations and why she used them, she struggled with attempting to answer the question and said she would come back to it. Following up on the question, she explained that she would do a demonstration of experiments to students before letting them do it, and would carefully monitor the students as they were doing the experiment, instructing them throughout. She noted the ‘spoon-feeding’ nature of her approach and when asked the main reasons for teaching experiments this way she commented:

I suppose number one, safety. Number two that it is done in the time allocated, you know, we're very restricted here. Two labs, 700 odd students so you want to get in, get it done, cleaned up and out again so you want it efficient.

When Martina was asked how she found the CoRe as an exercise she noted:

You see you don't really think about this. I just go in and teach it and where's my next class, you know, run.

Observation – Martina

Martina was first observed teaching the students about density using the VCL. It was a double lesson. She spent the first lesson explaining to the students how to use the VCL. The students were noticeably bored, with many of them slumped with their heads into their hands. For the second part of the lesson, Martina brought the students to the computer room to do the density problem on the VCL. There were 18 students in the class. Only two students in the classroom started doing the experiment by using a 10 ml graduated cylinder whereas the other students used a 25 ml or 50 ml
graduated cylinder. Many students then ran into difficulty in making a distinction between the displacements of water for each of the metals. Martina spent the entire lesson moving around the classroom, looking to talk to students constantly and not observing any of the students as they worked. Some students did not persist in attempting to solve the problem and waited for the teacher to come to them and explain where they were going wrong. Some students worked out the densities with time left in the class. Martina asked them to carry out the experiments again to see if they obtained the same results.

Similar issues emerged for the second observation where students attempted the titration problem related to vinegar. In the first lesson of the second observation, Martina again explained features of the VCL for the students to be aware of in attempting to solve the problem. She told students she would expect them to solve the problems without little help from her. In the second part of the lesson, students again went to the computer room to use the VCL. Some students brought out all the equipment on to the VCL workbench before considering the problem description. There was discussion between students in what volumes to use, what indicator to use and what the colour change would be. Martina looked to spend more time observing in this lesson, but found it difficult as she was still called on many times by the students. She noted to the researcher that she felt the students were ‘not switched-on’ to what they had to do. One student at the end of the lesson expressed frustration at the VCL problem:

\[I \text{ hate not having instructions. I’m used to having instructions.}\]

**Follow-up interview – Martina**

In the follow-up interview Martina was asked about the VCL as a learning tool, how the VCL could support inquiry, her role in the classroom and the use of the VCL as an assessment tool. Firstly, Martina commented that the VCL was an excellent learning tool and particularly for varying levels of student ability, as students could use it in their own time. Martina also felt the VCL took a bit of time ‘getting used to it’. Martina also noted that she had difficulties getting into the physical laboratory
sometimes due to clashes in her timetable with other teachers so she noted the VCL would be a very useful aid when the physical laboratory was unavailable.

Secondly, when asked about the use of the VCL to support inquiry, Martina expressed confusion on what inquiry meant. The researcher did not respond with his interpretation and instead, asked Martina what she thought inquiry was. She questioned out loud whether it meant the same thing as ‘investigative’. She said if it was the same thing then the VCL was useful in that it allowed students to make mistakes that could be easily rectified. She commented:

*I don't know whether investigative is inquiry. No, inquiry is more asking whereas investigative is maybe doing. I don't really know the answer to that question.*

Thirdly, Martina was asked about what her role in the classroom was using the VCL. She explained her role in terms of helping the students to use the VCL. She noted that it was difficult to motivate the students:

*I was stretched to go around and check, and as well as that, you know, you have to also check are they actually doing what they're suppose to be doing or are they looking up what tops are available on different websites, you know. There's that because you're not, you don't have a programme. It's not examinable so the motivation mightn't be there to actually be, go and do it.*

Finally, when asked about the use of the VCL as an assessment, Martina felt that the VCL could ‘definitely’ be used. However, she highlighted issues in relation to the course needing to change and also, she felt her school would not have the facilities to adequately support assessment using the VCL. She commented on the influence of current ‘high-stakes’ assessment on her use of the VCL as an assessment in class:

*That'll be course driven okay, or syllabus driven. I couldn't see myself giving them a practical exam unless it was going to be in the real Leaving Cert.*

**Student focus group – Martina**

This focus group had six students (all girls). The focus group centred on positive and negative aspects of the VCL, and the VCL as an assessment. Firstly, the students mostly enjoyed using the VCL as it was safe, there was no cleaning up and as a result, it was faster than REx. Students commented that they would like an un-do button on the VCL so mistakes within the VCL could be quickly readjusted. Some of the
students expressed frustration in not being given a method to follow when doing a
problem on the VCL. The following dialogue is taken from this focus group:

    Girl 3: If you gave us a method. (Others agree)
    Girl 1: Yes if you gave us some sort of guidance it would be really good.
    Girl 6 You just sit there, you don't know what you're doing so you just pour
        like random things and fooling around.
    Girl 1: You put all that into the desk bench so you hope for the best. (Others
        agree).
    Girl 2: The last experiment, the metal one was so hard, oh my god, I didn't
        know how to do it, I was trying every each way and it just wasn't working.
    Girl 4: I got two of them and then the last one wouldn't work out so I figured it
        had to be the other one.

Secondly, most of Martina’s students commented that they would like a mixture of
physical and virtual assessment. They pointed to the fact that the VCL would
facilitate a number of attempts at solving the problem. One student said she would
not like to be assessed using the VCL at all:

    I'd still go with practical because the computer, I'm just looking at it like okay,
    I'm looking at a screen, it doesn't make sense 'cause like I just found it really
    hard to navigate around the page and then once I tried to do it I just kind, I
    got confused and then the teacher kind of just walks around and you don't
    know what you're doing at all, you kind of zone out then.

4.8 Case study F: Susan

Susan is a newly qualified teacher who had recently completed her higher diploma in
education. She teaches in a girls-school in a big town, but a few boys from a nearby
school come to her class to do Chemistry, as it is not available in their school. Susan
explained that she is trying to find her feet in the classroom as a beginning teacher so
she is still experimenting with her teaching methodologies. This also applies to her
use of ICT in that she is not sure of what advantages it may have for student learning.
Susan participated in Stages 3 and 4 of the research.

4.8.1 Stage 3 - Susan

In Stage 3, Susan taught her fifth year students the topic of titrations, using the
vinegar related problem on the VCL. She completed a Pre-, Lesson- and Final-ISIS
(Appendix E), her lesson was video-recorded, she completed a final interview, and
some of her students completed SSA sheets. There was not time to complete a student focus group. The findings for each research tool will now be detailed.

Inquiry Science Implementation Scale (ISIS) – Susan

Of the four teachers that completed the ISIS, Susan had the most diverse responses to the Pre- and Post-ISIS. Only four items on the Pre- and Post ISIS were marked the same (Items 10, 12, 16, 22: monitor small group progress (10), circulate and interact with students (12), challenge students to consider the effects of errors (16), and have students ask questions about scientific phenomena (22)). Eight responses were different by one, six were different by two, three were different by three (Items 2, 3, 21: have students write the problem before doing an experiment (2), review relevant concepts from previous lesson (3), and use questioning strategies to respond to students’ questions (21)) and one was different by four (Item 9: check students’ designs for safety before allowing them to conduct experiments).

In terms of the introduction phase of an experiment, she marked Item 2 as ‘often’ in the Pre-ISIS and ‘never’ in the Final-ISIS, while Item 3 was marked ‘rarely’ in the Pre-ISIS and ‘always’ in the Final-ISIS. For Item 2 in the Pre-ISIS she remarked:

I would use that quite often. I would normally get them to write out safety features etc. before they do the experiment, then pop their books away and do the experiment. I find it works best.

In the Final-ISIS she ticked Item 2 as ‘never’:

No, I would never do that. Normally what I do is I will prepare a handout for them on the experiment and go through the handout with them on the experiment, the procedure, methods from the SLSS website or the iChemistry website and then, they will normally do the experiment and then they tend to write up the activity after they've done the experiment.

She marked Item 3 as ‘rarely’ in the Pre-ISIS and said:

I would say I would do that rarely. I mean obviously every day there's a continuum of classes, but I think skills it would be more on a weekly basis that I would do that.

She ticked Item 3 as ‘often’ in the Final-ISIS:

I would say I would always do that. Every day that they come in we tend to go back on what they have done before, the day before now. Whether I go back as far as I would like to, probably not.
In terms of the conduction phase of the experiment, Susan responded to Item 10 (monitor small group progress) and Item 12 (circulate and interact with students while they are conducting experiments) in the Pre-ISIS as follows:

**Item 10:** Always do that. I'm always walking around talking to them.
**Item 12:** Always, I think it's important from a safety aspect to keep walking around.

Susan’s responses to Items 13 to 17 (discuss variations in data collected (13), have students share predictions with the class (14), have students share their data with the class (15), challenge students to consider the effects of errors (16), and compare and contrast students’ explanations of findings (17)) varied from the Pre-ISIS and the Post-ISIS. In the Pre-ISIS she marked Items 13 to 15 as ‘sometimes’. In commenting on Item 13 in the Pre-ISIS she noted:

Sometimes we will do that. We started doing that more frequently now. We'd put the class results up for the titrations so we'd get an overall idea.

She noted that she did Item 16 in the Pre-ISIS as ‘often’ and questioned students in particular if a result was out of the ordinary. However, on Item 17 she marked ‘rarely’ for comparing and contrasting students’ findings. She commented:

That's something we don't do very often if I'm to be honest. By the time they are finished their experiments and their write-ups I assume that their explanations and findings are correct which is perhaps something I shouldn't do.

She noted Item 13 as ‘often’ in the Post-ISIS, saying she would take five minutes at the end to discuss the results as a group and how the experiment could be improved. However, she marked Item 14 as ‘never’ compared with ‘sometimes’ in the Pre-ISIS. For Item 15 she has moved from a ‘sometimes’ to an ‘always’ in the Post-ISIS. She remarked on Item 15 (have students share their data with the class):

That's as I said nearly always done every experiment that we do, there's a class group results put up and I think it helps the students as well to see that they're on target. That they're doing the same as everybody else 'cause they're very interested in making sure they're on a par with everybody else.

Susan marked Item 16 (challenge students to consider the effect of errors) ‘often’ for both the Pre-ISIS and Final-ISIS, but Item 17 (compare and contrast students’ explanations of findings) went from ‘rarely’ to ‘sometimes’ in the Final-ISIS. Susan commented on Item 17 in the Final-ISIS in comparing and contrasting students’ findings:
Chapter 4: Findings

"I'd probably say sometimes for that one just because we will go through the questions and stuff at the end of the experiment and the following day, but I probably wouldn't go back then and look at their findings or discussions or explanations of the experiment. I wouldn't ask for that again after the experiment has been done."

Susan remarked on Item 18 (question students as they conduct their experiments):

"Often do that. When you're walking around just it's easy to ask them a couple of questions to make sure that the theory that we've done in the morning has made sense to them and they can relate it to what they're doing now."

**Video observation and RTOP – Susan**

Susan brought the students (21 students: 13 female and eight male) into the computer room and explained the problem they had to do on the VCL. She explained to the students that she would only help them with technical aspects of the VCL, but wanted them to work out the problem on their own. The students worked on the problem in pairs and were very engaged in the problem throughout the lesson. Many students tried to ask Susan questions relating to the problem and she told them to think it out for themselves. There was obvious frustration for many students in Susan’s lack of support in helping them to work out the problem. Susan looked relaxed for most of the lesson, observing what students were doing as she walked around the classroom. She pointed to some things the students could consider, but kept the focus on the students working out the problem on their own.

In relation to the RTOP Susan scored 3 or 4 (occurred often to always) on 18 of the 25 Items. Some items that scored lower were similar to other teachers (Items 10, 11 and 16 – connections with other content disciplines, students used a variety of means, and students communicated through a variety of means). Items of interest for this lesson were Items 7, 14, 17 and 24. For Item 7 (the lesson promoted strong coherent conceptual understanding), it was questionable if the lesson promoted strongly coherent conceptual understanding, as many students were frustrated throughout the lesson and were still frustrated leaving the classroom. Students had made progress throughout the lesson in trying to understand the problem on the VCL. However, students still had questions to answer so Item 7 was marked 2 (sometimes). Item 14 (Students were reflective about their learning) was marked 1 (rarely). Students
became more frustrated than reflective over the course of the lesson. They were sighs of frustration throughout the lesson. However, a few students did attempt various approaches in attempting to solve the problem. For Item 17 (teacher’s questions triggered divergent modes of thinking), this occurred rarely as the teacher generally told students to think about it themselves and spent more time observing students, rather than questioning them. Finally, Item 24 (the teacher acted as a resource person, working to support and enhance student investigation) was marked 2 (sometimes). This item could be argued either way, as in one sense the teacher was a resource for the students in encouraging them to work things out on their own, while on the other hand, she was not a resource in providing the students with answers.

Final interview – Susan

In the final interview, Susan was asked questions relating to her views; on how the lesson went (strengths and weaknesses), on the use of the VCL as a learning tool, on her role in the classroom, and on the use of the VCL as an assessment. Firstly, Susan noted that the approach definitely aligned with inquiry and that is why her ‘students hated it so much’. Susan explained that her students like structure and routine as it is what they are most familiar with. Despite this, she noted that her students were still thinking about questions they had from the problem on the VCL when they were doing a similar problem in the physical laboratory. Susan also made note that of her students working well together when using the VCL and she felt that the VCL catered to varying student abilities within her class and thus encouraged all students to solve the problem.

Susan noted a weakness in that she felt her students gave up too easily in attempts to solve the problem. In explicating why students did this she noted:

*I think the fact that it's new and different for them. It's, you know, they don't do inquiry. They're given the answer and then they do an experiment. They don't use that inquiry system in the labs and that's what I think frustrated them. It's something completely different.*

Susan felt her students benefited from using the VCL and noted that they had answered a question on their Christmas test related to a problem on the VCL much better than other questions. She questioned if this could have been a result of students
also getting a similar experiment in the physical laboratory and hence, doing the experiment twice in a way.

Secondly, when asked about the VCL as a learning tool, Susan noted that she felt the VCL had ‘benefits’ and ‘definitely has its uses’, but highlighted the importance of students to know the technical aspects of using the VCL first. She commented:

*I seen the benefits when they came to do it in the lab[REx] and I think when I asked them a question on it in the Christmas paper and they did much better on that question than they did on a lot of the other questions. So I think they did understand it better. Whether that be because they did it twice. It could be but I think that they did benefit.*

She noted that the students took to REx much more easily after having had experience on the VCL:

*The next week we actually did the physical experiment and they flew through it. They had no issues and they were actually raging with themselves then that they couldn't go back and do the lab one because you were there and they were kind of like well if you would let us do it now, we'd be well able to do it. We know what to do now Miss. So they did, it was much easier, that lab, for them to do. They knew what they were suppose to do and they knew straight away to dilute.*

Thirdly, when asked about her role when using the VCL, Susan noted that she found the inquiry approach frustrating. She explained her frustration in the following way:

*I feel like I should just, you know, at the end bring it together for them and give them the answer, but I suppose that kind of goes against what the idea of the inquiry-based teaching is. It's me that kind of feels that I want them to all go away understanding it. I don't want them, some of them to go away thinking what's happened there. But I did see the benefit of that because then the following week they were still thinking about it so obviously they were working it through in their own minds and they probably will remember it better and understand it better as a result of that, but my frustration was probably that I didn't give them the answers going away.*

Finally, in relation to the VCL as an assessment, Susan expressed concern that the VCL would need to be integrated more into the current school system before it could be used as an assessment:

*Oh if I think it was to be used in assessment that it would have to be something that there was more preparation for, for the students. So, there are some students who are not as computer, like particularly. I'm surprised by some of their weaknesses when it comes to computers and IT. They're not as strong as I would have thought they would have been. So I think if it was to be used in*
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that manner there would definitely need to be, it would need to be incorporated into the course as well as much as possible.

Student Self-Assessment (SSA) - Susan

14 of Susan’s students completed an SSA sheet (out of 21). Students’ feedback on the SSA sheets was rather negative. Students had become frustrated with the inquiry approach taken by Susan. Students’ comments vented this frustration at the teacher for not supporting them in the normal manner. One female student marked herself ‘very bad’ on ‘understanding the processes of inquiry’ and justified her decision with the following comment:

It was quite infuriating the way we were given very little instructions. When I asked a question, the teacher answered with another question. I prefer the usual way of doing experiments.

Another female student marked herself as ‘very bad’ at ‘understanding the processes of inquiry’ and commented:

We couldn’t get any opinions from the teacher and she couldn’t answer any of our questions so most of the time, we were stuck on what we should do.

Two other female students marked themselves ‘bad’ at ‘understanding the processes of inquiry’ and made the following comments:

We were answered with more questions than answers.

I didn’t like the fact that when you asked a question you were answered with a question, no matter how basic or complicated your question was.

Of the 14 students that completed the SSA, only two students marked ‘good’ or ‘very good’ at ‘understanding the processes of inquiry’ (Two students ticked no box).

Students also rated themselves poorly on ‘understanding the science’. In the following comment the student rated their understanding of the science as ‘bad’ and justified their response as follows:

I found myself just randomly trying different methods without understanding what I was doing just in the hope that it would work.

Another female student marked her understanding of the science as ‘bad’ and justified her response as follows:
We had not been taught how much of each solution to add so it felt like we could’ve been there for days, working on different amounts of the same solution, let alone different solutions.

The student responses to ‘reasoning carefully’ were also quite negative. One female student marked their ‘reasoning carefully’ as ‘adequate’ and justified their answer as follows:

“This way definately [student spelling] helped me to realise if something wasn’t going to work but it was harder to understand why.”

However, a male student rated their ‘reasoning carefully’ as ‘bad’:

“Had no understanding and were just guessing methods.”

Another female student rated herself as ‘bad’ at ‘reasoning carefully’:

“This was difficult for me. We just tried different things and if they didn’t work we would try another.”

Of the 14 students who completed the SSA only three students rated themselves as either ‘good’ or ‘very good’ at ‘reasoning carefully’.

**Stage 4 - Susan**

Susan noted that she would like experiments related to rates of reaction on the VCL. She explained that she would only do an experiment on heterogenous catalysis as a demonstration exercise and so her students would not get a whole lot out of it. She also noted that the organic chemistry experiments were slightly dangerous, and that the students do not get a lot out of them for the time and effort the teacher has to put into preparing for them.

**4.9 Chapter summary**

This chapter has presented the findings from each of the four stages of research. The key findings from each research stage can be summarised as follows:

- **Stage 1:** The teachers and stakeholders highlighted many potential uses of the VCL within the Irish education system in relation to the teaching, learning and, assessment of science. However, concerns were raised on the sustainment of such uses in light of current assessment that is focused on
content recall and the difficulties in changing this assessment. There is a strong perception from teachers and stakeholders that current assessment best rewards didactic teaching approaches.

- **Stage 2:** Teachers’ use of the VCL without direction mirrored their current practice, whether this was didactic or inquiry-focused. Following the use of the VCL, certain teachers did begin to consider elements of their practice, in particular their approaches to REx and to a questioning of what their students achieved from it. Students highlighted the use of the VCL to allow them more ownership in carrying out an experiment and expressed interest in the more regular use of it. However, students had reservations about getting to do less REx in light of increased VEx.

- **Stage 3:** The use of the VCL in an inquiry-directed manner had different responses from teachers and students. In relation to the teachers, Eric and Shane enjoyed the use of the VCL medium to facilitate inquiry, while Susan was unsure of her role in such a setting. Mark showed a limited understanding of teaching by inquiry. The ISIS specific to the VCL lesson showed particular characteristics. Unsurprisingly, compared with the other ISISs completed by the teachers there were a lot more ‘never’ boxes ticked. This was due to it only being one lesson. Teachers did express concern that the ISIS specific to the lesson did not reflect their overall practice, but felt that it did represent the lesson they had just taught. In particular, in the ISIS specific to the lesson, teachers’ focus on safety was removed due to the affordance of the VCL. This allowed the teachers to focus more on what the students were thinking. In terms of the students, many enjoyed the added responsibility afforded by the VCL, while others disliked such an approach, preferring to be given the answer. Stage 3 brought many cultural issues in Irish classrooms to light in relation to perceived teacher and student roles.

- **Stage 4:** Teachers suggested many problems for the VCL related to the current curriculum. A main reason underlying these suggestions related to the difficulty in preparing, doing and tidying up of such experiments, particularly in relation to the learning achieved by students in doing them. It was felt such learning activities would be more efficient and beneficial in a VCL environment.
The next chapter will discuss these findings in light of the research questions outlined in Chapter 3.
Chapter 5: Discussion

5.1 Overview of discussion

The research questions outlined in Chapter 3 will be used to frame the first part of the discussion chapter. After discussing the research questions (Section 5.2 to Section 5.7) there will be discussion of the research tools used in this research (Section 5.8) and the overall methodological approach (Section 5.9). To recap, the two main research questions were:

1. What are stakeholders’ views of the current science culture in Irish schools and how does this relate to the integration of a VCL to support educational change in chemistry?
2. How can the VCL act as an enabling infrastructure for IBSE in teachers’ classroom practice?

The second question was further broken down into a subset of four questions, leading to four questions in total. It is under these five questions that the findings will be discussed. Following on from a discussion under each of these five questions, a summary section (Section 5.7) will be presented to tie these sections together under the two main research questions. Each research question is given at the start of each section.

5.2 Research question 1

*What are stakeholders’ views of the current science culture in Irish schools and how does this relate to the integration of a VCL to support educational change in chemistry?*

This question was answered through eliciting the views of various stakeholders on contemporary issues in science education and how a VCL may play a role as a teaching, learning, and assessment tool. Trant (1998: 7) argues for the need to ‘find a basis of co-operation rather than confrontation’ in preparing for the future of education in Ireland. The history of Irish education has been wrought with ‘struggles over management and control, and all the while the people whom the system is
supposed to serve are becoming increasingly alienated from it’ (*ibid*: 7). Trant (*ibid*: 7) points to the importance of partnership in curriculum change and so the biggest issue in Irish education is to find means of ‘bringing these partners together not to contest the control of the curriculum but to discover the means to understand it better and to realise its potential’. From discussion with some of these ‘partners’ in this project, both common ground and grounds of contestation emerged on the use of the VCL as a teaching, learning, and assessment tool. The teaching and learning aspects of the VCL will be grouped together for ease of discussion as some aspects overlap.

Firstly, in terms of teaching and learning, many different features of the VCL were noted that could aid in the enhancement of student learning. In particular, some teachers and stakeholders noted how students become bogged down on the ‘physicality’ of doing REx and hence, do not learn what was originally intended by the teacher in doing an experiment. This falls in line with Abrahams and Millar (2008: 1945) who note that REx is good for getting students to do physical manipulation, but that it is ‘much less effective in getting them to use the intended scientific ideas to guide their actions and reflect upon the data they collect’. They point to a lack of recognition of the connection between ideas and observables by teachers in their design of practical activities (*ibid*). However, some of the participants in this research did recognise the connection between observables and ideas, as they explained that the VCL would allow a greater focus on student thinking, as opposed to students’ physical manipulation of apparatus. It is important to consider why practical activities would lack a greater connection between observables and ideas, even when teachers are aware of this pitfall.

The focus between the physical aspect of doing experiments and the thinking aspects of experiments highlights distinct schema between teachers in their understanding of what they achieve through carrying out REx. Reasons explained in the findings for teachers’ strong focus on physical manipulation during REx are to ensure safety and the appropriate use of limited resources. Issues of safety and limited resources do place a restriction on student expression and also explains why students are given step-by-step instructions before doing experiments. These findings would raise questions about the ability of Irish Post-Primary schools to adequately support IBSE through REx. Issues of safety and limited resources are further compounded by the
fact that many classes have a large number of students and there are 28 mandatory experiments to be covered in two years for the Leaving Certificate. Time then becomes a further factor militating against IBSE through REx. When considering this culture it can be understandable why teachers may focus more on observables than ideas when conducting REx. Unfortunately, student expression becomes limited with such a focus and many interviewees illustrated an awareness of the lack of creativity in current school science.

Wong and Hodson (2008: 126) note that a common myth for science students is that ‘scientific experimentation is a fairly straightforward business’ and as a result, it is not seen as a creative process dependent on continuous monitoring and modification. This student perception of science is strongly supported by how REx is conducted by teachers, with little opportunity to engage in aspects of experimental design. Many interviewees noted the potential of the VCL to address this issue, but were unsure of how exactly it would take shape. This could be explained by the fact that the interviewees had little, if any, experience of the VCL outside of what the author showed them before interviewing them. Also, this relates to teachers’ schema in that most of the teachers are not used to experimental design themselves. They have not been practising scientists and are products of the same system they are now a part of, hence reproducing it. Waight and Abd-El-Khalick (2011) found this in their efforts to introduce a new technology designed by scientists into Post-Primary schools, in that there was a ‘disparity between scientists’ and educators’ views of science, inquiry science teaching, and the related roles of technological tools’. Penuel et al. (2009) reported similar issues, with a lack of alignment between teachers’ enactment of curriculum materials and those intended by policy makers. These findings from the research literature, alongside the finding of teachers’ limited experience of the VCL, reinforce the need for change efforts to evolve based on partnership. Trant (1998: 4) explains that teachers should be actively involved in all aspects of curriculum: ‘setting aims and objectives, choosing content, discovering the best teaching and learning methodologies and implementing the most suitable assessment and examination modes’. Through this process of partnership in all stages, issues unconsidered can emerge.
Teachers and stakeholders expressed varying views on how the use of a VCL would take shape in the classroom, if at all and how a VCL may overcome issues associated with REx. With the expression of concern by teachers and stakeholders alike, that REx might be replaced by a VCL, it would suggest that teachers and stakeholders have strongly held beliefs about the importance of practical work. The rationale behind doing REx was often explained in that ‘hands-on’ is an effective way to learn and it enhances students’ enjoyment of science. Other studies point to the value of REx being justified by teachers based on the enjoyment that students derive from it (Hume & Coll, 2008; SCORE Report, 2010). However, Hodson (1991: 176) argues that practical activities in many schools are ‘ill-conceived, confused and unproductive. For many children, what goes on in the laboratory contributes little to their learning of science’. These studies and the findings of this research serve to highlight that what students are probably mostly taking from practical work is simply physical manipulative skills, where theory either comes before or after the experiment. There is also the attitudinal aspect in that students enjoy doing REx.

Teachers in this study appear to have considered doing practical work on gestalt/schema levels, but no teachers gave evidence of considering this belief in relation to educational theory. Zacharia and Olympiou (2011) raise concerns about the value placed in REx, in that they argue that there is a paucity of research on how touch affects learning and ‘it is remarkable that the emphasis on physical manipulation is so prevalent among educators’ (p. 319). This research study would point to the value of REx in school classrooms in supporting the learning of manipulative skills and students’ enjoyment of school science. There are many issues to be considered about the amount of student thinking occurring in REx, the amount of experiments needed to master manipulative skills and where both REx and VEx fit into the broader picture of students’ learning of science.

From the discussion of the teachers and stakeholders, the use of VCL to support varied teaching methods was highlighted. The VCL could easily be used in a didactic manner to simply show students an experiment with the aid of a data projector. However, it could also be used to give students more ownership of an experiment and to let them investigate on their own through the safety of its infrastructure in a school computer room. There is a discrepancy in how some of the teachers and stakeholders
view the use of VCL to support teaching. This discrepancy serves to highlight that simply giving teachers the VCL to use may not meaningfully change their practice. As noted by Cuban (1986: 58), the tools integrated by teachers over time (chalkboard and books) ‘have been simple, durable, flexible, and responsive to teacher-defined problems in meeting the demands of daily instruction’. This point again serves to highlight the importance for change efforts to consider first and foremost, teachers’ existing schema. Teachers’ schema would first need to appreciate IBSE as a necessary teaching strategy and then would need the exemplification of the VCL being used in an inquiry manner to begin to make changes to their practice.

Secondly, in terms of the VCL as an assessment, many interesting findings emerged. A key issue that surfaced in the interviews in Stage 1 was the role that the current assessment can play on teacher practice. Although the questions were intended to discuss the use of the VCL as an assessment tool, many responses centred on frustrations with the current assessment system. Of significance was the suggestion that the current assessment militates against the use of ICT as grades can be achieved more easily through traditional methods. The ability to achieve grades without ICT can act as a demotivating factor towards using ICT in teacher practice. Cuban, Kirkpatrick and Peck (2001) also echo this in that they suggest that the demands of curricular coverage and assessment may inhibit technology use in classrooms and broader changes in teaching practices. Whether teachers are influenced by assessment in their use of technology relates to teachers’ personal beliefs about curriculum and instructional practice (Niederhauser & Stoddart, 2001). Despite this potential influence of assessment, teachers in this study still used ICT. However, the ways in which teachers used ICT was unclear from Stage 1 beyond the teachers’ own explanations of their practice, which reflected different instructional strategies. These findings point to the importance of considering teacher schema for ICT use in that there are different interpretations across teachers of how they should act with ICT in the classroom. When considering the lack of ICT policy in Irish schools (McGarr, 2009), finding a range of mixed teacher schema on ICT use in Stage 1 is not surprising. This teacher schema may diversify even further with the continuing emergence of ICT affordances and thus, is important for ICT based research projects to consider.
Some interviewees also noted that the current assessment was not modern and thus, was difficult for students to find relevant to their everyday lives. Other interviewees critiqued the current assessment in that it largely involved memorisation, thus it militates against creativity, as it does not assess higher order thinking skills, such as problem solving. Williams and Wong (2009) also raise similar issues as they argue that the use of closed-book examinations goes against real-world problems and is not engaging for students. The responses of the interviewees in this research would strongly suggest the need the current assessment to change, if it is to align more closely to IBSE. Otherwise, students will continue to believe in science as a linear process (Park et al., 2009; Wong and Hodson, 2008), as the questions in the current assessment value product over process.

Ultimately, the clearest message emerging from the interviewees was that there is a uniform desire for the current assessment to change, i.e. a ‘bias for action’ (Fullan, 2007). However, what a new assessment will look like is still unclear to the interviewees, despite varying ideas. The varying ideas expressed by interviewees related to new assessment types, such as a practical exam, interviews, or the VCL. In terms of teachers assessing their own students, two interviewees discussed this, but expressed that many teachers were not willing to do this due to parental pressure. This would suggest a lack of teacher empowerment in their willingness to examine their own students and to stand over the grading of their students. There is also an issue of how involved parents are within the schooling process. However, the wider issue would be that teachers do not draw enough on educational research to support their practice. Hence, it is not a surprise that parents can feel at a level to critique teachers’ practice.

In relation to a practical examination, it was noted by six interviewees as too difficult in terms of logistics and safety precautions. The difficulty of a practical examination would be expected, considering the efforts in preparing for REx, coupled with the teachers’ focus on ensuring student safety throughout an experiment. This is where either interviews or a VCL may have a role to play, in that they remove this teacher focus on safety. As a result, this would encourage students to take more ownership in experiments, as they will need to be able to explain the experiments in an interview, or to apply their knowledge of experiments to a novel problem on the VCL. These
types of assessment (the use of interview or a VCL) would certainly encourage a movement away from the current focus on the recalling of facts. An issue noted by some interviewees was that the use of the VCL as an assessment could be assessing ICT skills, as opposed to chemistry knowledge. This was a pertinent concern to be followed up on in the study of teachers’ practices. Other interviewees noted the potential of the VCL to highlight the thought processes of students in how they carried out experiments and this is something that is missing in the current assessment. Overall, there was quite a difference expressed by the interviewees on how exactly a VCL could be used in assessment. The use of the VCL as an assessment is something that would need further research in determining the VCL’s exact role within assessment.

5.3 Research question 2 (a)

*How does teachers’ knowledge of the teaching of particular content relate to how they adopt a VCL within their classroom practice?*

This research question focused on the various knowledge areas used by teachers in integrating a VCL into their classroom practice when teaching particular content. The CoRe and PaP-eRs (Appendices I & J) highlighted where the teachers’ focus lay in terms of student learning, but in so doing also gave some very useful insights into various knowledge areas of the teachers. The following discussion centres on the different knowledge areas in Figure 4, except knowledge of educational needs as this did not emerge through the interviews. The knowledge areas are discussed in terms of the three teachers who carried out a titration problem on the VCL with 5th year students: Eric, Shane, and Paul.

Firstly, in terms of **content knowledge**, when teachers were asked about what they intended students to learn, they placed significance on the importance of procedural knowledge in doing titrations, with proper preparation and assembling of apparatus. The use of a VCL would not be suitable towards this end. Teachers also noted the importance of definitions and theory. Eric went into more detail than Shane and Paul, noting the importance of students being able to make connections between the content areas, being able to transfer this content knowledge to other areas, and developing
appropriate ability to calculate the amount of material needed to react with a substance. In studying the content knowledge between novice and expert teachers Käpylä et al. (2008) noted expert teachers showed a clearer connection between concepts. However, Eric articulated greater connections than Shane and Paul. This could be coincidental, but could also suggest the presentation of scientific knowledge to students in a fragmented manner. The presentation of knowledge in this manner would be supported based on the current assessment that favours content recall. The VCL could aid in a greater connection of concepts for students in that they could attempt novel problems on the VCL related to their mandatory physical experiments. The problems on the VCL could also be broader so as to require students to draw on and connect various aspects of their chemistry content knowledge. It is important to note that the teachers tended to discuss the content in more subject and general content terms, rather than in a more topic-specific manner, as noted by Lee and Luft (2008) in relation to the use of CoRe. This finding could be attributed to the nature of the topic (titrations) or the nature of the study in that teachers were not asked for the ‘big ideas’ when completing the CoRe, due to the CoRe being carried out individually.

Secondly, in relation to knowledge of curriculum and assessment, all teachers highlighted, in some form, the restriction placed on their teaching by the final examination. This view is then perpetuated by the students, in that they will sacrifice meaningful learning if it does not align with the final examination. The importance of getting exactly right answers restricts the potential to allow students to explore and develop understanding, and would also explain why students would see scientific experimentation as ‘a fairly straightforward business’ (Wong & Hodson, 2008: 126) rather than as a creative endeavour. The issue of assessment raises the bigger issue of teachers’ lack of ‘ownership of the curriculum’ (Trant, 1998). Trant (ibid) explains that the curriculum is a way of empowering teachers. However, the teachers in this study have no say on final examinations, but still must prepare their students for them. This restriction on teachers would thus be an important contributing factor to teachers’ schema in considering any changes to their practice. Another issue, in terms of curriculum and assessment, is that one teacher (Paul) in this case study perceived students’ lack of ability to recall (disconnected) information learned for the purposes of an exam as an issue with the students and not the assessment structure in place.
This teacher perception highlights that the fragmented nature of the final assessment has perpetuated into this teachers’ schema in what he determines as important for students to know. It would suggest that the assessment has not empowered this teacher but shapes their practice. Based on this knowledge of curriculum and assessment expressed by teachers, it would be understandable why certain teachers would not have favourable attitudes towards the use of a VCL, in that it does not fall in line with the current assessment structure.

Thirdly, in relation to knowledge of learners, many important factors came to light, both in the CoRe and the PaP-eR. In terms of the CoRe, Paul felt students were bored with the number of titrations they had to do. This viewpoint conflicts with Shane’s who felt students enjoy doing titrations. Shane felt all students should do titrations. This again raises questions around what exactly students are getting out of practical work, whether they are doing it for the sake of getting to be more “active” or they are actually learning from them, i.e. “hands-on”, rather than “minds-on” (Abrahams & Millar, 2008; SCORE Report, 2010). Gunstone (1991) explains that getting students to develop scientific ideas from practical experiences is a complex process, but is possible if students are given enough time and opportunities for interaction and reflection. This explanation from Gunstone (1991) may suggest the difference between Paul’s and Shane’s views on titrations are based on how they approach REx with their students. From his comments it would appear that Paul views titrations as something to be simply done, as opposed to positive learning opportunities for students, like Shane. Paul’s view would point to an overriding influence of the knowledge of assessment over a consideration of developing students’ attitudes to science.

It was noted by Eric and Shane that students enjoy working out calculations correctly and like when they see connections of the practical work to everyday applications. This would point to why practical work is worth teaching in the eyes of the students and points to the importance of providing ‘metacognitive activities’ (Hofstein & Lunetta, 2004: 32) to students within practical activities, i.e. opportunities to interpret and reflect on their beliefs in light of an inquiry. Students like to be challenged, but this must be appropriately scaffolded (Vygotsky, 1978). The challenge should not stretch too far beyond their habitus. When asked about ascertaining students’
understanding, Eric noted an important knowledge of learners is the significance of feedback. This would make sense in that feedback would allow students to more greatly consider their metacognitive activities. Feedback is an integral part of being a learner and also as a teacher (Hattie, 2003) in instructing on more effective future practice.

In relation to the PaP-eRs, an important knowledge of students that was stressed by teachers was students’ previous knowledge. Some students view chemistry as being hard, they have limited practical work experience from previous years doing science and have difficulties with basic arithmetic. Students’ previous knowledge again relates to the importance of recognising students’ ZPD (Vygotsky, 1978) in constructing classroom activities. Also, a further note on calculations was that students struggle most in understanding how moles relate to dilution and have developed views on formulas as something they merely need to plug figures into. This approach to calculations raises concerns over students’ epistemological framing (Scherr & Hammer, 2009) and this framing can be argued as a result of the culture created by the final assessment, as it favours content recall above the connection of ideas by students. Importantly, such framing by students would impinge on attempts to integrate IBSE. The characteristics of learners highlighted here illustrate important areas where the VCL could be of use, in particular that the VCL encourages students to connect practical work with calculations and the instant feedback nature of the VCL can enhance student learning.

Fourthly, in terms of **knowledge of educational context**, an important consideration is that some teachers avoid practical work with students and this is important for other teachers to be aware of when taking on a new class group, as there can be a large discrepancy between different students’ experience of practical work, depending on the teacher they had previously. As noted in the *Report and Recommendations of the Physical Task Force* (2001), 10% of students report doing no practical work at all. It would be interesting to consider if these students’ grades in the final examinations differed much from students who had completed practical work. Some teachers not completing REx would suggest that the final examination is perceived by some teachers as not rewarding REx and thus that REx is unnecessary. The students’ previous teacher also comes through in terms of students’ understanding of arithmetic.
in that there is a broad range in student understanding, based on their past experiences of mathematics with other teachers. This knowledge would also encourage the use of the VCL by teachers, in that students would at least have a virtual experience of practical work, as opposed to no experience at all.

Fifthly, **resource knowledge** was only touched on directly by Eric in the CoRe. When he was explaining advice he would give to a beginning teacher of the topic, he explained that a teacher should develop their own set of varied material, such as things from the web, things for Moodle, PowerPoint, etc. The development of resources points to the importance of teacher ownership of what they use in their teaching and the VCL could be used here, in that it has an authoring tool to allow problems on it to be modified. Teachers developing their own resources links well to Cuban (1986: 58) who makes the point that the resources that have been integrated by teachers into their classroom practice are the ones that are ‘responsive to teacher-defined problems’. The findings in relation to the VCL are no different in that teachers in Stage 2 have adopted the VCL to where they believe it will more greatly support their practice. This teacher adoption highlights the importance of acknowledging existing teacher schema with any new resource. Over time using the resource however, teachers’ schema may begin to change towards other approaches, provided the resource supports this transition.

In terms of using the VCL in Stage 2, teachers highlighted a lot of knowledge that they had developed and these indeed linked to other knowledge areas, but will be discussed in terms of resource knowledge. Firstly, teachers noted the confidence the VCL gave their students and the time it allowed them in carrying out tasks very quickly. Hence, this gave the students more time to think about the experiments they were doing, as they spent less time on the physical aspects of REx, i.e. increased metacognitive activities (Hofstein & Lunetta, 2004). Again, this is not to demean the importance of REx, but that once manipulative skills are mastered, the setup stages of REx can become cumbersome. Therefore, VEx comes into its own in this regard. Eric noted that the VCL resource allowed him scope with his students outside of a 40 minute lesson, in that students could work on the problems at home to develop their understanding beyond the strictures of school structure. The teacher could then tailor the 40 minute lesson for REx to answer much more focused student questions. This
tailoring of a REx class highlights a unique way of engaging students ‘in ways consistent with their diverse experiences, knowledge, and cognitive preferences’ (Hofstein & Lunetta, 2004: 37). Even Paul, who noted that he would use a talk and chalk method, explained the VCL still allowed another way for students to consider the experiments. The teachers had not initially anticipated these affordances of the VCL, but through using the VCL their schema began to appreciate the enhanced student learning the VCL could support.

Sixthly, in regard to **pedagogical knowledge** there was no explicit mention of pedagogical approaches until the teachers were asked about their teaching methodologies and the reasons for using them. Even then, teachers’ explanations tended to lack a ‘language for sharing their thinking’ (Carter, 1993). Paul stated that he unfortunately had to use a chalk and talk approach, explaining that it was the only way he knew how to teach. This could point to the fatalist nature of teaching (Portelli, 2010), in that Paul feels powerless to teach in other ways and that to do so was beyond his control. This powerlessness could be based on environmental factors of the school, such as principal, parent or student pressures, or may point to a need for professional development. Elmore (1992) notes that the nature of school structure (student grouping, one teacher per group of students, use of standardised tests organised by subject) becomes so engrained that some teachers often do not realise alternative ways of teaching exist and are possible. However, the other two teachers expressed a greater sense of empowerment in their teaching and described varied approaches they used in their teaching that aligned quite well with inquiry-based approaches (Bell *et al.*, 2010). The difference between these three teachers highlights that being an experienced teacher does not ensure that the teacher will ‘know conceptually strong or powerful activities’ (Magnusson *et al.*, 1999; 114). Magnusson (*ibid*) suggest professional development can enhance teachers’ topic-specific strategies. Pedagogical knowledge would have important implications for how teachers would adopt a new technology, such as a VCL.

Finally, some interesting points emerged relating to **PCK** and as noted earlier, these comments tended to be more subject-related PCK and general PCK, rather than topic-specific PCK. This is an interesting result as already argued; the CoRe and PaP-eRs are meant to be more topic-specific. This finding ultimately relates to the nature of
this study with individual teachers, in that they had no other teacher to discuss their ideas with. In terms of the CoRe and PaP-eR, Shane explained that he would do the theory throughout the practical work and after it, but never before it, as he felt it could not possibly make sense to the students yet. Eric had an opposite view, in that he felt it was important to give students a conceptual framework on which they could then hang their experience in the laboratory. The differing viewpoints highlight a clear conflict between the teachers in their subject PCK. This is also interesting in that teachers used the VCL in a similar manner, where Shane used it after doing the physical experiment and Eric used it before doing a physical experiment, as a means to highlight issues around the theory of the experiment. Baxter and Lederman (1999: 158) note that ‘PCK is both an external and internal construct…constituted by what a teacher knows, what a teacher does and the reasons for the teacher’s actions’. The difference between the two teachers in this research highlight the contested space PCK exists within and that how it materialises in the classroom is based on teacher decision making. This highlights the importance of developing an awareness of individual teacher schema, if appropriate support is be provided to teachers.

Another point of interest was the issue of how material is covered in the textbook. Eric highlighted concern that if a teacher was to follow a textbook, it would leave gaps in students’ understanding and that teachers are there to add value and meaning to the textbook, not simply follow it. Paul also noted that the ordering of material in the textbook was inadequate, and some areas had to be covered before others, in order to ensure better student understanding. It is clear that textbooks are a focal point of teachers’ subject and general PCK and this could also be related back to resource knowledge. This finding falls in line with other studies that found that novice teachers, with limited teaching experience, originally place more value in texts and curriculum guidelines, ‘but quickly find their implicit beliefs rising to the forefront of decision making’ (Gess-Newsome, 1999: 81) as experience develops. It then follows that experienced teachers, ‘hold tightly to techniques and methods that have worked well for them in the past’ (ibid: 81) and they critique new materials in light of what has worked before. Factors that influence the adoption of new materials relate to ‘time, subject matter knowledge, orientations [to teaching], and curriculum mandates’ (ibid: 81). This point is interesting in relation to the VCL in that if teachers were to become curriculum makers, problems on the VCL could be structured and tailored by
teachers. This development by teachers would highlight their construction of curriculum and where improvements may be recommended on an individual basis for each teacher.

One final point relating to PCK in the CoRe as expressed by Shane was the importance of teachers to not always be focused on control and let the students experiment. This point was also touched on by Eric. Allowing students to experiment more freely points to a strong PCK, in that the teachers realise the importance of student ownership of their own learning and therefore, have a greater engagement with the content. However, the amount of structure, alongside the difficulty of the learning task and the type of feedback given, ‘vary depending on contextual factors such as the age, ability, gender or cultural background of the students’ (Morine-Dershimer & Kent, 1999: 25). This would suggest the importance of the teacher having a strong knowledge of their learners before supporting greater student learning opportunities. The teachers in this research did highlight some important knowledge of students that affected their PCK. Teachers noted the importance of allowing students to feel comfortable in the physical lab for greater learning to occur. Eric also highlighted the importance of spending time on calculations related to molarity, as many students have basic issues with mathematics and these need to be resolved before the chemistry content can be understood. Shane suggested that getting the students to do the calculations on titrations in a logical manner, as opposed to plugging numbers into a formula, highlighted many students’ lack of understanding. These issues noted by Shane and Eric highlight why a VCL would be favoured by the teachers, in that the VCL could provide greater ownership to students in their experiments through its infrastructure and could allow a deeper understanding of how calculations relate to practical work. Students would also be provided instant feedback from the VCL to further enhance their learning.

Based on the issues raised by the teachers, the infrastructure provided by a VCL could allow a greater development of many of the teacher knowledge areas and a greater inclusion of inquiry elements in classroom activities. For example, the VCL aided teachers in terms of their knowledge of educational context and resource knowledge and in turn, this knowledge allowed them a greater knowledge of their learners. The VCL allowed teachers to move more quickly from a focus on the physical aspects of
practical work (dictated by educational context) to a greater focus on the underlying content in doing practical work (Subject matter content knowledge/Resource knowledge). Hence, students could focus more clearly on the higher-order aspects of the experiments (Knowledge of learners) and in turn, find out more for themselves over the course of the experiments. It could be argued that the use of the VCL, in combination with REx, developed teachers’ PCK in how they can greater aid students in understanding their practical activities. The reasons as to why teachers would choose to use a VCL become clear in the particular knowledge areas they draw on to support its use, in particular knowledge of learners, knowledge of content and knowledge of pedagogy. Likewise, reasons as to why the VCL may not be used were reflected in other knowledge areas, such as knowledge of curriculum and assessment, and knowledge of educational context. The knowledge of assessment relates in particular to the influence of the final assessment.

5.4 Research question 2 (b)

In what ways do teachers integrate an ICT resource into their practice?

This research question sought to explain broader issues in terms of teachers adopting an ICT-based resource into their classroom practice. Based on the literature review and on the findings of this research, a generic model of teacher ICT integration (Figure 9) was developed. The findings and the literature lend themselves to many interpretations, but predominant issues that surfaced in Stages 1 to 4 are the influence of curriculum/assessment on teachers’ practice and difficulties associated with teachers’ perceived efficacy in technology use. A model was desired that acknowledged different teacher stances on technology integration, but that also highlighted significant and important boundaries between these stances.

As noted in the literature, Sorienta and Jimoyiannis (2008) identify three types of teacher stances on ICT integration: traditional teachers, non-traditional teachers and undecided teachers. They also make note of the role assessment plays in classroom activities chosen (Eisner, 2000) and the potential of ICT initiatives to enhance teacher confidence (p.189). Their categorisation of teachers has similar characteristics to the model proposed here. However, the model in this research identifies four types of
teachers in relation to ICT integration into their practice. These teacher types were determined from the teachers in this research, but were also considered in relation to findings in other research literature. Details of how these teacher types were determined will be explained in subsequent sections. The four types of teachers are (i) a Contented Traditionalist, (ii) a Selective Adopter, (iii) an Inadvertent User and (iv) a Creative Adapter. These four types of teachers have also been further positioned in terms of two main teacher conflict areas emerging from the research that affect teachers’ integration of an ICT resource, i.e. empowerment versus fatalism and a learning focus versus an assessment focus. These four types of teachers are not deemed as an exhaustive categorisation of teachers, as the types are open to different interpretation and indeed, alteration. Another researcher may have developed the framework in a different way, but what is presented here is one possible interpretation of the data. It could be argued that teachers display characteristics of more than one type within the framework outlined. However, the findings of this research would support these four teacher types as a useful means for considering teachers’ practice in relation to ICT integration.

Firstly, in relation to empowerment and fatalism, the findings of this study highlight how some teachers see ICT as an opportunity for them to do something new and interesting with their students in terms of how the students learn, while other teachers feel the use of ICT in their classroom may not make any real difference to their students’ learning. This teacher conflict links to Ertmer (1999)’s first-order barriers. Teachers who have a sense of ownership will push to have a greater variety of resources in their classroom and this includes ICT. Secondly, in terms of learning and assessment, the findings would suggest teacher difficulty in attempting effective ICT integration, in light of assessment that favours content recall. This is reinforced by Ertmer (1999) who cites assessment types as an issue in terms of second-order barriers. She also notes student-teacher roles, teaching methods, and management and organisational styles in terms of second-order barriers. These can also be linked to the influential factor of assessment and how it interacts with learning objectives, and thus teacher- versus student-centred classroom activities.

In the Teacher ICT Integration Model (TICTIM) (Figure 9), the two conflict areas are represented as two continuums intersecting. For the purpose of this model and based
on many contemporary assessment types (excessive content recall), assessment focused teachers are viewed as being aligned with teacher-centred approaches, while learning focused teachers are aligned with student-centred approaches. This is to say that if assessment changes to align with more varied learning approaches, the model would expect more teachers to incorporate greater student-centred approaches. The next section proceeds to explain the four teacher categorisations based on the findings in terms of the teachers’ focus, their level of ownership and their PCK.

![Teacher ICT Integration Model (TICTIM)](image)

**5.4.1 Contented Traditionalist (CT) focus, ownership and PCK**

CTs’ focus would be on assessment and they would use limited teaching approaches. The underlying reasons for their focus are extrinsic factors, such as the curriculum, the principal, school management, etc. They lack intrinsic motivation and this relates to their fatalist views on the education system within which they work. They know what they will be most merited on (student examination results) and feel no pressure to move beyond chalk and talk, unless extrinsic factors change. As noted by Ward and Parr (2010: 120), some teachers see no real need to use computers when ‘traditional practices continue to work’ and hence, see ‘no clearly recognised need to change’.
CTs would lack a sense of ownership and empowerment in terms of what their classroom activities can be and hence they would allow their actions to be strongly swayed by the prevailing culture within the school. They would not question the syllabus and would essentially view being a teacher as being a technician. They would generally tend to adhere to the textbook quite strongly and would not look to deviate beyond material outside of the curriculum. Once the curriculum has been covered by these teachers, they would engage in examination drill exercises with their students, which are also based around an authoritative source, e.g. doing past exam papers or using revision based books. These teachers

‘feel the most pressure to show traditional academic success for all students, that is achievement in national qualifications. These are the subject areas where the canon of knowledge, what students are expected to learn, is the most clearly determined and where the match between traditional methodologies and desired outcomes (generally success in national examinations) is likely to be the strongest, lessening the need to either change practice or to use computers.’

(Ward & Parr, 2010: 120)

CTs would be considered to have a low PCK. They may only start to use an ICT tool if it becomes the norm in the culture of the school, but even then, they will try to resist it, citing they do not need it for their practice. Even when use of the ICT occurs, CTs would be unquestioning of the particular effect the ICT is having on students’ learning. They would use ICT only towards an attempt to improve students’ grades and would not think critically as to what elements of the ICT tool lend to a greater understanding for the students. In terms of their teaching methodology, they would be very much of the persuasion that if something is not broken, then why fix it? They would not question the system within which they work and this lack of questioning would lead to a limited scope in opportunities for how the students get to learn.

It is difficult from this research to say which teachers exactly would fall into this group, as CTs would be difficult to engage in ICT-based research. However, from the comments of the various teachers in the initial interviews (Stage 1), it is acknowledged that CT teachers do exist within schools and hence, their inclusion in the framework.
5.4.2 Selective Adopter (SA) focus, ownership and PCK

SAs’ focus would be on assessment with varied methodology use. The underlying reasons for their focus would be both due to extrinsic factors and importantly, intrinsic factors. SAs would have a strong desire for their students to do well and will work hard within the system which they are placed, in order to maximise their students’ success. Unfortunately, the assessment system within which they work would not reward varied types of student learning and thus, would not motivate a teacher to diversify their teaching approaches. SAs would only adopt and continue to use an ICT resource if it helps their students do better in their final assessment. Niederhauser and Stoddart (2001: 27) note that teachers will select particular curricula and instructional methods that fall in line with their already existing pedagogical perspectives and it is these perspectives that have a strong influence on how computers are integrated into the teacher’s practice. In the model proposed, the SAs’ pedagogical perspective would be on the final assessment.

SAs would have a strong sense of ownership and empowerment, in that they strive to be very successful within the system in which they are placed. The ultimate motivating factor for an SA would be that their students get good results in final examinations, even if this involves simply a ‘transmission’ form of teaching. When faced with integrating any new ICT into their practice, they would be happy to take it on, if they feel it will fall in line with their existing perspectives that have rewarded them in the current system. If an SA feels their ownership lessened in any way by adopting a particular ICT, they would most likely stop using it.

SAs’ PCK would be considered high, but only in a narrow sense of student understanding for assessment. Whether students think like scientists would be a completely different issue. SAs would know how to help students learn for the assessment, but would sacrifice students’ understanding. They would aid their students in getting similar grades in ‘high-stakes’ assessment, using chalk and talk methods (including incorporating ICT), to a Creative Adapter using many varied teaching methods. This would be all that matters as far as SAs are concerned.
Based on Stage 2, it would be felt that Mark would be considered an SA. Mark demonstrated teacher-centred approaches within the observations and in the follow-on interview, he noted the VCL for what it was in terms of trial and error, but then suggested changes to the VCL to make it into a lesson that would guide students more. It is felt that if these changes were made to the VCL it would simply become an exercise in which students plugged in figures until they were told they got the right answers and this would not truly represent scientific processes. Hence, this suggestion by Mark to change the VCL serves as another reason as to why Mark would be an SA, in that he will only properly integrate a technology if it falls in line with his current practice. Paul would also be considered as an SA. The observation of his use of the VCL did not highlight this, but in the follow-up interview, he noted that he integrates ICT only to reinforce the didactic method of ‘chalk and talk’ and also expressed his desire to put problems on the VCL that related specifically to the Irish curriculum.

5.4.3 Inadvertent User (IU) focus, ownership and PCK

An Inadvertent User (IU) would not have a particular focus per se, in that they are more of an accidental user of a particular ICT in their classroom. They would not feel particularly competent in using new ICT. The prevailing culture in their school may be encouraging the use of a particular ICT-related resource and they would take up the use of the resource from a sense of external pressure and/or a certain mixture of curiousness, but with hesitation. Using the resource, however, would actually move the teacher towards a more learning focused and student-centred approach, but the teacher would be unaware of the implications of what is occurring in their classroom. Their motivation to use the resource would not be grounded in concrete terms. Hennessy et al. (2005: 185) highlight ‘the dangers of uncritical use’, in that ICT should only be used where it enhances learning over other methods. This is not to say that IUs would be completely uncritical, but that they would be missing a clear focus. Voogt (2010) notes the importance of science teachers having enough time to construct routines into their ICT integration in their practice. This point would link strongly to an IU in that they need time to use ICT in an effective manner.

It is not surprising that IUs would lack ownership in their use of a new resource in their classroom. The most explanatory reason for IUs’ lack of ownership of a new
resource, is that the resource would have either been pushed on them by another teacher or the principal to use, or they would have decided to participate in research, in which case the resource is still pushed on the teacher. Either way, the teacher would not have sought out the innovation. The innovation would have come to them. They would seek a lot of advice from whoever recommended the ICT tool to them. The following quote by Hennessy et al. (2005: 186) highlights important considerations for researchers attempting to bring about ICT integration in schools and relates well to how and why IUs would struggle for ownership:

‘A degree of caution by teachers is inevitable. The widespread use of ICT is a relatively recent phenomenon within education and the top-down approach, which imposes use of ICT in subject teaching and learning, may lead to critical questioning of the value of using ICT instead of a sense of ownership. Work on organizational change shows that, for an innovation to have a significant impact, shared ownership of plans is required—starting by experimenting in small ways and then expanding upon success—while individuals must work out their own meanings (over a realistic time-frame).’

(Hennessy et al., 2005: 186)

IUs would have a low PCK, as they would not critically question and reflect on their own knowledge and would have certain trepidation towards new teaching ideas. When using a new ICT in their practice, it may help them teach better ‘because of the built-in pedagogy steeped into the design of the tool’ (Ferdig, 2006: 756). In most cases, they would rely on feedback from other sources on what they are doing in their classroom. These teachers would have low confidence in their ability. Lee and Luft (2008: 1361) highlight the importance of teachers needing knowledge of resources for teaching science to aid their PCK, as it is resources that can provide teachers with instructional experiences outside of the curriculum.

From the case study, Martina and Susan would be considered as IUs. Martina would not be an IU in the complete sense, as some of her practice was quite teacher-centred, but from her use of the VCL she was beginning to see how it was aiding her in giving the students more ownership of the material, as opposed to Mark who wanted the VCL changed to incorporate other features. However, as noted in the findings in terms of Martina’s students, not all her students desired this sense of ownership, in that some students explained that they wanted to be given the method to do the experiment. This finding from this student focus group highlights the difficulty in changing perceived teacher-student roles in integrating ICT effectively. Susan, as a
beginning teacher, was also an IU, in that she wanted to move beyond an assessment focus, but was unsure how this would take shape.

5.4.4 Creative Adapter (CA) focus, ownership and PCK

Creative Adapters would have a strong focus on student centred approaches that facilitate meaningful learning. They would have no qualms about trying new techniques in their teaching if they think it may lead to greater learning for their students. As noted by Becker (1994: 289), exemplary computer-using teachers were not teachers who simply liked computers, but had ‘significantly more well-rounded educational experiences than the other teachers had had’. These well-rounded educational experiences would underlie CAs’ strong focus on meaningful student learning. This is not to say they would ignore assessment, but that they would be keen on keeping the focus on learning.

CAs would have a strong sense of empowerment in their teaching. They would be very wary of the intended and unintended restraints that curriculum or assessment place on student learning and would very much continuously question what is included on the syllabus. CAs would not see themselves as shackled by the system, but would try to overcome these issues as effectively as they can. A quote from Ward and Parr (2010: 120) sums up the confidence CAs would have:

‘This idea of level of confidence could also explain, at least to some extent, the importance of student-centred activities. Where such activities are being undertaken in the classroom already, not only are teachers more likely to see advantages to using computers and have a greater perceived need to do so, they are also less likely to be concerned about their ability to facilitate student learning in an environment over which they have less perceived control.’

CAs would have a wide-scoping and rich variety of PCK which they would utilize in all their classroom practice. They would be very reflective on their practice and would carefully consider the effect a new resource had on student learning. They would be very critical in terms of the possible teaching approaches they use to aid students in their understanding of content. A comment by Ferdig (2006: 756) suggests the ease at which a CAs’ PCK could aid them in adapting a new technology:

‘There are other times when a knowledgeable person can take a technology and make it pedagogically sound ‘on the fly’.’
In relation to the case study, Shane and Eric would be considered CAs. They kept a focus on the examinations, but their ultimate focus was to aid meaningful learning for each student. They adapted the VCL quite readily and noted the particular advantages and limitations it had in terms of enhancing their students’ learning experience. Their degree of comfort with the VCL and insight into how it would enhance student learning pointed to a strong PCK.

**5.5 Research question 2 (c)**

In what ways does the teachers’ use of the VCL support or hinder inquiry-based approaches?

This research question sought to find evidence relating to the VCL to either support or hinder inquiry. In answering this question, findings from Stage 2 and Stage 3 are utilised. For Stage 2, teachers adopted the VCL in a manner that suited their current practice, whether that was an inquiry approach or a more traditional approach. Some of the teachers removed all elements of inquiry from the VCL by telling the students exactly what the problem was and how to solve it. The lesson became a simple exercise for the students in verifying what the teacher had told them to do. This fell in line with approaches to REx as a recipe style task (Clackson & Wright, 1992) and teachers’ strong focus on knowledge goals in terms of learning the products of science (Gyllenpalm et al., 2010). However, other teachers told the students they would be given a problem and they had to figure out for themselves how to solve it. Students were left to work on the VCL and to see if they could get any answers. This approach to the use of the VCL put a much greater focus on features of inquiry normally poorly represented in schools: explaining, connecting, and justifying results (Asay & Orgill, 2010). The findings from this study would suggest that the VCL could support IBSE, but the ability of the VCL to do this was either supported or hindered by the teacher.

For Stage 3, teachers were directed to use the VCL in a guided inquiry manner. The results of Stage 2 had shown that the VCL had the potential to support student inquiry, but that this support was not utilised by all teachers. In requiring teachers to teach through inquiry it was hoped to bring to light teacher schemas that caused difficulties in using this approach, in particular teachers who may not use IBSE in
their regular teaching. The author was cautious to ensure that teachers did teach the lesson as asked and did not revert to their preferred style of teaching by removing all elements of IBSE in the lesson (Hewson, 2007). Based on the findings of Stages 2 and 3 and Abrams et al. (2007)’s levels of inquiry, a spectrum of inquiry-based learning is presented (Figure 10). It is important to note that this spectrum is open to interpretation and also, alteration. Another researcher may have developed a different framework based on the data, but the following is the author’s interpretation. The various types of inquiry: verification, structured, guided and open are not presented as levels but as a spectrum. This presentation of the the types of inquiry as a spectrum relates to Settlage (2007)’s point that open inquiry is not the ideal way to teach science but the optimal level of inquiry varies depending on the context and the demands of the material. The types of inquiry are presented in relation to appeasing surface learning and assisting deep learning. Appeasing here is meant in relation to teachers simply giving the students the answer to their questions, without challenging the students to consider solutions on their own, i.e. presenting science knowledge as a product to be learned (Gyllenpalm et al., 2010). If a teacher solely focuses on verification type inquiry, then the learning process dictates that students simply passively conform to what is asked of them. This conformity would be viewed as appeasing surface learning. On the opposite end of the spectrum, if a teacher moves to other types of inquiry, such as structured, guided and open, then students are being assisted to become creatively engaged in the learning process, i.e. promoting varied features of IBSE such as explaining, communicating, connecting, questioning, analysing and producing evidence (Asay & Orgill, 2010). This creative engagement would be viewed as assisting deep learning. It is important to re-iterate that the type of inquiry used by teachers depends on various factors, but teachers should be aware of the implications of these factors for student learning.

![Figure 10 - A Spectrum of inquiry-based learning: From surface to deep learning](image-url)
The use of the VCL in Stage 3 in a guided inquiry manner brings many important considerations to light that will now be discussed, in terms of teachers’ practice, student learning experience, the affordances of a VCL for teaching and learning and also the utility of the ISIS to give insight into teacher decision making. Firstly, in relation to teachers’ practice, many issues came to light that mirror many findings in the current research literature. Abrahams and Miller (2008) note that REx invariably involves students simply producing the phenomenon, and not matching the physical skills developed with conceptual development. All of the teachers in this case study, apart from Eric, see the area of analysing the findings of an experiment as an afterthought. It is not that they do not think it is important, but in light of an assessment focus it becomes a secondary activity, only to be done if there is time at the ‘end of class’. This resonates with Hume and Coll (2008) who noted teachers’ practice is dictated by a strong focus on the final assessment. Also, based on the ISIS, teachers’ practice relating to REx is strongly guided by a focus on student safety.

In relation to Susan’s practice, two issues emerge (learning as a cookbook approach and teaching as appeasement or assistance) that give a glimpse into the deeply hidden beliefs and values that influence teachers’ practice and highlight the difficulties associated with implementing a guided inquiry-based approach. Wilson et al. (2010) argue that the issue of student frustration with inquiry approaches, noted by Kirschner et al. (2006), relates to a Level 3 ‘open’ inquiry approach. However, this case study would also highlight frustration associated with Level 2 ‘guided’ inquiry approach. This frustration may also highlight that any form of IBSE will meet considerable resistance if traditional practices are deeply embedded, i.e. habitus. Varying levels of frustration were expressed by students and frustration was also noted by the teacher in attempting an inquiry-based approach. Abrams et al. (2007) explain the need for prior experience of inquiries and certain skills for open inquiry and this case study would also highlight these as issues for a guided inquiry approach. The findings indicate a lack of student and teacher experience with this approach and this lack of experience could be used to explain their frustration. It could also be argued that whatever about the details of the inquiry process, the role of teacher decision-making is vital. Until the teacher is comfortable (and indeed students) with the majority of responsibility being in the students’ hands, he/she is unlikely to move towards more
ambitious IBSE approaches. Change needs to start with where students and teachers are at in relation to the ownership of classroom decision-making.

The VCL can play a useful role here in that it can act as a scaffold to both students and teachers in their movement towards more IBSE. IBSE for many students and teachers are vastly dissimilar from their current experience and thus time is needed to develop their zones of proximal development and *habitus* in order to move beyond this. The VCL can aid this development of teachers through having problems that teachers and students are familiar with, but that require more ownership and decision-making from students in completing them. With greater exposure to such problems on the VCL, teachers can more adequately develop appropriate schema to facilitate student inquiry.

Secondly, how teachers carry out practical work leads to important implications for student learning. Some students found the use of their teacher’s approach quite alien, with the exception of Mark’s students, as he taught the lesson closer to verification type inquiry, as opposed to the intended guided inquiry approach. As noted by Eric, students have had a ‘lack of practice’ with such an approach. Wong and Hodson (2008) highlight the importance of teaching science in a way that it is feasible and acceptable to have different solutions. However, with teachers spending more time on students simply producing phenomena (Abrahams & Millar, 2008), divergent modes of thinking are not encouraged. This lack of divergent thinking feeds into the learning environment in the classroom in that students are more concerned with what other groups are getting than first and foremost being able to stand over their own results.

The case study of Susan highlights the enculturation of the students into a passive form of learning where science is presented as a *fait accompli*. Within this context, there is a strong dependence on the teacher and despite the potential of inquiry approaches to allow ‘new roles and responsibilities’ (van der Valk & de Jong, 2009), as opposed to traditional approaches, the students are not excited by the prospect. It must be also noted that the school in question was quite a middle class school attracting female students from affluent families. Within this environment, educational success, as measured by performance in state examinations, is given a very high level of priority. This expectation and demand for success may have played
a role in the frustration experienced by both students and the teacher and may also help to explain the appeasement of the students by the teacher. Formal state examinations, which tend to grade student performance and determine entry to university courses, have long been criticised within the Irish context, but remain dominant within the Irish education system. The case study of Susan shows that its influence has deep rooted effects within the classroom in relation to teacher schema that stifle IBSE. If technologies or initiatives are to change teacher schema towards greater IBSE, the system needs to change alongside these technologies in that it would necessitate such characteristics to be displayed by students, e.g. demonstrating understanding in REx.

The long-term impact of this representation of science can be detrimental. From responses in the SSA by Shane’s and Susan’s students, it is evident that this environment has created a misconception in students of what science is. These students showed little appreciation of the ‘grey’ area of science where knowledge floats within the contested space of inquiry and debate. The demand for the ‘right’ answer highlights the distorted representation of science in Irish schools and the widening gap between the ‘real’ world of science and the contrived experiences presented to students as science. Yet how can contested knowledge find a home within a system that prioritises facts and figures and where concepts and ideas are distilled to unquestioned definitions?

The role of the teacher is critical in this context, indeed any classroom context (Fullan, 2007), since the teacher is ultimately responsible for challenging the students’ perceptions of science. Students can be challenged through an inquiry approach, but teachers must also face the challenge of dealing with the potential backlash from students seeking the ‘right’ answer and from the challenge of teaching in the contested space. The strong inertia of the prevailing culture of appeasement should not be underestimated however, as this reaches beyond the walls of the science laboratory and is a reflection of a much broader systemic issue. Initial and continuing teacher education is critical in this context since, as this study highlights, the introduction of potentially powerful enabling technologies can have limited effect with such settings. Indeed, their introduction can be counterproductive as their role
can be modified to cater for the existing needs of the ‘system’, rather than facilitate alternative practices (Cuban, 1986; Hewson, 2007).

Thirdly, the VCL demonstrated many ways in which the issues of teacher and student practice above could be overcome. As noted by Shane, the VCL allows a movement away from procedure to more problem solving and this is aided through it being student-centred. The VCL causes students to engage in experimental design and this is not something they are used to. This engagement in experimental design serves to present a more authentic picture of science to students in that scientists are not always given a procedure and must decide an approach to a problem, continuously monitoring and modifying the approach as necessary (Park et al., 2009; Wong & Hodson, 2008). This involvement in experimental design in turn makes it not just feasible and acceptable to have different solutions, as noted by Wallace and Kang (2004), but also feasible and acceptable for students to have different approaches to the same problem. Once students decide an appropriate approach, they can then get to the findings stage of an experiment much more quickly through the infrastructure of the VCL, as issues of physicality and resources are removed. Hence, teachers would be afforded more time to discuss and critique the findings with their students. An important point relating to the student-centred nature of the VCL is that it caters very effectively for mixed ability students. Students can test many questions they have within the VCL and hence, progress at ‘their own pace’. Through greater exposure to the VCL students can be scaffolded to move away from previous practices of simply following instructions to greater decisions around what the instructions should be. Of course, as noted by Shane, a drawback of the VCL is that despite its advantages it is still not real.

Finally, the use of the ISIS gave some interesting findings, but it would be important to use them in combination with other research methods to get an accurate picture. Interestingly, on the ISIS specific to the lesson when teaching with the VCL, all four teachers marked Item 9 as ‘never’ (check students’ designs for safety). Items 10 to 12 and 18 (monitor small group progress, encourage students to collaborate, circulate and interact with students, and question students as they conduct experiments) on the Lesson ISIS had responses of ‘always’ by Shane and Mark and varied responses by Eric (mostly ‘always’) and Susan of ‘sometimes’, ‘often’ and ‘always’. This would
highlight the VCL facilitates a shift away from a focus on safety, but still encourages the other items (10-12 and 18) while students conduct experiments. The Lesson ISIS reinforced this idea that very little time, if any, is given to the discussion of findings during the course of an experiment in a lesson (Asay & Orgill, 2010) and is something that may be done in a following lesson. Items 13, 14, and 16 (discuss variations in data collected, have students share predictions, and challenge students to consider effects of errors) were marked ‘never’ by all four teachers. Item 15 (have students share findings with the class) was marked ‘never’ by three teachers except Shane who said ‘sometimes’. He referred this to the fact that students were comparing findings with each other. This comparing of findings was not a result of Shane’s instructions. For Item 17 (compare and contrast students’ explanations of findings), Eric and Shane said ‘never’, while Mark said ‘always’, and Susan said ‘rarely’. Both Mark and Susan explained this in relation to comparing and contrasting findings with individual groups of students. The difference with which Mark and Susan did this highlights varying perceptions of the two teachers in how much they felt they did this through the course of the lesson.

The ‘talk aloud’ approach used in this study with the ISIS gave interesting insight into teacher decision making around their practice when doing experiments. This metacognitive activity raised awareness of schema for both the teachers and the researcher. Some teachers may not have given much consideration to some of the statements on the ISIS or all the statements on the ISIS as a whole, in terms of their classroom practice. This raising of awareness by teachers was informative to the researcher in how teachers considered certain elements of their practice and their overall practice. Teachers scored relatively well on the RTOP as the lesson was specifically designed in an inquiry manner and was supported strongly through the use of the VCL. The teachers noted themselves the utility of the VCL to support inquiry, but it is clear from the findings that the culture of classrooms needs to be addressed to sustain this practice.

5.6 Research question 2 (d)

What are teachers’ and students’ reflections on the use of the VCL as a potential teaching, learning, and assessment tool?
After having taught a lesson using the VCL, teachers and students had many ideas relating to the use of it as a teaching, learning, and assessment tool. Discussion of this question centres on Stages 2 and 3 of the research. All teachers agreed that the VCL had particular affordances (Webb, 2005) towards teaching and learning, but opinion was divided in relation to it being used as an assessment tool. Students, however, expressed mostly positive views towards the use of the VCL as an assessment, but a few students had particular hesitations.

Firstly, in terms of teaching and learning, it was noted that the VCL provides a safe and open environment in which students have the opportunity to ask many questions at their level that they can answer quite readily within the VCL receiving instant feedback. As noted by Morine-Dershimer and Kent (1999: 25), students learn more when they are assigned tasks at ‘appropriate levels of difficulty, and when they are provided with adequate feedback on their task performance’. This affordance lends to the student design of investigations, as they can attempt problems at their level of understanding and see immediately from the VCL if their strategies are working. Unfortunately, in REx students may not have the confidence in their manipulative skills, enough time to answer these questions or may need assistance from the teacher before progressing. There are also issues in relation to the teacher, such as having enough resources and appropriate facilities, safety, teacher inexperience, time, etc. (SCORE Report, 2010). In many cases the teacher spends a large portion of REx attending to these issues. However, the VCL removes and reduces the impact of some of these issues and thus allows the teacher more time to observe the students as they go about their VEx.

Teachers can observe what the students are doing on screen and focus on students’ thought processes as the students discuss the problems amongst themselves and decide an appropriate approach. This resonates with Dolan and O’Grady (2010: 50) who highlight the importance of teachers identifying students ‘doing’ versus reasoning. When the teacher is actually called on by students during VEx, the questions tend be higher-order in nature, attempting to understand why certain things are happening. This enhancement of student questioning is important in terms of a teacher’s role in that the dynamic of the classroom changes. The teacher is afforded
greater flexibility in their gestalt (reaction at the spur of the moment) (Korthagen, 2010) as they have more time to consider students’ questions in VEx instead of having to maintain a balancing act of answering a question while having to observe other students for safety concerns. Of course, higher-order questions can occur in REx, but teachers noted that the VCL facilitated a quicker progression to these questions due to the removal of the ‘hands-on’ aspects of doing REx and as a result, a greater frequency of higher-order questions would occur within a class period using the VCL. It is important to re-iterate that this is not to dismiss the importance of the ‘hands-on’ manipulative aspects of REx. However, it does highlight a need for teachers to more carefully consider the intended learning from carrying out practical activities and how they are structured and monitored for IBSE (Abrahams & Millar, 2008; Dolan & O’Grady, 2010; Windschitl, 2004).

Overall, the students enjoyed using the VCL within classroom practice and also at home. However, students were clear that they would not want practical work replaced. This comment highlights the satisfaction students derive from doing practical work and that it is an important factor in why students continue to study science in school (Regan & Childs, 2003; SCORE Report, 2010). Students were favourable towards the VCL, but some students did not respond well to the VCL being used in an inquiry manner in Stage 3. This frustration from these students was based on the inquiry approach as it is not something the students were used to, or indeed some of the teachers either. This explains student frustration in IBSE (Brown & Campione, 1994; Kirschner et al., 2006). This lack of experience of inquiry raises important questions about how students are being taught science in our schools, as was discussed in a previous section.

Teachers can enhance their teaching methods for practical work as well as other areas through the use of a VCL. REx can be a very important part of students’ learning and enjoyment of science. However, the physicality of REx can unfortunately often be counterproductive to intended teacher objectives due to the amount of time needed for setup, clean up and focus on safety during the practical work (Hofstein & Lunetta, 2004). When considering the organisational aspects of REx, beside the fact that teachers only see some students for 40 minute periods, teachers have little time to engage students beyond ‘recipe’ approaches (Clackson & Wright, 1992) to more
‘minds-on’ or ‘brains-on’ approaches (Helms-Silver et al., 2007; SCORE Report, 2010). The VCL affords teachers a concrete example of inquiry through which they can begin to reflect on their practice and encompass this approach beyond the scope of the VCL into other areas of their teaching.

Students expressed other ideas in relation to how they would like to use the VCL and have the teacher use the VCL. Some students explained the value of using the VCL before an experiment, in order to know what to do in a real experiment, while others noted the VCL would be useful as a follow-up exercise after doing a real experiment. Some students noted they would like to use the VCL both as a pre- and post-experiment exercise. These comments on use of the VCL as a pre- and post-exercise to an experiment again reinforces the importance of metacognitive activities (Hofstein & Lunetta, 2004) for students in that they want time both to consider the underlying ideas behind an experiment and to re-consider the ideas in light of completing the experiment. Within classroom time, the students have mixed views about the use of the VCL so it would highlight difficulties a teacher may have in catering the VCL to students’ desired approaches in class. Also, some students noted that they think a VCL should not even be used in school, but completely as a homework/revision tool. The reasoning behind this was that during class time as much REx as possible should be done as it is the only time students get a chance to do ‘hands-on’ practical work. These students noted that the VCL can be used any time by the students so why not outside school hours. This is a valuable point considering the limited time teachers get to see students, where oftentimes teachers’ preoccupation with technical details ‘seriously limits the time they can devote to meaningful, conceptually driven inquiry’ (Hofstein & Lunetta, 2004). How teachers would scaffold this approach between REx and VEx would need to be explored.

These changes in student-teacher roles have many important implications. Many instructional approaches for teachers ‘lack a clear definition of the teacher’s role in computer-supported instruction’ (Urnhane et al., 2010) and the five practising Chemistry teachers in Stage 2 did suggest they were figuring things out through trial and error and never received any feedback on their approaches. This became clear in that some teachers did not see the potential of the VCL to give them immediate and dynamic insights into student decision-making and misconceptions; rather they used
the VCL to enhance existing practice. However, certain teachers having used the VCL began to reflect on new roles emerging within their practice. The VCL has the potential to significantly change the role of the teacher as the VCL acts as a ‘scaffold’ within their zone of proximal development (Vygotsky, 1978). The VCL provides an example of how an ICT-based innovation challenges teachers in terms of their roles within a classroom and in turn, leads teachers to a questioning of their perceived pedagogical skills. Morine-Dershimer & Kent (1999: 27) explain that a critical aspect of teacher pedagogical knowledge is the possible alternatives of instruction and their appropriate uses, even in the light of apparent constraints relating to the organisational structure of schools. The re-orientation provided by the VCL exposed substantial gaps in some of the teachers’ pedagogical knowledge.

Teachers could use the VCL in a multitude of ways depending on what they felt was most appropriate for their students and what the demands of the material were. The desire expressed by teachers to design their own problems on the VCL indicated the personalized nature that an appropriately designed VCL could afford teachers and this would encourage teachers as curriculum-makers (Fullan, 2007; Trant, 1998). However, Cuban (1986: 65) notes that the changes teachers have embraced relating to technology ‘have solved problems that teachers identified as important, not necessarily ones defined by nonteachers’. This teacher use of technology again points to the importance of first understanding teacher schema if new innovations are to change practice in a desired direction. The online nature in the development of teacher problems on the VCL would afford the NCCA with concrete examples of teacher interpretations and modifications of curriculum materials. This would aid in a greater alignment between differing stakeholders in how the curriculum takes shape in the classroom (Penuel, 2009).

The findings would suggest a need for a re-conceptualization of the role of the teacher in teaching and learning (Postholm, 2006; van der Valk & de Jong, 2009) as the VCL can potentially reinforce traditional models if teachers do not have the scope to explore the full affordances offered by the VCL. Changes will need to be made at a higher-level by policy-making stakeholders to support teacher ICT integration. Interestingly, after having used the VCL, some teachers reflected on different elements of their practice beyond the scope of the VCL, namely REx. This reflection
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indicates the capacity of the VCL to be a catalyst for teacher professional development outside of the sphere of the technology. Through further reflection, the VCL could potentially have broader effects on the teacher in terms of implications for non-ICT practice also. Dexter et al. (1999: 1) note that progressive teachers do not acknowledge computers as a catalyst for changes in their practice but noted factors such as ‘reflection upon experience, classes taken, and the context or culture of the school’. The findings of this research would indicate the VCL as an important stepping stone to impacting teacher reflection and also shifting the culture of school science.

Finally, in terms of assessment, most of the teachers liked the idea of a VCL within a new varied assessment structure. However, they did note the current system as a barrier that they felt would be extremely difficult to overcome. This conception can point to an actual need for the current assessment to change to more greatly support other teaching approaches (Towards Learning Report, NCCA, 2009), but can also point to the fatalist nature (Portelli, 2010) that emerges within the teaching profession in that teachers feel they cannot do anything about the system they are placed within. It reinforces the importance of having teachers who can continuously think outside the box of high-stakes examinations. Constructivist teaching methods are still possible even in light of accountability (Blanchard et al., 2010). This teacher perception highlights that the ‘high-stakes’ examinations have the capacity to enforce certain teacher competencies. Unless these competencies are challenged, teachers are unlikely to change with a new assessment. Even when presented with new curriculum, experienced teachers have been shown to retain topics from previously-taught classes (Lantz & Katz, 1987) and new assessments may involve ‘risky upheavals in classroom practices, and in relationships with colleagues, principals and parents’ (Smith, 1999: 190) that teachers are not sufficiently prepared for. This again raises the importance of teachers developing their PCK to challenge the ‘sociocultural milieu’ (ibid).

In terms of assessment, many students expressed interest in having the VCL as part of or as an option within their final examination. However, other students expressed concern over the use of the VCL as an assessment and how reliable it would be in terms of ensuring no cheating. These comments would suggest that each student has
a preferred learning style and hence, would prefer to be assessed in certain ways. The VCL is only one tool by which students could be assessed, but should not be the only way. However, the current Irish chemistry examination only assesses students through a written examination. It becomes clear that a one size fits all system does not cater to all students and more varied assessment should be encouraged.

5.7 Summary of the research questions

The research questions have addressed important issues around the use of the VCL, highlighting how the VCL may make science education more authentic, lead to greater student engagement and develop students’ conceptions of science. As can be seen from the findings, it can do this through providing a mediating role between teachers and stakeholders and allow for important changes to occur within the classroom dynamic towards inquiry. A tentative conceptual framework in the form of a Venn diagram is presented (Figure 11) to highlight the interplay between enabling and limiting factors emerging from this project. The conceptual framework goes some way to explain how the mediating influence of a VCL between enabling and limiting factors may offer a potential solution to the issues highlighted. At the centre of the diagram is assessment. This positioning of assessment relates to the multifaceted nature of assessment within this project, i.e. in the diagram assessment can be interpreted in at least four different ways:

1. as a problem in making science education more authentic (Top of Figure 11),
2. as an enabling factor to support stakeholder change (Left of Figure 11),
3. as a limiting factor in the classroom roles it can create (Right of Figure 11),
4. and as a potential solution if emphasising greater student decision-making (Bottom of Figure 11).

Other interpretations of assessment are possible, but for this research these interpretations apply most. Factors related to alignment, ownership, reliability can also be interpreted within the four ways noted above. Figure 11 will now be explained in more detail.
Firstly, in terms of enabling factors (left-hand side of Figure 11) the VCL can offer many affordances. The infrastructure of the VCL allows both teachers and stakeholders to design problems in a shared and visible manner. Teachers can thus begin to see what inquiry problems look like and have the time to practice such problems within the VCL with reduced concerns of cost, resources and time. The use of the VCL would begin to influence teacher schema in the direction of IBSE and greater IBSE would fall in line with what is being espoused by current stakeholders at policy and research level (Hmelo-Silver et al., 2007; Rocard et al., 2007). Secondly, following on from enabling factors, the VCL can address many limiting factors towards inquiry approaches (right-hand side of Figure 11). Teachers will have time
to challenge their schema through using the VCL and begin to move towards more IBSE. However, professional development would be needed for teachers in terms of using a new ICT resource and exemplification of new roles within the classroom in using inquiry-based approaches (Urhahne et al., 2010; van der Valk & de Jong, 2009). As the findings of this study highlight and findings from other research (Rushton et al., 2011; Smithenry, 2010), many teachers have limited experience of inquiry-based approaches, if any at all. As a result, these teachers do not have the skills to utilise the value of the VCL. Maybe through having more time with the VCL, the teachers would begin to see the value of IBSE and make it more part of their schema and thus common practice. However, as noted, there are major cultural issues and misconceptions of science that need to be tackled in order for the VCL to be used in a more inquiry manner (Crawford, 2007; Windschitl, 2004). This is not just applicable to teachers, but is a systemic issue. Teachers feel a demand to be the suppliers of information by their students (and oftentimes by parents also), and unless they challenge this expectation, their practice will continue to be traditional in nature. Dealing with this demand again points to the importance of professional development related to teachers constructing PCK, in order for teachers to aid parents and principals to ‘learn about what understanding in science entails’ (Smith, 1999: 190).

Thirdly, an important crossover between enabling factors, limiting factors and central issues is that of assessment (centre of Figure 11). As is clear from the literature and findings of this research, assessment can encourage various teacher practices. The VCL could be used as an assessment tool and thus allow for more varied assessment arrangements in the current Irish examination system. The VCL again provides a platform through which teachers and stakeholders could communicate their ideas. Despite this potential of the VCL and the desire of many teachers and stakeholders for assessment to change, there is a bigger issue of stagnancy in the assessment structure. Science as black and white is much easier to correct than science as a cloudy area of argument, debate and challenging ideas. As the teacher Eric commented on the Irish examination system, we value what we can measure instead of measuring what we value.
5.8 Discussion of research tools

The main research tools used in this research related to Pedagogical Content Knowledge (PCK) and inquiry. Research tools relating to each area will now be discussed in relation to their utility within this research and how they may be used in future research.

5.8.1 Pedagogical content knowledge research tools

PCK certainly has a great deal of use and hence, it is no surprise that it is viewed by some as an established construct within science education. Abell (2008) highlighted that the usefulness of PCK will lie in its ability to answer the big questions of science teacher education: Why do teachers teach the way they were taught, even after teacher preparation programmes focused on reform-minded instruction? Why do teachers not always learn from experience? Why is the landscape of science teaching and learning so difficult to change? In attempting to answer these ‘big’ questions ‘finding, capturing and elucidating PCK may well represent what some might describe as the holy grail of teacher development!’ (Rollnick et al., 2008). Despite this perceived difficulty, the current use of PCK in this search is encouraging and thus its future use worth reflecting on.

Firstly, Grossman (1990) listed four ways by which teachers’ PCK could be developed: Disciplinary education, observation of classes, classroom teaching experiences and specific courses. Teacher learning communities as a means to improving teachers’ PCK are not made explicit by Grossman and it should be included based on other research (van der Valk & Broekman, 1999). van der Valk and Broekman (ibid) found teachers promoted the development of their PCK when talking to the interviewer about their lesson. This promotion of PCK can be connected with knowledge of resources (Lee & Luft, 2008) as teacher learning communities can provide an outlet to the sharing of this knowledge and other knowledge of expert teachers (Sanders et al., 1993). This in turn would develop PCK further as gathering resources is useful to increased effectiveness and fluency in the re-teaching of specific topics (Clermont et al., 1994). The author feels this would impact significantly on how ICT innovations are adopted within schools.
Secondly, another area of interest that has not been considered directly in the PCK literature, in terms of teachers’ knowledge of students, is the effect of peer-learning among students and what role ICT plays within this. Student-teachers already bring a certain level of classroom experience with them from their time as students (Clermont et al., 1994). PCK could not just illuminate how resources used by teachers make the subject matter content comprehensible for students, but how students in turn communicate the content to each other, especially with the added dimension of ICT resources. An important area within student communication would be that of group work as students trained in peer interaction show ‘greater active learning, depth in understanding as well as independent thinking and responsibility in one’s own learning.’ (Baines, Blatchford, & Kutnick, 2003: 30). This articulation of student approaches to learning could shed light on important questions at the core of student thinking skills and add greatly to teachers’ professional development: How do students use their teachers’ explanations to explain concepts to others? How can students be taught to constructively critique their teacher’s explanation and those of classmates? Will this critique of their teacher’s and peers’ explanations lead to greater conceptions/more meaningful thinking from students? How will teachers’ planning change as a result? A study in this area of peer teaching and learning, in light of a focus on students’ PCK, could produce key considerations for teachers’ practice.

Thirdly, having made PCK explicit in teacher training programmes, explicit teacher practice would open the door to deeper changes. Teachers would have the use of CoRes to further their planning, teaching and reflecting (Sanders et al., 1993; Nilsson, 2008). Through a development of teacher learning communities, PCK would be further expanded (Wilson, 2008) and this expansion could potentially lead to an almost ‘theoretical saturation of CoRes’ (O’Reilly, 05-03-2009, personal communication) on varying Science topics. A theoretical saturation of CoRes would lead teachers to a greater awareness of the resources available for teaching and how these resources can be used most effectively in the classroom. This CoRe saturation could in turn lead to further development of teacher training programmes as teachers could even rehearse to teach (Inoue, 2009). The use of rehearsal is not to say that teaching would become a simple process leading to a particular product, as has been warned against (Lederman,
Gess-Newsome, & Latz, 1994), but would give beginning teachers greater insights into students’ conceptions and difficulties in learning these topics (ibid).

Finally, another knowledge that is implicit within PCK that needs to be made explicit is that of knowledge of self (Santoro, 2009). This knowledge area would underpin all the previously discussed knowledge areas, but is oftentimes overlooked. Mortimer’s Conceptual Profile as used by Padilla et al. (2008) has touched on this area slightly, but only in terms of a teacher’s scientific reasoning. This knowledge connects well with McCaughtry (2005: 380/381) who sought to elaborate PCK by stressing the overlooking and underrepresentation of ‘how teachers’ emotional and social knowledge of their students interacts with more disciplinary-based thinking and teaching’. A greater knowledge of self would help teachers communicate why they teach the way they do and would be the first steps to giving some explicit form to tacit teacher knowledge.

5.8.2 Inquiry research tools

The two research tools used relating to inquiry were the Inquiry Science Implementation Scale (ISIS) and the Reformed Teaching Observation Protocol (RTOP). Firstly, the ISIS served as a very useful tool in understanding teachers’ practice in this study when coupled with a ‘talk-aloud’ approach. The use of the ‘talk-aloud’ approach highlighted varying teacher interpretations of what each statement on the ISIS was referring to. Teachers, for the most part, interpreted the statements as intended, but the ‘talk-aloud’ approach gave a greater richness to each statement in that some of the underlying reasons for teachers’ practices emerged. However, the boxes ticked on the ISIS alone provided insight. Eric would have been considered as a teacher who used inquiry most based on Stage 2 of the research and his responses to the Pre- and Final-ISIS showed the most consistency. Shane, who also would have shown elements of inquiry in Stage 2, had good consistency between the ISIS completed. Interestingly, Mark, who would have had a similar amount of teaching experience as Eric and Shane, showed many inconsistencies between the Pre- and Final-ISIS and from Stage 2 he would have been considered more didactic in his teaching. Finally, Susan had a lot of inconsistency between her Pre- and Final-ISIS. This inconsistency
links well to the fact that she was a beginning teacher. Another utility of the ISIS was to highlight the phases of experiments that teachers concentrate most on. The use of the ISIS in a Pre- and Post manner has been a very useful exercise within this research. Also, the ISIS specific to the lesson taught with the VCL provided a useful interpretation of the lesson by the teachers.

Secondly, the RTOP served as a useful lens through which to observe elements of teachers’ practice in using the VCL. Certain statements, in particular, led to more important considerations in terms of teachers’ practices when attempting to teach through inquiry. In particular, statements 7 and 17 relating to coherent student conceptual understanding and the encouragement of divergent modes of thinking are two particular areas that the use of the VCL in an inquiry manner shed significant light on. As with any Likert scale, determining where teachers fall between the gradings can be difficult. However, statement 7, in particular, on the RTOP is difficult to assess based on observing one lesson or through observation alone. The other statements on the RTOP were relatively straightforward and easy to determine on observation alone. The RTOP is a worthwhile research tool for observations.

5.9 Discussion of overall methodological approach

The novelty of the VCL within the Irish education system allowed for many potential avenues of research to be pursued and some of these will be discussed in the following chapter in relation to potential future work. This discussion section will focus on the overall methodological approach for this study and important issues that shaped the research design. Before carrying out any research, the author carried out a detailed literature review of issues related to technology use by teachers and the differing factors underpinning this. This review led to broader issues around educational change and the role of external factors in teachers’ use of technology with their students. An important issue that emerged from this literature review was the need to encompass as many stakeholders as possible in the research process for meaningful change to occur (Fullan, 2007).

It was felt that an effective way to incorporate stakeholders early on in the project was through interviews and thus, interviews became the basis for Stage 1 of the research
design. Also, these interviews were important so as to have a starting point on which the rest of the project could take shape and to have the views of those who would play an important role on any impact the VCL may have. An interview topic guide was developed based on salient issues that emerged from the research literature and this guide also had questions related to views on the use of the VCL in schools. The teachers within the interview sample were recommended by the SLSS and these teachers were described as open-minded to the use of ICT and had attitudes that represented a range of enthusiasm towards ICT use in schools. These teacher attitudes were important in receiving feedback from the teachers on the potential use of the VCL in their classroom practice and possible issues underpinning such practice.

After analysing the findings from Stage 1 of the research it became apparent that teachers and stakeholders had various ideas on how a VCL could be utilised in schools. It was felt by the author that it was important to see how these ideas transpired in practice and, likewise, the importance of distinguishing between teacher views and practice had been raised in the research literature (Monsour, 2009; Ertmer et al., 2001; Fang, 1996). The importance of classroom observation led to Stage 2 of the research. As the research was focused on capturing teacher beliefs through the use of technology in practice, the PCK tools used (CoRe and PaP-eRs) in combination with observation were deemed suitable means towards this end. Importantly, these research tools also allowed for comparison across the teachers. The CoRe highlighted the teachers’ ideas around elements of their practice related to a particular topic and the PaP-eRs allowed the teachers to focus on particular aspects of the CoRe having taught with the VCL. The five teachers in this case study had differing ideas around the use of the VCL and these ideas became evident from their practice. As noted, some teachers used the VCL in a manner related to inquiry, while others used the VCL in a more didactic manner. Interestingly, the two teachers who used the VCL in a more inquiry manner taught in mixed schools, while the three teachers who fell more in line with didactic approaches taught in single-sex schools. This finding raises the question of the influence of school culture on teacher practice towards IBSE. Vedder-Weiss and Fortus (2011) noted a difference in the motivation of students to do science between traditional and democratic schools with greater motivation from democratic schools where students have more decision-making. This may also be the
case in Irish schools, where mixed schools would be more democratic in the sense of having to foster a school environment that caters to both sexes.

After Stage 2, different lines of research were considered, from doing a quasi-experimental study of Post-Primary students’ or pre-service teachers’ learning gains in using the VCL compared with REx or carrying out PCK related research with pre-service teachers in the use of the VCL. However, it was felt that continued research on the teachers from Stage 2 would provide meaningful and more in-depth data on school-based issues related to inquiry practice. Also, these teachers would have experience with the VCL and hence, may be in a better position to utilise the VCL in such a way in a subsequent study. There would also be potential for a reduced reactive effect by the teacher to the researcher being in their classroom. It was clear from Stage 2 that the VCL could support inquiry, but the question remained as to how the teachers in the sample would react to being explicitly asked to use the VCL in an inquiry manner. Teachers’ reaction to the use of the VCL for IBSE was the basis for Stage 3 of the research. The author was cognizant of how he explained his interpretation of inquiry to the teachers providing them with a handout containing Abram’s (2007) levels of inquiry, as noted in the methodology chapter. Hence, teachers were clear as to what the author would interpret as representing inquiry in their use of the VCL. Research tools developed specifically for inquiry-based studies (ISIS, RTOP and student self-assessment) were used so as to capture as much detail as possible. These tools furnished very meaningful insight on each teacher’s directed use of the VCL in an inquiry manner and aspects that linked with it. Interestingly again, issues with the inquiry approach arose more in single-sex schools than mixed schools. This may have just been the teachers in this study, but it does raise the question if single sex or mixed schools are more conducive to IBSE in classrooms. A possible reason for this is that mixed schools place more value on student differences and this value is then reflected in the school culture where students are afforded greater decision-making.

Finally, having completed Stages 2 and 3, it was felt that it was important to gain insight into what types of problems the teachers would like to see on the VCL if it were to be developed further. Also, these problems could be available to be put on a modified VCL and hence, it would include teacher-designed problems. Teachers’
development of problems for the VCL was the basis of Stage 4 of the research. The development of problems involved simple discussion with the teachers from Stage 3 of the research. These discussions highlighted particular concerns of the teachers in relation to current practical work and how a VCL may provide a useful affordance to overcome these concerns.
Chapter 6: Conclusions

6.1 Overview of conclusions

The following chapter contains five sections detailing:

- The key findings of the research (Section 6.2),
- Implications for practice (Section 6.3),
- Limitations of the research (Section 6.4),
- Future research directions (Section 6.5), and
- A final note by the author on the overall research experience (Section 6.6).

6.2 Key findings of the research

The key findings of the project will be concluded under the following headings related to the research questions:

- A virtual chemistry laboratory to mediate educational change (Section 6.2.1),
- Knowledge areas in teaching particular content (Section 6.2.2),
- Teacher integration of ICT resources (Section 6.2.3),
- A virtual chemistry laboratory to support inquiry (Section 6.2.4), and
- Teacher and student reflections on the virtual chemistry laboratory (Section 6.2.5).

6.2.1 A virtual chemistry laboratory to mediate educational change

The NCCA would like more varied science assessment arrangements in schools, as opposed to just a written examination, and this has been the basis of their consultation process with schools. The NCCA hope that any new assessment would encourage curricular alignment with IBSE. However, despite developing an ability to assess inquiry, scaffolding would still be required for teachers. The VCL has the potential to meet all these areas in acting as an infrastructure for assessment, a scaffold for teacher development in terms of a \textit{habitus} conducive to inquiry and affording teachers the opportunity to become curriculum makers. Many of the comments from teachers and
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stakeholders expressed interest in how the VCL might do this. No teacher or stakeholder has rejected the idea of the VCL being used as an assessment, but some did express varying reservations. This point alone highlights that the VCL is something both teachers and stakeholders are willing to consider and discuss. As noted though, reservations were expressed towards the use of the VCL in the Leaving Certificate examination system. In terms of teachers, some raised issues of the VCL not supporting real practical work and that it could be assessing ICT skills over chemistry skills. In terms of some of the stakeholders, the SEC like the idea of a VCL, but the use of the VCL as an assessment deviates strongly from the current written assessment; hence they require concrete exemplification of how the VCL could work as a reliable and valid assessment tool for large scale assessment (Penuel et al., 2010; Waight & Abd-El-Khalick, 2011). Other stakeholders noted the cultural issues within schools that would be difficult to overcome in that there are many defenders of the current examination system. These cultural issues resonate with Smith (1999: 190) who notes that new assessments may involve ‘risky upheavals in classroom practices, and in relationships with colleagues, principals and parents’. Through exemplification and time the changes required in classroom practice could begin to take shape.

It is interesting to see how discussion around the VCL with teachers and stakeholders brings many contemporary issues of schools to light. Many of the teachers and stakeholders highlighted the various ways in which the VCL could address these issues so it would appear that the VCL could provide a common space for all involved to interact within. Teachers and stakeholders could design problems together and the online nature of the VCL encourages the sharing of these problems. This, in turn, would encourage teachers to be more collaborative in their teaching, not just with other teachers, but with stakeholders also. Through this process, teachers could begin to greater exemplify inquiry-based problems within the VCL and thus, move into greater practice of IBSE. For this use of the VCL to occur, the assessment structure would need to change to align with the VCL as a teaching and learning tool in the classroom. Teachers would be much more likely to begin to engage if the assessment aligned, as the VCL encourages the student engagement and ownership needed for IBSE. That is not to forget that many teachers in this study wanted to engage already,
even without a change in the assessment regime. However, these teachers did recommend changes to assessment to motivate other teachers’ involvement.

6.2.2 Knowledge areas in teaching particular content

The teachers in Stage 2 of this research highlighted many knowledge areas on which they draw in their teaching. The use of CoRes with individual teachers illustrated certain types of PCK, mostly general PCK. The greater articulation of general PCK would suggest that many teachers do not deeply reflect on the link between content and pedagogy. If teachers more greatly reflected on the link of pedagogy and content, then more detailed topic-specific PCK would be articulated. Interestingly, the types of general PCK noted by teachers illustrated areas of contestation within teaching. For example, there was a contestation between whether theory should be covered before or after an experiment. The rationale put forth by teachers to explain their approaches had limited aspects of educational theory connected to them and instead, were based more on a general feeling from classroom practice. It is clear that educational theory is not something many teachers reflect upon in light of their practice, with the exception of Eric. Of course, the argument put forward is that classroom life takes over which is understandable, considering many teachers jump from lesson to lesson each day, with little time to stop and think. Some teachers do note that they would love to integrate educational theory into their practice more, but again cite time as a major issue.

6.2.3 Teacher integration of ICT resources

The Teacher ICT Integration Model (TICTIM) was an attempt to explain teacher stances on ICT integration and the factors underlying these stances, based on findings from this research and findings from the literature. Not all teachers would fit perfectly into the teacher types and may in fact exhibit characteristics of two stances to ICT integration. However, the framework could act as a useful starting point in determining how particular teachers may be effectively supported to move towards other stances on integrating technology into their practice. It could also be useful for teachers to consider where they themselves fit within the framework and thus reflect on the reasons for this. Interestingly, two teachers (Shane & Eric) did not have second-order barriers to integrating technology in that their beliefs favoured IBSE.
The VCL helped them overcome first-order barriers in terms of an infrastructural enhancement to their preferred approaches.

Of significant interest is how the environmental factors of a school influence a teacher’s integration of technology. There were a few examples of teachers over the course of this research who pulled out of the research due to pressure from their students or the students’ parents to teach in a particular manner. Student and parent pressure relates back to the importance of a teacher’s empowerment in their classroom and whether a teacher sees themselves as assisting or appeasing their students. A reason for teachers’ lack of empowerment is underpinned by teachers’ lack of a professional language for teaching, in that parents and students believe they know enough about education to critique a teacher’s approach. This is not to say that their points are not pertinent and in fact, their points could be instructive, but a teacher should be readily able to stand by their approaches based on educational theory. Teachers without a strong knowledge of educational theory have little grounds for justification when their methods are critiqued.

6.2.4 A virtual chemistry laboratory to support inquiry

This research has produced evidence of the utility of the VCL to support inquiry. However, there are much bigger issues at play that hinder the use of the VCL in this way. The overarching influence is that of the high stakes assessment and how this has created perceived norms of teacher and student roles (*habitus*) in the classroom that are not easily challenged. Firstly, in terms of many students, they have become passively encultured learners dependent on the teacher as the gatekeeper to understanding. The more encultured students become to this type of learning the more they depend on it and as a result, the more challenging they find it to think for themselves. Hence, certain students in this research reacted negatively to the use of the VCL in an inquiry manner. This student role has further consequences in terms of science education in that students see science as a body of foregone conclusions, and have little understanding of the contested knowledge space of science and an appreciation of the epistemology of science.
Secondly, in terms of teachers, the assessment creates certain environmental factors that pressurise many teachers into the role of appeasing their students for the final high stakes examination leading to ‘ritualized routines’ (Nuthall, 2005) in test-preparation activities. Some of these environmental factors relate to pressure from students, parents, and principals. In light of attempting to cover an overloaded curriculum within a short time span, many teachers find it easier to take on the role of the teacher as the transmitter of knowledge. This role of the teacher as a transmitter of knowledge in turn has led to a teacher *habitus* of feeling uneasy when their students are perplexed. It is this uneasiness that militates strongly against an inquiry-based approach. Teachers need to develop appropriate means of scaffolding student inquiry so that students themselves see perplexity as a natural part of learning and even more rewarding to overcome. This research highlights that such changes are possible through the support of the VCL, but that changes in teachers’ schema will be incremental and that a stepwise approach is needed.

Change efforts need to be cognizant of the need to locate inquiry development in the ZPD of both students and teachers. Teachers need, firstly, to tease out what inquiry means to them and secondly, decide what steps are needed to move from their existing practice towards greater IBSE, appreciating the role of students’ attitudes and beliefs throughout such change. As already alluded to, many teachers’ current schema is strongly underpinned by the influence of external examinations and this influence can be attributed in varying ways to issues with roles in the classroom, e.g. teaching as telling, recipe approaches to experimentation and difficulties in students investigating. These roles are difficult to address as students are used to recipe type approaches and have little conceptualisation or appreciation of what it means to think, plan and take initiative like a scientist. Any change effort must address these restrictions and start at the base of student planning and decision-making, before moving to a consideration of other elements of IBSE. Such a movement towards IBSE will develop teacher schema and ultimately, add to teachers’ repertoire of approaches and thus, enhance student learning.
6.2.5 Teacher and student reflections on the virtual chemistry laboratory

A broad range of insights on the VCL were offered by teachers and students in relation to how it could be most effectively used in relation to teaching, learning, and assessment. Firstly, teachers noted many values of the VCL in its affordances for their teaching and their students’ learning. In particular the use of the VCL caused teachers to reflect on their approaches to practical work in general and what they were achieving by getting students to do experiments. The teacher reflection tended to focus on how much ‘hands-on’ or ‘minds-on’ activities that were occurring during the experiments. Despite this reflection on their teaching and students’ learning, teachers expressed many barriers to a VCL being used as an assessment. This is not to say they did not desire it, but felt external factors would make any changes incredibly difficult and in turn, slow.

Secondly, many students expressed an enjoyment in the use of the VCL, but expressed a preference for REx, suggesting the core use of the VCL as something outside of class time. Some students expressed strong frustration with the VCL being used in an inquiry manner and this highlights the new student roles that the VCL could support in schools. However, students would need time to adjust to new roles and also, teachers would need support in structuring these new roles. In terms of assessment, many students expressed that they would be happy to have the VCL used as part of their assessment or to at least have the option of using the VCL in their assessment.

6.3 Implications for practice

The findings of this research have a number of implications for the research community. The implications relate to the research questions in terms of the school science culture and how it links to a VCL, and how a VCL may support IBSE. There are also implications for the use of certain research tools.

Firstly, in relation to the culture of schools, there is a strong desire for the current assessment to change from many of the teachers and stakeholders in this study.
Hennessy et al. (2005: 186) note the difficulty in significantly changing subject cultures due to the restraints of ‘nationally prescribed curriculum and assessment frameworks’. However, the NCCA (Towards Learning Report, 2009) notes the need for more varied assessment structures and this project would re-iterate this need. Teachers and stakeholders note the need for new assessments to provide the students with greater engagement and ownership of their learning and encourage critical thinking. Many participants noted the value of a fully developed VCL as a means to promote greater student-centred approaches and hence, could act a useful assessment for students. Within the VCL infrastructure, students could be asked to complete a plan of their experiment, carry out the experiment with all the actions required, and modify the plans as needed in completing the experiment. Grades could be awarded based on the thought processes illustrated by students. Importantly, the role of all stakeholders would need to be carefully considered in any project that is looking to meaningfully integrate technology into the Irish education system, due to varying perspectives, i.e. the NCCA is focused on developing new curriculum materials, the SEC is focused on validity and reliability of assessment, and teachers’ ultimate job is to get students good grades through whatever means necessary (noted by Shane). There are indeed other complicating factors in what differing stakeholders focus on, but any systemwide change would need to accommodate all involved. Even then, change may be slow as people need time to adjust to what can be viewed as ‘upheavals’ (Smith, 1999: 190) not just in classrooms, but in broader cultural and societal terms (Fullan, 2007). As noted by Eric in the findings, it important to respect the ICT level each person is at, but that people should still be encouraged and provided with ‘as much support and resources as possible’ to take on new ICT. This statement by Eric can be applied to educational change in general.

Secondly, in relation to how a VCL could support IBSE, a fully developed VCL could have a significant impact on the teaching and particularly, the learning of science through IBSE. The open infrastructure and instant feedback nature of the VCL could greatly facilitate student learning and could also be used to provide feedback to teachers in how the students are attempting to solve problems on the VCL. An important aspect of a fully developed VCL is that teachers have ownership of the problems in it. Hence, it would be important that teachers could easily modify the problems to suit their students. A fully developed VCL could develop a concept of
scientific inquiry amongst the community of Irish chemistry teachers. If teachers were to submit problems to the NCCA based on their ideas of inquiry practices this would be significant in influencing the schema development of teachers in considering other teachers’ approaches. As noted by Fullan (2007) teachers prefer to learn from other teachers.

Teacher professional development is needed in a broad range of areas, but the effect of such development may be minimal without a change in assessment. Change efforts need to support teachers in seeing the value of the change within and beyond the high-stakes assessment. Specific to this project, professional development is needed geared at more effective practical work, the critical use of ICT, developing teacher PCK and supporting IBSE. As noted by Ward and Parr (2010: 121), through professional development, ‘teachers are likely to be more willing to learn, to try new things and to move away from more traditional classroom practices’ (Ward & Parr, 2010: 121). Importantly, the findings would suggest the need to understand and appreciate the individual beliefs of each teacher, before appropriate professional development can be provided. Instructional change that ignores teachers’ beliefs leads to disappointing results (Clark & Peterson, 1986; Richardson, Anders, Tidwell, & Lloyd, 1991). This relates to the importance of change efforts to first and foremost consider teachers’ schema appropriately, so as to ensure that initiatives are not beyond the ZPD of teachers. Even if teacher beliefs are favourable to changes in teaching and learning, their schema needs to be sufficiently challenged, supported, and developed to be able to enact such change. Teachers would require exemplification of approaches intended so that change becomes ‘feasible and viable in the mind of the teacher’ (Crawford, 2007: 638). Extending Crawford’s (ibid) statement further based on this research, teachers then need to develop strategies that support students in seeing such approaches as feasible and viable. Further still, strategies are needed for the wider education community to appreciate the value of such approaches.

Finally, the research tools in this study would be of useful consideration to other researchers studying IBSE. The use of CoRes and PaP-eRs are a useful means for teachers to explicate their practice in relation to particular content. Teachers’ practice can then be considered from varying angles. The CoRes and PaP-eRs are also an
effective strategy for encouraging teachers to more greatly engage with educational theory for their practice and thus broaden their schemata (Korthagen, 2010). If teachers developed a stronger understanding of educational theory, teachers would develop much greater confidence in their practice, thus more empowerment and the willingness to challenge the school structure. Increased teacher empowerment would not just lead to a greater ‘bias for action’ (Fullan, 2007) from teachers, but in turn, they would transfer a ‘bias for action’ to other stakeholders. The net result would be much greater forces for change within the education system.

The use of ISIS, RTOP and SSA would have certain benefits to educational researchers. In this research, the ISIS was used in a ‘talk-aloud’ manner, providing insights into teachers’ perceptions of their overall practice related to IBSE and the rationale underpinning this practice. Using the ISIS in a ‘talk-aloud’ manner gave teachers the opportunity to explain why they choose certain categories and highlighted salient factors in teachers’ practice. The RTOP was not particularly useful to the small number of teachers studied in Stage 3. However, the RTOP did provide means by which to consider the teachers’ practice and led to further considerations of teachers’ roles in a classroom context. The SSA provided very useful insight on the students’ reaction to a lesson taught using the VCL to support IBSE and would have use to any researcher attempting to incorporate student feedback on students’ responses to new teaching approaches.

6.4 Limitations of the research

6.4.1 The data sets

The criteria for choosing the stakeholders for Stage 1 was based on an attempt to incorporate external Post-Primary school institutions with roles related to the teaching, learning and assessment of science. Many of the main institutions were represented in the stakeholders, except the Department of Education and Skills (DES), who refused the opportunity for interview. The DES would have provided important data so this is a limitation on the findings of Stage 1.
The teachers for this study were recommended by the Second Level Support Service (SLSS). There was potential bias in how these teachers were recommended by the SLSS. However, the author did specify to the SLSS that the teachers recommended were to have different ICT backgrounds and would be willing to become involved in a research project. Access to teachers in Irish schools is difficult so other means of attempting to contact teachers would have been much more complicated. Even some of the teachers contacted through the SLSS suggestions were curious as to how the author had heard of them. The SLSS only provided teachers’ schools and the author initially contacted teachers through the school secretary.

Limitations of Stage 1 relate to all of the teachers interviewed being male, hence a gender bias in the teacher findings of Stage 1. Other limitations relate to the teachers not having much experience of the VCL before the interviews. Hence, some teachers may have not had enough time to adequately reflect on some of the questions they were asked. Limitations of Stage 2 relate to only two teachers from Stage 1 continuing their participation. This led to three new teachers who had to be explained the VCL and its features before being able to participate in Stage 2. Also, there were four male teachers and only one female teacher in Stage 2, representing a gender bias. However, this number is representative of the gender ratio of both students and teachers (3:1) in the Physical Sciences in Irish schools. In the academic year 2000/2001, 29% of students in the Physical Sciences were female (Report and Recommendations of the Physical Sciences Task Force, 2001). Limitations of Stage 3 relate to the loss of two teachers from Stage 2. The additional teacher added to the project (Susan) was at a disadvantage to the other teachers in that they had experience of using the VCL from the previous stage. The male/female ratio for Stage 3 was 3:1. All four teachers from Stage 3 participated in Stage 4.

6.4.2 The research methods

The differing research methods had particular limitations for each stage of the research. Firstly, in terms of interviews the topic guides for the semi-structured interviews and focus group interviews had not been piloted. Hence, particular issues with how the questions were interpreted could not be pre-empted for all participants. As noted in the methodology chapter, a critical friend was used to enhance the
reliability and validity of the topic guides before using them. This aided in reducing the bias from the researcher and allowing for easier interpretation of each question by the participants. The CoRe and PaP-eRs had possible limitations in how they were interpreted. However, the open representation of the CoRe and PaP-eRs as research tool makes this interpretation very explicit (Appendix I and J).

Secondly, in terms of observations, there is potential bias from the researcher relating to their pre-existing beliefs (Jones, 1996) in that they can influence what the researcher views as important when taking notes in unstructured observations. This would apply to Stage 2 of the research where unstructured observations were used. Video observations were used in Stage 3. This reduced the potential of researcher bias, but on the other side, did not allow the researcher to focus as easily on activity missed outside the camera shot (Wilson & Cox, 2009). As noted in a previous section, the RTOP provided certain insights into this research, but was originally designed to provide statistical data on a number of lessons. This was a limitation in this research in that some of the statements on the RTOP were not applicable.

Finally, in terms of questionnaires, bias of the researcher was reduced in that teachers and students could interpret the questions without input from the researcher. The researcher was present though when the ISIS was completed so teachers may have felt a pressure to answer the questions at a certain pace and not reflect on them as much as they would have liked. However, they were encouraged to ‘talk-aloud’ to articulate their rationale in choosing responses on the ISIS. The SSA was completed by students in their own time so they could provide adequate responses. However, a limitation of the SSA was that some students did not respond to all the questions on the questionnaire. This led to a limitation of comparison across all students.

### 6.5 Future research directions

The conclusions highlight many potential lines of research that could be followed from the project. Firstly, research into the exemplification of the VCL as a reliable and valid assessment tool is needed for the VCL to become part of a large scale assessment. This research would involve the testing of inquiry-based assessment rubrics that are incorporated around problems on the VCL. The VCL could then be
much more easily argued as a reliable and valid assessment tool to be used on a national scale.

Secondly, many real life problems could be developed on the VCL that could be used to engage and motivate students’ interest in science, and see its potential applications to everyday life. For example, the VCL currently has an exercise on it that explains the issue of arsenic poisoning in Bangladeshi drinking water. Students are provided water samples from a chemist in Bangladesh and must determine the concentration of arsenic in the samples using a spectrophotometer. Students are also asked to explain what a cheap approach to determining the arsenic concentration may be, but have to also highlight limitations with such an approach. This leads students to suggest the densiometric determination of arsenic. It is a relatively cheap approach, but has a limitation in assuming that arsenic is the only compound in the water. More problems such as these on the VCL would provide students with real life examples beyond the scope of the school laboratory and would be a useful line of research towards enhancing student perceptions of the utility of science.

Thirdly, explicit research on PCK could be carried out with pre-service teachers. The pre-service teachers could be split into two groups where one group would be trained on the VCL and the other would not. Both groups would be taught explicitly how to use CoRes and Pa-Pers as a means of reflecting on lessons. From this research it would be hoped to see the enabling features of the VCL to scaffold the pre-service teachers using it in a more inquiry-based approach, as opposed to the pre-service teachers who do not use the VCL. Some of the lessons of the pre-service teachers could be observed, recorded, and analysed using RTOP. Again there would be a strong focus on what features of inquiry emerge from the pre-service teachers’ involvement in the project. The ISIS could be used as a reflective exercise for the pre-service teachers.

Fourthly, a quasi-experimental study on two groups of post-primary school students could be carried out to measure the learning gains between students who use a VCL and students who just use a physical setting. The purpose of this study would be to determine where real experimentation and virtual experimentation fail or succeed in moving students from recipe type experiments to inquiry type experiments and to
decide from the findings how real and virtual experimentation can be appropriately combined for effective student learning. This study would also provide strong exemplification towards the utility of the VCL as a teaching and learning tool.

Fourthly, a questionnaire could be submitted to students through SciFest. This is a project-based science fair for Post-Primary School students, that focuses on the promotion of science as inquiry. Students would be asked to solve problems on the VCL and offer their feedback on it through a questionnaire. It is felt that it is important to incorporate as much student feedback into the software as possible, as it will ultimately be the students who will benefit most from the VCL. Student feedback on the VCL will offer students increased ownership of their learning.

Finally, an interesting piece of research would be to examine if there is a correlation between types of schools (mixed or single sex) and their conduciveness to IBSE. The case studies in this research would suggest mixed schools are more favourable to IBSE. As noted in a previous section, Vedder-Weiss and Fortus (2011) found that students in democratic schools had a greater motivation to do science than students in traditional schools, as students in democratic schools have more decision-making. It could be a similar case in Ireland that mixed schools place a greater value on student decision-making and hence, are more favourable to IBSE. More explicit research on these issues would need to be carried out.

6.6 Reflection on research experience

Over the course of this research project I have constantly sought to be cognizant of my role within the research in terms of how my own views could potentially bias results. Flick (2006:16) notes that qualitative methods, unlike quantitative research ‘take the researcher’s communication as an explicit part of knowledge instead of deeming it as an intervening variable’. Hence, the role I have played as a researcher in this project becomes important in relation to my influence on its structure and design, its data collection, analysis, and presentation of the findings. As noted by Bruner (1993) ‘The qualitative researcher is not an objective, authoritative, politically neutral observer standing outside and above the text’. Before even discussing this project, it is significant to highlight that I am the second youngest of a family of six
children, who all have degrees. Hence, education was and is highly valued in my family, without my parents or closest relatives being involved in education related professions. However, all six children are in distinct fields from statistics to theatre studies to network engineering. These factors do point to a strong inherent value of individuality within my family background and could be interpreted as a bias towards inquiry-based approaches that value ownership and initiative in the learning process. I would acknowledge such a bias, but do realise the importance of other approaches depending on the context in which they apply.

Despite a potential bias towards inquiry-based approaches, throughout my degree course of Physics and Chemistry Education I would have been frustrated with the education modules I had to do. I felt there was a large discrepancy between the ideas being covered relating to student-centred approaches and what actually went on in schools, and as a result, I had little appreciation for what was being espoused. I had never taken time to truly reflect on why there was a discrepancy and what could be done about it. Also, the approaches being espoused were outside my own schooling experience and hence, made it more difficult for me to understand such approaches.

On seeing the VCL for the first time my curiosity was stirred. I tried to complete what I considered a simple density problem on it, but it highlighted how little I knew of experimental design, despite nearing the completion of my degree. I found something I considered trivial quite tricky, for example to consider what sized beakers to use and what amounts of substance to add. This experience made me see the VCL as a concrete way to facilitate student centred approaches in schools and to mirror more closely what scientists do and hence, why I felt happy to pursue it as a research topic.

Only through my research have I come to understand why I found Education modules frustrating. Firstly, I had one particular view of what education was, based on my own school experience, and I realise now how narrow of a view this was, i.e. a jug and mug view of the teacher-student role. Secondly, I would have had a fatalist view on the power of the teacher to change anything in schools. I see now that what happens in a classroom ultimately resides with the teacher. Thirdly, I listened too much to teachers who dispelled the importance of educational theory in teaching. I see, that to do this, leaves a teacher with very little footing on which to base their
classroom activities and as a result, they will revert to traditional practices when pressured by students and parents.

I believed starting out that the VCL could support inquiry in some manner, but was unsure of how it might take shape. I was careful to explain to teachers in Stage 2 that I was simply interested in how they would use the VCL within their practice, without pushing any particular approach. The result was that some teachers did use the VCL in an inquiry oriented manner, while others did not. It was in the follow-up interview I asked the teachers about the VCL in terms of inquiry. In Stage 3 however, the concern was actually that the teachers taught the lesson in an inquiry framed manner. I was careful to explain to teachers what I was interpreting as inquiry so that they were clear what the study entailed.

Overall, the research experience has been a mostly enjoyable one, but also challenging. Access to schools was very difficult whether it was attempting to get in contact with a teacher or to organise a suitable date to meet. This experience has made me realise how engrossed many teachers are within their own classroom, and the fact that they take little time to consider what is going on outside of it. This of course can be a result of many reasons, but it begs the questions of how isolated and insular the teaching profession can be, and how this can be addressed. However, the teachers who were kind enough to let me observe their lessons made the research extremely worthwhile, in that they provided me with very useful insight to aid in answering my research questions, but also helped me consider other important factors in terms of their day-to-day activities as teachers.
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Appendices

Appendix A

Stage 1 Semi-Structured Interview Topic Guide

Note: Before beginning the interview participants will be explained the general purpose of the interview (what the findings will be used for) and informed of any relevant procedures/layout relating to the interview.

- What do you feel are the challenges in teaching science in Irish schools today? What challenges affect you most?

- What is ICT’s role (if any) in meeting these challenges?

- What are your views on how ICT has been used by teachers in this school to date? Reasons for this. How would you describe your use of ICT?

- What reasons would cause you to use a Virtual Chemistry Laboratory in class?

- How do you think you would use a Virtual Chemistry Laboratory in your teaching?

- What is the best way to assess learning in your opinion? (written, aural, oral, practical examinations)

- Ideally, how would you like to see student learning assessed? (Compared to current assessment methods)

- Do you think a Virtual Chemistry Laboratory would be useful in the assessment of practical work? Why?

- What are your views on ICTs future direction in schools? (What is its place in Post-Primary schools?)

- What do you think will be the changes to assessment in the future?

- Do you think there are other issues I should be aware of for this project?
Appendix B

Stage 2 Content Representation (CoRe) Questions for Teachers

Topic: ______________________________

1. What you intend the students to learn about this idea?

2. Why it is important for students to know this?

3. What else you know about this idea (that you do not intend students to know yet)?

4. Difficulties/Limitations connected with teaching this idea.

5. Knowledge about students’ thinking which influences your teaching of this idea.

6. Other factors that influence your teaching of this idea.

7. Teaching procedures (and particular reasons for using these to engage with this idea).

8. Specific ways of ascertaining students’ understanding or confusion around this idea (include likely range of responses)

9. If you were to give advice to a new teacher doing this topic for the first time what would it be?
Appendices: Appendix C

Appendix C

Stage 2 Focus Group with Students

Opening Question:
Describe your experience of using the Virtual Laboratory in class.

Underlying Questions to opening question:
What did you see as advantages or disadvantages of using the Virtual Laboratory?

How was using the Virtual Laboratory different from previous Chemistry classes?

Are there changes you would make to the Virtual Laboratory?

Would you rather use VCLIPPS first before having to do an experiment in reality?

How do you feel the Virtual Laboratory impacted on your learning of the topic? In relation to the topic being taught?

Would you say it would have been worse, the same or better to have used other means to learn the topic instead?

Would you use the Virtual Laboratory at home if you could access it online?
In what ways would you use it – to aid homework, curiosity etc?

How would you feel if the Virtual Laboratory was used to test your knowledge of experiments (i) in everyday class by the teacher?, (ii) in end of term exams by the teacher?, and (iii) in the practical element of Leaving Certificate Chemistry exam? Are there are any important issues that need to be considered?

Concluding Question:
Any final comments you would like to make about the Virtual Laboratory?
Appendices: Appendix D

Appendix D

Stage 2 Post-lesson Semi-Structured Interview Topic Guide

• What are your overall comments on the lessons you taught under the topic of (topic taught)? Were they what you expected or not?

• What have you learned from teaching this topic to these students?

• Are there any other thoughts you have after having taught the students about (topic)?

• How did you make the topic of (topic) understandable to students? What were the methods you used?

• Why did you use these methods? As opposed to other methods? Particular reasons?

• What ways did you determine that you made the topic understandable to students?

• What were typical responses/actions from students that demonstrated their understanding of the topic to you?

• What were the typical questions asked by the students?

• Was there particular attributes/characteristics of the students you had in mind when teaching the topic?

• What is your thinking on the use of the Virtual Chemistry Laboratory as a learning tool? How effectively do you think it could facilitate inquiry methods of teaching?

• What do you see as your role in the classroom when the students are using the Virtual Chemistry Laboratory? Why?

• What is your thinking around the use of the Virtual Chemistry Laboratory as an assessment tool?

• Do you see yourself using the Virtual Chemistry Laboratory next year? Why or why not? If yes, in what way?
### Appendix E

The Inquiry Science Implementation Scale (Pre-inquiry lesson)

<table>
<thead>
<tr>
<th>Q.</th>
<th>When you teach chemistry, how frequently do you:</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>demonstrate the use of a new instrument?</td>
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<tr>
<td>2.</td>
<td>have students write the problem or activity before doing an experiment?</td>
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<td>3.</td>
<td>review relevant concepts and skills that were learned in previous lessons?</td>
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<td>4.</td>
<td>introduce new vocabulary words?</td>
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<td>5.</td>
<td>ask students to identify and define words?</td>
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<td>6.</td>
<td>ask students to make predictions about an experiment?</td>
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<td>7.</td>
<td>check to ensure that students understand new procedures before beginning an experiment?</td>
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<td>8.</td>
<td>discuss how everyday situations directly relate to experiments that students are currently or will be conducting?</td>
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<td>9.</td>
<td>check students’ designs for safety before allowing them to conduct their experiments?</td>
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<td>10.</td>
<td>monitor small group progress during experiments?</td>
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<td>11.</td>
<td>encourage students to collaborate within their groups?</td>
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<tr>
<td>12.</td>
<td>circulate and interact with students while they are conducting experiments?</td>
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<td>13.</td>
<td>discuss variations in data collected by students following their experiments?</td>
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<td>14.</td>
<td>have students share their predictions with the class?</td>
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<tr>
<td>15.</td>
<td>have students share their data or findings with the class?</td>
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<td>16.</td>
<td>challenge students to consider the effects of errors on groups’ results?</td>
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<td>17.</td>
<td>compare and contrast students’ explanations of findings?</td>
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<td>18.</td>
<td>question students as they conduct their experiments?</td>
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<td>19.</td>
<td>connect new information with students’ personal lives (interests, home environment, community, culture, etc.)?</td>
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<td>20.</td>
<td>connect current events and other subjects with current science concepts, skills, and investigations?</td>
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<td>21.</td>
<td>use questioning strategies to respond to students’ questions about experiments?</td>
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<tr>
<td>22.</td>
<td>have students ask questions about the scientific phenomena addressed during experiments?</td>
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</tbody>
</table>
Appendix F

Stage 3 Final Teacher Interview Topic Guide

1. Was there evidence of student progress? Observations, class work, homework etc?

2. Was the lesson taught as planned? Inquiry?

3. What strengths did you see in students’ work?

4. What aspects of an inquiry approach would have contributed to these strengths?

5. What weaknesses did you see in students’ work?

6. What aspects of an inquiry approach would have contributed to these weaknesses?

7. What would you describe as your role within the classroom?

8. What is your thinking of the VCL as a learning tool?

9. How would you view the VCL if it were to be used in assessment?

10. Would you consider using the VCL in future? Why?

11. Do you feel the VCL supports an inquiry-based approach? Why?
Appendix G

Student Self-Assessment

1. UNDERSTANDING

(A) Understanding the Science

Justify your score based on your work:

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

(B) Understanding the Processes of Inquiry

Justify your score based on your work:

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

(C) Making Connections

Justify your score based on your work:

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

2. PERFORMANCE: DOING SCIENCE

(A) Being Inventive

Justify your score based on your work:

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
Appendices: Appendix G

(B) Being Systematic

N/A 1 2 3 4 5
Very Bad Bad Adequate Good Very Good

Justify your score based on your work:
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

(C) Using the Tools of Science

N/A 1 2 3 4 5
Very Bad Bad Adequate Good Very Good

Justify your score based on your work:
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

(D) Reasoning Carefully

N/A 1 2 3 4 5
Very Bad Bad Adequate Good Very Good

Justify your score based on your work:
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

3. SOCIAL CONTEXT OF WORK

(A) Writing and Communicating Well

N/A 1 2 3 4 5
Very Bad Bad Adequate Good Very Good

Justify your score based on your work:
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

259
(B) Team work

![Team work icon]

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>Very Bad</td>
<td>Bad</td>
<td>Adequate</td>
<td>Good</td>
<td>Very Good</td>
</tr>
</tbody>
</table>

N/A

Justify your score based on your work:

____________________________________________________________________
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4. REFLECTION

(A) Self-Assessment

![Self-assessment icon]

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<th>N/A</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tr>
<td>Very Bad</td>
<td>Bad</td>
<td>Adequate</td>
<td>Good</td>
<td>Very Good</td>
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How well do you think you evaluated your work using this scorecard?

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
Appendix H

Stage 3 Student Focus Group Topic Guide

1. Could you describe your overall feelings towards chemistry as a subject? Positive, negative or neutral?
2. Why did you choose chemistry as a subject for your Leaving Certificate?
3. What is your favourite topic in the chemistry course? Why?
4. What is your least favourite topic in the chemistry course? Why?
5. What do you view the teacher’s role as within the class? What do you view as your role within the class?
6. Do you think a teacher should use computer technology in class? Why? How do you think the technology should be used?
7. Do you think students should use technology in class? Why?
8. Do you enjoy doing practical work? Why?
9. Do you enjoy using the Virtual Lab? Why? Improvements?
10. Would you prefer just practical work, just Virtual Lab or a mix?
11. How do you feel about the Virtual Lab as a learning tool?
12. What are your thoughts on the use of the Virtual Lab as an assessment tool?
13. Would you view the use of the Virtual Lab as a pre-lab, post-lab activity or both? Why?
### Appendix I

#### Stage 2 Content Representation (CoRe): Titrations

<table>
<thead>
<tr>
<th>Laboratory Technique</th>
<th>Assessment</th>
<th>Knowledge/Understanding</th>
<th>Calculations</th>
<th>Etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What you intend the students to learn about this idea.</td>
<td>The proper preparation and assembling of the equipment with correct setup. (Shane)</td>
<td>Definitions of acids and bases, the theories of them. (Paul)</td>
<td>That they can transfer their knowledge in volumetric analysis for example from acids and bases eventually to volumetric analysis questions that would involve oxidation/reduction but also this knowledge and understanding of molarity, molar volumes of gas and so on into areas like fuels etc. (Eric)</td>
<td>Developing skill in calculating the approximate amount of material that would be needed to react with a substance. (Eric)</td>
</tr>
<tr>
<td></td>
<td>Developing the manual skills of making up solutions. (Eric)</td>
<td></td>
<td>Understanding the links between the concentration of solutions, the amount of solutions, molarity, that in terms of how much of an active ingredient is actually in a mixture taking part in the chemical reactions. (Eric)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proper technique of doing the titration so they get an accurate result. (Shane)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2. Why it is important for students to know this.</td>
<td>Good laboratory technique applicable to other areas of life so is important for their broader education and planned careers: No matter where they are working they have to be able to work logically, in an organised method and keeping records. They need to plan (think ahead), think it out so they are not wasting time having to go back and correct mistakes. (Shane)</td>
<td>It is rigourously examined and if the procedure is slightly out in the exam they’ll lose a lot of marks. (Shane)</td>
<td>For a practical knowledge of chemistry they need to how the theoretical knowledge of moles and molarity etc. can be used practically in so many different ways. (Eric)</td>
<td>It's fundamental in terms of their understanding of chemistry and developing a love and knowledge of chemistry. (Eric)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The aim is to get the A in Leaving Cert chemistry. (Paul)</td>
<td>For effective learning it has to be embedded in real life problems and using theoretical knowledge and skills to solve them. (Eric)</td>
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<tr>
<td></td>
<td></td>
<td>For college if they are doing a science degree (Paul)</td>
<td></td>
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<tr>
<td>3. What else do you know about this idea (that you do not intend students to know yet).</td>
<td>They do not need to know anything about the theory (Arrhenius, proton donor, Brownsted Lowry) to actually do the titrations. That would be filled in later...and they are much more accepting of the theory then because they see the theory then as fitting. (Shane)</td>
<td></td>
<td>Any of the background information, be it historical information, anecdotal information, would not really be held back in terms of subjects. Even if it is remotely of interest it will be lashed in somewhere. Apart from maybe more difficult questions and if there are questions for example that they are beyond the scope of the course they will be challenging and difficult but the effort really would not be worth the payback so maybe in terms of that. (Eric)</td>
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<td></td>
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<td></td>
<td>The section of the course that deals with</td>
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</tr>
<tr>
<td>4. Difficulties/ Limitations connected with teaching this idea.</td>
<td>In terms of the labs themselves the procedures of doing titrations and volumetric analysis is boring. After students do two of them they are wondering why they have to do another ten of them. Simply to solve the same problems but they are there and they have to be done. (Paul) Lack of laboratory experience for Junior Cert. and TY students so need to help them become comfortable. (Eric)</td>
<td>Developing a clear understanding of what is meant by a mole. (Eric) Students come in from teachers who did not do much chemistry in Junior Cert., particularly things with formulas or balanced equations. Expectation of students knowing certain things yet they do not e.g. how to write a balanced equation. In fact a lot of people in the class it might be quite alien to them to write ( \text{H}_2\text{SO}_4 ) and to have any concept of what it is because the teachers have avoided it in Junior Cert. (Shane)</td>
<td>Developing a degree of comfort with arithmetic manipulation. (Eric) Range of abilities of students with those studying to a high level of Maths with those who are at a low level. (Eric) Not being able to continue on through to doing pH and pH calculations. (Paul)</td>
<td></td>
</tr>
<tr>
<td>5. Knowledge about students' thinking which influences your teaching of this idea.</td>
<td>Students get bored of doing titrations, repeating the same procedures and trying to understand that they have to get an accurate answer every time and that there is a precision involved in it is difficult to get over to them. They are quite happy to just do three titrations and get any sort of answer at all. (Paul) Students do not see titrations as something that are done in the real world. (Paul)</td>
<td>Different learning styles depending on the desired theory, Myers-Briggs or talk about Howard Gardiner, that people will have different ways of taking in the information, different ways of representing this information within their own brain and different ways of kind of learning and making it their own, and what a teacher has to be very conscious of is that they don't limit the way in which they deliver the material, the way which makes sense to them, because of their preferred learning style. This would be one of the factors which would certainly influence or the knowledge of their thinking which would influence. (Eric) Students are nervous about Chemistry from JC as it has a reputation of being a hard subject. Some students need remedial work to get them up to speed on things like bonding, chemical formulas and so on and a lot of confidence building as well so this influences activities.</td>
<td>The poor grasp of concepts for example like molarity that they have and certainly they have not brought anything like this from Junior Cert. (Eric)</td>
<td></td>
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</tbody>
</table>
### Expectation there that they know how to write a neutralisation reaction but it would be a surprise. (Paul)

6. **Other factors that influence your teaching of this idea.**

   The kids get a good kick out of the titrations so well it's a dead cert for the exam! (Shane)

   There's motivation to do titrations because of those everyday applications of it, ethanoic acid's a very good example of it. (Shane)

   They get good at them. They make sure they all do them, as many groups as possible do it. Ten groups if possible. Certainly no more than two in a group because kids like doing them. (Shane)

   Kids like that! Money in the bank. So there's a payback. (Shane)

   If you do something like ethanoic acid and you haven't shown them the bottle and calculations and then they get the number out, 5% and they look at the bottle and they see it. They get a good kick out of that when it comes. (Shane)

   Demonstration: About 15 minutes of equipment out and explain to them about setting it up, safety precautions, glassware, breakages, getting involved. Then show them the start. (Shane)

   Practical: They do it, and Shane gets in and explains it. They're going along trying to work out a little bit more slowly than the teacher goes in and out and explain to them about using it. (Paul)

   Practically: Get them through all the prescribed procedures, the precautions, the containers of chemicals from the chemical store and put them there and say right they're suppose to wash everything and how accurately they have to do it. (Paul)

   Practically: They're doing the experiment okay. They have this idea of going back to the equipment, another voice. (Shane)

   Practically: To compare like with like? (Eric)

   Practically: The art of the leader, not the leader's. With guided discovery they believe that they've nearly discovered this concept. (Shane)

---

### Appendices: Appendix I

### Guided discovery

- **Appendices:** Appendix I

### Reflective teaching

- **Appendices:** Appendix I
Appendices: Appendix I

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).</td>
<td>Could visit each group ten times in a practical so picking up stuff early by watching and talking to them and then getting them to do the calculations will show up difficulties straight away, homework or one to do in class It can be seen where they're not able to do the calculations. Written work will identify student understanding. (Shane)</td>
</tr>
<tr>
<td></td>
<td>A written test. There is no actual practical for the Leaving Cert so the questions are based on a written answer. The idea of being able to use Virtual Lab as a sort of semi-written test is favourable. They are not actually doing the chemicals but they can do some sort of a test there. It should give a better idea of how they understand what they are at. (Paul)</td>
</tr>
<tr>
<td></td>
<td>Lunch time sessions. These are informal sessions to deal with specific problems and it's supposed to be dealt with as soon as they crop up. Sometimes students don't quite get what has been done in class but even having done it two or three times or having spent a long time checking it, it hasn't clicked for them. So as a second bite to the cherry a lunchtime session can be organised, minimum of two students, maximum of five. So it's another bite of the cherry for kids who feel too intimidated to tell a teacher. They may not tell a teacher straight out 'I don't fully understand this.', although something a teacher should insist, keep on telling feedback. (Eric)</td>
</tr>
<tr>
<td></td>
<td>Demonstrate it themselves first then because unless they're experienced teaching they don't realise the things that could happen. When they've a bunch of kids down, they might have shown them the pipette and burette but they'd be surprised by what they do with it, like so they should demonstrate it fully themselves first if they were a young teacher, and that gives them confidence doing it right because when they're actually, okay they know how to do it because they've done it in the past before. They actually set it up here in their own lab with the same equipment the kids will have, if they do it themselves, they maybe see the snags and let the kids see them doing it. (Shane)</td>
</tr>
<tr>
<td></td>
<td>Let the kids do it. If the kids can do those experiments, teachers might demonstrate a bit too much, let the kids do it. Don't be afraid to let them do it. (Shane)</td>
</tr>
<tr>
<td></td>
<td>Try to think about from a kid's point of view. Like, what knowledge does a student have coming into this topic. What do they need to know? What are the building blocks? What's the kind of, what's the logical progression? How do they get the molarity? They can't get the molarity unless they're using, whichever the two it happens to be but also to develop their own set of results, taking stuff from the web, taking stuff for example they mightn't have a moodle or whatever, taking maybe, making PowerPoint presentations, having kind of visual aids whatever, having demonstrations and also having practical work, they will do things themselves. (Eric)</td>
</tr>
<tr>
<td>9. (Additional question to current CoRes) Advice you would give to a teacher teaching this idea for the first time.</td>
<td>Demonstrate it themselves first then because unless they're experienced teaching they don't realise the things that could happen. When they've a bunch of kids down, they might have shown them the pipette and burette but they'd be surprised by what they do with it, like so they should demonstrate it fully themselves first if they were a young teacher, and that gives them confidence doing it right because when they're actually, okay they know how to do it because they've done it in the past before. They actually set it up here in their own lab with the same equipment the kids will have, if they do it themselves, they maybe see the snags and let the kids see them doing it. (Shane)</td>
</tr>
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<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td>Like a lot of things, think about it a lot themselves and feel it's a bit like a story about a guy who goes into the staffroom. He says 'I explained it, suddenly I understood it' and they didn't understand it and I explained a second time and a third and a fourth time but the fifth time I explained it, suddenly I understood it and very often teachers, I think can get very, very ambivalent and feel that they really understand something but they think an awful lot about it and try to go at it from different angles. (Eric)</td>
</tr>
<tr>
<td></td>
<td>Kids are not given enough opportunity, to contribute. They're suppose to be part of a school community but their contribution is, in being aware of the textbook that they're using, whichever the two it happens to be but also to develop their own set of results, taking stuff from the web, taking stuff for example they mightn't have a moodle or whatever, taking maybe, making PowerPoint presentations, having kind of visual aids whatever, having demonstrations and also having practical work, they will do things themselves. (Eric)</td>
</tr>
<tr>
<td></td>
<td>Teachers have a tendency to follow whatever chapters are done in the book or whatever looks nice or interesting. Suddenly they're into a topic and they realise oh there's gaps here. So plan out, if they hadn't done this before, think very carefully about what are the prerequisites to teaching this and what additional information whatever and it's coming from them, they understand it that little bit, more than a little bit, a hell of a lot better. The foundation, the time that a teacher invests in that in the beginning pays off many times over later on when doing more complicated questions. (Eric)</td>
</tr>
</tbody>
</table>
they understand what a mole is and they can't understand what a mole is really until they start talking maybe about molecular mass and how molecular mass they need to know about atomic, there is a sequence and there is a structure. (Eric)

an awful lot of cases, where they have to wear a uniform tidily, could be here on time and sit quiet in class. That's not much of a contribution to a community. Whereas for something like this, yes, here's something they can do. That makes them feel good for another teacher to say 'Listen, thanks for that. I appreciated that.' (Eric)

because remember, again, nobody should teach from the textbook. Use if for scaffolding but the kids have the textbook that they can bring home. A teacher is there to add value to it, to add meaning, to add value. (Eric)
Appendices: Appendix J

Appendix J

PaP-eR: Using a Virtual Chemistry Laboratory to Teach Titrations

Various teaching methodologies can be adopted for laboratory work. This PaP-eR describes teachers’ experience of using a Virtual Chemistry Laboratory to aid in their teaching of acid/base titrations.

Well worth doing the Virtual Lab before they come to doing the actual hands-on titration because you are not worried about safety, breakages and actually just collecting the equipment and getting it all laid out and when the Virtual Lab is done then you can just clear the desk in one click almost! And it is done so it is very time efficient. The kids built up a good bit of confidence and I think they thought about it a lot because they had not to, they had a good clear picture of what they were trying to do because they had not to worry about spillages and getting burnt with acid or having their protective glasses on and breaking glassware and getting cut and where was everything and knocking things over. So some of the kids actually get a bit fretful when they, inevitably, they will knock over a beaker and they will break it and they get all hot and bothered about it so there was none of that issue at all. I think when they came back to do the actual hands-on one they were, they were much more confident in it. So I like the idea of doing the virtual first now...and I did not start off at that. I started off doing the hands-on one first and then to the Virtual Lab but now I switched around. I will do the Virtual one first. (Shane)

You have too many distractions to distract you from what you are trying to do when you are going around the lab, ‘Where is this glassware? Where are the beakers? Where is the acid? How do I fit the filler on to the pipette without breaking it?’ There are too many physical things to be done that distracts them. I felt that the Virtual Lab goes straight on to the doing of it and not having all those distractions and safety as well. (Shane)

I think something like a virtual laboratory is extremely useful because with a limited 40 minutes, if you have got a certain number of pupils, the amount of time you can fairly allocate to each child in a class is quite limited, whereas with something like this they can go home or in their spare time they can tease around with it and they can
play with it and manipulate it until it really makes it their own or what can happen and happened on a number of occasions for example one student [name removed], he came back with much higher order questions. He left the class not understanding it but he came back next morning with a clearer understanding of what he did not understand through the, if you understand what I mean, through the playing around with it at home. (Eric)

The virtual lab gives students an opportunity to learn or to study or to play around with concepts any time in any place, that the learning is not being limited to the classroom. Learning is not being limited to the school and not only that it allows them to replicate what they would be doing in a real world. So it is not just reading about how a titration can be carried out. It allows them to carry out the titration so therefore they are in a position to make mistakes. They are in a position, you know, to carry out the activities themselves and that I think, real learning, for learning to take place the activities or the learning activities have to be realistic and I think virtual chemistry laboratory provides that level of realism. (Eric)

I suppose in science teaching I am looking for some way all the time of re-inforcing the chalk and talk. Okay and as a method of giving homework, rather than just here is a hand-written problem, the figures are all there, work it out. With the Vlab you are making them at least repeat the experiment from the chemistry lab okay. So it is extending their, their approach to the question. It is the exact same question that you would have given them had you written it out and said a student did something and here are their results. Now you are saying here are the chemicals, you get the results. So you are re-inforcing the whole learning that way. (Paul)
Appendix K
Nodes for Initial Interviews (Free Mind Software used to map nodes)

First Draft of Nodes for Initial Interviews

The author coded nodes as issues appeared from the interview transcripts (See Appendix A for topic guide).
*Second Draft of Nodes for Initial Interviews*

The author refined the nodes more clearly with many of the responses relating to resources students or another factor mentioned, dependent on the question asked.
**Appendix L**

**Reference Table of Teachers in the Case Studies**

This appendix provides information related to each teacher in Stage 2 and Stage 3. Where relevant the author has included page numbers within the thesis to highlight evidence of a teacher classification. The purpose of this table is allow the reader a quick and easy means to compare teachers within the case studies.

<table>
<thead>
<tr>
<th>Teacher Pseudonym/ Characteric</th>
<th>Eric</th>
<th>Paul</th>
<th>Mark</th>
<th>Martina</th>
<th>Shane</th>
<th>Susan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years Experience</td>
<td>20+</td>
<td>20+</td>
<td>20+</td>
<td>10</td>
<td>20+</td>
<td>1</td>
</tr>
<tr>
<td>School Type</td>
<td>Mixed</td>
<td>Girls</td>
<td>Boys</td>
<td>Girls</td>
<td>Mixed</td>
<td>Girls</td>
</tr>
<tr>
<td>School Location</td>
<td>City suburb</td>
<td>Rural town</td>
<td>Rural big town</td>
<td>Rural town</td>
<td>Rural town</td>
<td>Rural big town</td>
</tr>
<tr>
<td>ICT comfort</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Assessment Focus</td>
<td>Low (p.109)</td>
<td>High (p.107)</td>
<td>Medium (p.113)</td>
<td>High (p.112)</td>
<td>Medium (p.105)</td>
<td>High (p.141)</td>
</tr>
<tr>
<td>Empowerment</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Understanding of Inquiry</td>
<td>High (p.110)</td>
<td>Medium (p.108)</td>
<td>Low (p.113)</td>
<td>Low (p.113)</td>
<td>High (p.119)</td>
<td>Low (p.126)</td>
</tr>
<tr>
<td>Comfort with researcher</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Direction needed from researcher</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Positive Attitude to VCL</td>
<td>High (p.117)</td>
<td>Medium (p.118)</td>
<td>Medium (p.117)</td>
<td>High (p.117)</td>
<td>High (p.116)</td>
<td>Medium (p.140)</td>
</tr>
<tr>
<td>Students taught using the VCL</td>
<td>5th years</td>
<td>5th years</td>
<td>2nd Years</td>
<td>Transition Years</td>
<td>5th Years</td>
<td>5th Years</td>
</tr>
<tr>
<td>Stages of research involved in</td>
<td>Stage 1, 2, 3 &amp; 4</td>
<td>Stage 2</td>
<td>Stage 2, 3 &amp; 4</td>
<td>Stage 2</td>
<td>Stage 1, 2, 3 &amp; 4</td>
<td>Stage 3 &amp; 4</td>
</tr>
</tbody>
</table>
Appendix M

Reformed Teaching Observation Protocol

I. BACKGROUND INFORMATION

Name of teacher __________________________ Announced Observation? __________________________
(yes, no, or explain)

Location of class __________________________ (district, school, room)

Years of Teaching __________________________ Teaching Certification __________________________
(K-8 or 7-12)

Subject observed __________________________ Grade level __________________________

Observer __________________________ Date of observation __________________________

Start time __________________________ End time __________________________

II. CONTEXTUAL BACKGROUND AND ACTIVITIES

In the space provided below please give a brief description of the lesson observed, the classroom setting in which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students (number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

Record here events which may help in documenting the ratings.

<table>
<thead>
<tr>
<th>Time</th>
<th>Description of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

272
III. LESSON DESIGN AND IMPLEMENTATION

<table>
<thead>
<tr>
<th></th>
<th>Never Occurred</th>
<th>Very Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The instructional strategies and activities respected students’ prior knowledge and the preconceptions inherent therein.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>2</td>
<td>The lesson was designed to engage students as members of a learning community.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>3</td>
<td>In this lesson, student exploration preceded formal presentation.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>4</td>
<td>This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>5</td>
<td>The focus and direction of the lesson was often determined by ideas originating with students.</td>
<td>0 1 2 3 4</td>
</tr>
</tbody>
</table>

IV. CONTENT

Propositional knowledge

<table>
<thead>
<tr>
<th></th>
<th>Never Occurred</th>
<th>Very Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>The lesson involved fundamental concepts of the subject.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>7</td>
<td>The lesson promoted strongly coherent conceptual understanding.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>8</td>
<td>The teacher had a solid grasp of the subject matter content inherent in the lesson.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>9</td>
<td>Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>10</td>
<td>Connections with other content disciplines and/or real world phenomena were explored and valued.</td>
<td>0 1 2 3 4</td>
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</tbody>
</table>

Procedural Knowledge

<table>
<thead>
<tr>
<th></th>
<th>Never Occurred</th>
<th>Very Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>12</td>
<td>Students made predictions, estimations and/or hypotheses and devised means for testing them.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>13</td>
<td>Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>14</td>
<td>Students were reflective about their learning.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>15</td>
<td>Intellectual rigor, constructive criticism, and the challenging of ideas were valued.</td>
<td>0 1 2 3 4</td>
</tr>
</tbody>
</table>
Continue recording salient events here.

<table>
<thead>
<tr>
<th>Time</th>
<th>Description of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

V. CLASSROOM CULTURE

**Communicative Interactions**

<table>
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<tr>
<th></th>
<th>Description</th>
<th>Never Occurred</th>
<th>Very Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Students were involved in the communication of their ideas to others using a variety of means and media.</td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>The teacher’s questions triggered divergent modes of thinking.</td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>There was a high proportion of student talk and a significant amount of it occurred between and among students.</td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Student questions and comments often determined the focus and direction of classroom discourse.</td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>There was a climate of respect for what others had to say.</td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
</tbody>
</table>
## Student/Teacher Relationships

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>21)</td>
<td>Active participation of students was encouraged and valued.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>22)</td>
<td>Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>23)</td>
<td>In general the teacher was patient with students.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>24)</td>
<td>The teacher acted as a resource person, working to support and enhance student investigations.</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>25)</td>
<td>The metaphor “teacher as listener” was very characteristic of this classroom.</td>
<td>0 1 2 3 4</td>
</tr>
</tbody>
</table>

Additional comments you may wish to make about this lesson.