Concept Mapping in Physics in an Irish University:

An investigation into the application of the tool with particular reference to its relevance to problem solving and the use of scientific language

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Abstract

Irish students’ interest and enjoyment of science deteriorates as they progress through formal education and subsequently enrolments in the physical sciences at second and third level education are low. Research in science education has identified reasons for the poor uptake of science subjects with attitude identified as a key factor (Regan, 2005; Smyth and Hannon, 2002). This thesis documents a research study in which Concept Mapping was introduced into a third level education physics classroom with the aim to improve students’ attitude towards Physics (Phase 1 and Phase 2). The research was developed further to investigate the role of Concept Mapping in analysing physics students’ use of scientific language when problem solving (Phase 3).

Due to the diversity of the research questions a mixed-model methodology was employed incorporating both qualitative and quantitative research paradigms. The research participants employed in this action research study (longitudinal study) consists of 88 pre-service science teachers enrolled in a science education degree in the University of Limerick. The initial phases (Phase 1 and Phase 2) of this longitudinal study examined the use of Concept Mapping in third level education in Ireland and analysed pre-service science teachers’ opinion of the tool. The third phase of the study involved the analysis of the research participant’s use of scientific language. Experts were recruited in this phase to examine the comparable use of language used by both students (novice) and experts. Data collection tools involved the use of student constructed concept maps, questionnaires and semi-structured interviews.

The research findings from this study support the use of Concept Mapping in third level education, particularly for use in pre-service science education courses. The findings strongly indicate that third level physics students find Concept Mapping extremely useful in the classroom, both as a student and a teacher. The students report positive views on the use of the tool when learning physics and also on improving their attitude towards physics. The findings outlined from the third phase of the study indicate that there are several levels of scientific language used when problem solving, namely scientific, intermediate and instinctive, however there is a clear distinction in the approaches used by experts and novices. An important outcome of this study is the relationship between proficiency in scientific language and ability in problem solving. The essential role of scientific language in problem solving is identified through this research as it is the means by which students explain their understanding of physical phenomenon when answering both qualitative and quantitative word problems. This research provides information that can be used to improve the teaching and learning of science subjects, both at pre-service and in-service level.
Declaration

This thesis is presented in fulfilment of the requirement for the degree of Doctorate of Philosophy. It is entirely my own work and that it has not been submitted for any other academic award or part thereof, at this or any other educational institution. Where use has been made of the work of other people it has been fully acknowledged and fully referenced.

Signature: ___________________________ Date: _____________

Joanne Broggy November 2010
Dedication

I would like to dedicate this to all my family. Thanks for all the support and encouragement.
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To my parents and family, especially my twin, Teresa. You will never again hear me say ‘I can’t, I’m sorry; I have work to do on my thesis’. Thanks for all your words of encouragement, support and advice throughout the duration of this project.

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Chapter 1

Introduction

1.1 Introduction

Despite the centrality of science to our life and to the progress of our society, many students opt not to study science related subjects in second and third level education and thus fail to acquire scientific knowledge, understanding and abilities. This is having a negative effect on the number of science graduates available to work in scientific industries and also on the public’s view of the science subjects. This problem has been voiced in many publications in Ireland (Report of the Task Force on Education of Mathematics and Science at Second Level, 2010; Report and Recommendations of the Task Force of the Physical Sciences, 2002) and with each new publication new recommendations are highlighted to rectify the problem. These recommendations include the allocation and distribution of funding to science teaching in both primary and secondary level (Task Force on the Physical Sciences, 2002) and the introduction of Science as a compulsory subject in Junior Cycle (Engineers Ireland, 2010) amongst others, including the development and piloting of innovation approaches to teaching and learning.

This research project outlines and presents research on the use of one such innovative approach, Concept Mapping (Novak and Gowin, 1984). The study originally focused on the design, implementation and evaluation of the Concept Mapping tool, (Phase 1 and Phase 2). Following analysis of the results from the first two phases it was decided that further exploratory research was required to identify the difficulties encountered by students when representing their knowledge (Phase 3). This led to a thorough investigation of the students’ use of scientific technical language during problem-solving. As each phase informed and defined the subsequent phase the research aims and questions evolved throughout the research project and are identified below. However, before these are identified
the author will discuss the background to the research and the purpose of this research study.

1.2 Background to the Research

The increased enrolments in third level education in recent years have resulted in increased student diversity in the lecture halls in first year science (Buntting, Coll and Campbell, 2005). Consequently, teaching and learning strategies need to be introduced and developed in the classroom as not all students learn in a similar manner and each student will possess different understanding of science as a result of their own experience.

One of the key objectives within any university degree is to present the core concepts of the topics. However students, particularly those enrolled in science and physics degrees often have difficulty understanding the various concepts taught (Karenauskaite and Katiliute, 2007) and are unable to solve conceptual problems relating to basic physics principles. To facilitate students understanding there is thus a need to find new teaching strategies that will improve the quality of physics studies. Teaching instruction must make the shift from “teaching by telling” (Thornton, 1992) to one that allows students get actively involved in their own learning in the classroom. One such teaching strategy is Concept Mapping. This is an innovative method based on the constructivist approach that depicts ones understanding of key concepts within a specific domain. Concept Mapping has been reported in past and current research studies to “provide a very effective strategy to help students learn meaningfully” (Buntting, Coll and Campbell, 2005, p.643) as well as facilitating collaborative learning (Edwards and Fraser, 1983) and promoting students problem solving ability (Okebukola, 1992).

1.3 Research Purpose

During the past thirty years a steadily increasing number of educationalists and physicists have being contributing to the growth of a new field for scholarly inquiry: the learning and teaching of physics, supplying a rich source of information (McDermott, 1993). From the literature it is evident that studies have focused on why students study physics (e.g. Woolnough, 1994a; Woolnough
others have focused on the success of students in college physics (e.g. Yager and Krajcik, 1989; Sadler and Tai, 2001) and the initial knowledge state of first year undergraduate students (Halloon and Hestenes, 1985), however very little work has focused on students use of language in physics, particularly their use of scientific technical language.

The research presented in this thesis was motivated by the falling number in enrolments in the physical science subjects in second and third level education. The focus of the study is on the design, implementation and evaluation of a Concept Mapping intervention in third level physics modules. Since the introduction of Concept Mapping numerous research studies and reports have documented the advantages of this form of knowledge presentation and their positive effect on student learning (for example Zieneddine and Abd-El-Khalick, 2001; Ferry, Hedberg and Harper, 1997; Adamczyk and Willson, 1996; White and Gunstone, 1993; Novak and Gowin, 1984). Despite the vast array of literature pertaining to the use of Concept Mapping in educational situations, little work reflects the use of the tool in improving students’ attitude towards science and physics in particular. The majority of the literature refers to use of the tool as an assessment instrument and its use in analysing students knowledge structures. Thus, the research presented in this thesis is unique as it aims to expand the role of Concept Mapping and examine its use in improving attitudes towards physics and also to investigate the role it can play in investigating students’ proficiency in scientific language.

The significant role of language in science education is an important issue that cannot be ignored. The language of science is the key component of communication in a science classroom and can be in the form of oral (listening and talking) or written (reading and writing). The ability of students to communicate in a classroom depends on the richness of their vocabulary. However the students not only need to be familiar with and understand the meaning of the words, they must also be able to relate them to prior knowledge. With this in mind the purpose of this research study was twofold:
1. To examine pre-service science and physics teachers experience of Concept Mapping.
2. To assess pre-service science students proficiency in scientific language.

Further, more specific, research questions emerged from these initial research questions.

1.4 Research Questions

The research evolves with a main focus on the use of Concept Mapping in third level education in an Irish university. In this task the author is guided by the following research questions for each phase of the research study.

**Phase 1 (Pilot Study)**

The aim of the pilot study was to introduce Concept Mapping to undergraduate physics students and to evaluate its feasibility within the University of Limerick setting.

Several objectives were outlined for the pilot study. They included:

1. To train students how to construct a concept map insuring all components of a map are present.
2. To help students connect knowledge, both prior and new.
3. To encourage students to summarise information graphically in the form of a concept map.

**Phase 2 (Exploratory Study)**

Phase 2 was informed by the results generated in the pilot study. The students’ positive reaction to Concept Mapping was evident however Phase 2 was designed to report on the benefits of Concept Mapping in an Irish third level institution. To facilitate this analysis the following research questions were outlined.

1. How do concept map scores correlate with progression through a specified module?
2. What elements are essential for the training of undergraduate physics students in Concept Mapping, as seen by the students?
3. Does experience of Concept Mapping improve students’ attitudes towards Physics and what issues concerning the use of the tool are identified after one semester experience?

4. Are concept maps valid assessment tools in third level education?

**Phase 3 (Development of the Concept Mapping Study)**

The nature and characteristics associated with Concept Mapping lends itself to many diverse avenues of investigation. Having successfully reported the benefits of the tool within the physics classroom during the exploratory study (Phase 2) the author synthesised the research findings and expanded the study further into a second year physics module with the aim to evaluate the students’ use of scientific language using concept maps and physics word problems. The following research questions were considered in Phase 3 of the research study.

1. Can solutions to theoretical qualitative physics problems be categorised into levels of scientific language? If so how many categories of language are used when answering physics problems and what are the characteristics of each category?

2. Is there a significant difference in the levels of language used by experts and students when solving qualitative word problems?

3. Is performance in physics word problems affected by the level of scientific language proficiency? If so, to what degree does language proficiency have an effect on problem solving ability?

4. In what way, if any, did the lecturer’s use of language and problem solving ability impact on the students’ proficiency in scientific language and problem solving ability?

5. What issues in relation to students’ attitudes and beliefs concerning concept mapping and the use of the tool in a science classroom come to light following a year’s experience of the tool?

6. Does having experience in concept mapping encourage pre-service teachers to use the tool in their own teaching? If so, in what aspect of teaching do they incorporate it and what are their conceptions concerning Concept Mapping following its usage?
1.5 Research Methodology

In order to facilitate the analysis of the research questions outlined above mixed methods were employed during this year-long study resulting in both qualitative and quantitative data. The research project presented in this thesis incorporated a five-phased approach. The structure of this research project was that of action research which allowed the author to focus on finding a solution to a local problem in a local setting (Leedy and Ormond, 2005). The individual phases of this research study are outlined briefly in the following concept map (Figure 1.1).

![Concept Mapping Study]

Figure 1.1: Research Methodology employed in this research study

1.6 Significance of Research Study

This research is of significance to the domain of physics education and Concept Mapping as it extends the knowledge base that currently exists. The research findings of this study contribute to the national and international studies that have, and are currently taking place which address the important areas including low
numbers of students studying science subjects and factors affecting their subject choice.

The use of Concept Mapping is relatively new in Irish schools and third level institutions and as of yet no such research has been carried on their use in third level in Ireland. This study has significant implications for the development of teacher training programmes and also the status of physics in Irish second level schools as the results signify the importance and the role of scientific language to students’ problem solving and subsequently their understanding of scientific topics.

The students who embraced Concept Mapping in this research study have welcomed the educational benefits it has to offer and reportedly used it in their own teaching as they believe it improves attitudes towards physics and is a very useful tool in the classroom, both for instructional and assessment purposes.

The researcher intended to further develop the use of Concept Mapping in examining students’ scientific language. The output of this stage of the study will provide insights into how students use scientific language and help educators and teachers understand reasons why students struggle with problem solving. Ultimately, the author believes that this research will help raise awareness among those who are unfamiliar with the potential applications and benefits of Concept Mapping in educational settings in Ireland. The research also contributes to research in the field on scientific language and the negative affects poor scientific language can have on student problem solving.

1.7 Definitions of Terms used throughout this Research Study

Longitudinal Study
A longitudinal study is a research study that involves repeated observations and collection of information of the same group of individuals over long periods of time.
Primary Education
The Irish educational system is divided into three levels, the first being primary. Primary level education is 8 years in duration consisting of two initial years (Junior and Senior Infants), followed by classes 1 to 6. Most Irish children commence at the age of four or five years and complete at the age of 12/13. The primary curriculum is very broad and covers areas including languages, mathematics, social, environmental and scientific education, arts education (including visual arts, music and drama), physical education and social, personal and health education.

Secondary Education (Post-Primary Education)
The second level in the Irish education system is identified as secondary education or post-primary. Secondary level education builds on the foundation of primary education and is a 5 year programme. There is an option for a sixth year which runs after year three and prior to year four, this year is identified as Transition Year (TY). The secondary-level education sector comprises secondary, vocational, community and comprehensive schools. All of these schools provide the Certificate courses prescribed by the Department of Education and Science which are known as the Junior Certificate and Leaving Certificate examinations.

Third Level Education
Third Level Education in Ireland is provided by Universities, Institutes of Technology and Colleges of Education. Entrance into third level education is decided through the use of a ‘points system’. Students Leaving Certificate exam grades are converted into numerical points. The students are given access to the course depending on the number of points they have. Most degree programmes are of the duration of four years with the majority of students finished their third level education at the age of 22. Students can also opt to complete a certificate or a diploma in third level institutes.

Junior Certificate Examination
The Junior Certificate examination is held at the end of the Junior Cycle in post-primary schools. Students normally sit for the examinations at the age of 14 or 15,
after 3 years of post-primary education. The examination consists of individual exams for each of the subjects the individual studied in their junior cycle.

**Leaving Certificate Examination**

The Leaving Certificate examination is the final exam in post-primary education. Students usually sit this exam at the age of 17 or 18 years of age. This programme takes two years to complete and again consists of individual exams for the subjects the students have chosen in their senior cycle. Students who wish to attend higher level education must complete the Leaving Certificate exam or foreign equivalent.

**Action Research**

Action research is a systematic form of inquiry that is collective, collaborative, self-reflective, critical, and undertaken by the participants of the inquiry (McCutcheon and Jung, 1990). Action research revolves around reflection where it is first essential to understand what is happening and to evaluate it, then to introduce change and evaluate the new situation.

**Concept Mapping**

Concept Mapping is a practical teaching tool that was first developed by Novak and his research team in Cornell University in the early 1970’s. A concept map is a graphical representation that shows relationships among concepts. The characteristics of a concept map set it apart from other graphical representational tools.

**Meaningful Learning**

Meaningful learning is the opposite of rote learning and occurs when new and old concepts are combined to make new meanings.

**Attitude**

There is no agreed definition for attitude; however it is often a response to an object, person, situation or concept. This response can be positive or negative and often determines behaviour towards or opinions and beliefs about the object, person, situation or concept.
Scientific Language
Scientific language differs from that of everyday language in that it contains gestures, unique symbols and signs, mathematical formulas and graphic representations. Scientific language includes technical and non-technical language that together form to generate a collection of words that describe scientific phenomenon, laws and principles.

Novice
A novice is a person or creature who is new to a field or activity.

Expert
An expert is a person with extensive knowledge or ability based on research, experience, or occupation and in a particular area of study.

1.8 Structure of the Thesis – Overview of thesis chapters

Chapter 2
This is the first of three literature review chapters, which opens by setting the context of science in Ireland. In this chapter the author explores the provision and student participation of science in the Irish education system. Particular emphasis is placed on Irish students’ participation in Physics. The characteristics of third level Physics students are examined followed by a detailed discussion of the factors that affect students’ subject choice.

Chapter 3
Chapter three is a review of the current literature on Concept Mapping which explores current thinking and previous research on the use of the tool in educational settings. The use of the tool as both an instructional and assessment tool is discussed. There is also a special focus in this chapter on the theoretical frameworks from which Concept Mapping developed. The chapter concludes with an insight into students attitudes towards the tool.
Chapter 4
Chapter four is the final literature review chapter. This chapter examines and reviews the literature on problem solving and scientific language. This chapter begins with a detailed account of distinction between experts and novices. The author then explores the literature on problem solving, including that of types of problems and problem solving strategies. The chapter proceeds with a review of scientific language and particular focus is placed on the examination on the technicality of scientific language.

Chapter 5
In this chapter the author provides a detailed description of the methods used in the design, implementation and evaluation employed in this study. This chapter provides the rationale for the selection and implementation of the research design. Theoretical and procedural issues concerning the research process are also examined, while discussing in detail each stage of the research process.

Chapter 6
This chapter provides a comprehensive analysis of Phase 1 and Phase 2 of the research study. The chapter focuses on the students’ experience and opinions of Concept Mapping. The maps collected, together with student questionnaires and semi-structured interviews were evaluated and analysed to determine the benefit, if any, of Concept Mapping for Irish students. The chapter concludes with a detailed discussion of the research conclusions of both phases.

Chapter 7
Chapter 7 has a dual purpose. Initially the chapter focuses on the pre-service students’ proficiency of scientific language and problem solving ability of 10 students from the original large sample. The associated findings from 6 experts are also presented and compared against those of the students (novices) to determine the differences that exist between an expert and a novice when problem solving. The second purpose of this chapter is to present the findings of the final questionnaire that focuses on the pre-service teachers’ conceptions of the Concept
Mapping tool following Teaching Practice (TP). These findings are clearly laid out and discussed in relation to the use of the tool in teacher education courses.

**Chapter 8**

This is the final chapter of the research thesis. In this chapter the author summarises the main conclusions of the research study according to the research questions. The closing sections of this chapter include a discussion of the research contributions and limitations of the work. Recommendations and suggestions for future work conclude this chapter.
Chapter 2

Student Participation in Science in Ireland and the Reasons Affecting Subject Choice

2.1 Introduction

The literature is replete with studies concerning physics education. Internationally, substantial research has been carried out in an attempt to resolve the “swing from science”. Ireland is no different as the nation is also struggling with low numbers of students studying science in secondary level education and subsequently third level education. In recent years there has been a steady decline in the number of students studying science subjects and in the context of Ireland’s technological society and economy, students’ interest in the physical sciences is of utmost importance. In order for Ireland to sustain a competitive economy the number of students taking science subjects, in particular Physics and Chemistry, must increase.

This chapter begins with a brief description of the Irish educational system and continues to discuss student participation in the physical science subjects, focusing particularly on physics. The physics student population is also examined, while also addressing the issues of student retention and students’ attitudes towards physics.

2.2 Irish Educational System

The Irish Educational System is composed of primary, secondary, third-level and further education (Figure 2.1). Education is compulsory in Ireland from the age of six to sixteen, or until the student has completed at least three years of second level education. Every child is eligible for free education provided by the state, unless you choose to send your child to a private institution. The individual levels of the Irish education system are now discussed individually.
Figure 2.1: Structure of the Educational System in Ireland (Department of Education and Science, 2004)
2.2.1 Primary Level Education

As stated above, the compulsory age for students to commence primary level education is 6 years; however it is normal for students to begin the September following their fourth birthday. The primary level system includes eight levels or classes, each of which takes a year to complete, ranging from junior infants (4 year olds) to sixth class (12 year olds). The general aims of first level education are outlined in the primary school curriculum (Department of Education and Science, 1999, p.7) stating that it aims to:

1. enable the child to live a full life as a child and to realise his or her potential as a unique individual.
2. enable the child to develop as a social being through living and co-operating with others and so contribute to the good of the society.
3. prepare the child for further education and lifelong learning.

These aims are carried out through the integration of curriculum which “reflects the educational, cultural, social and economic aspirations and concerns of Irish society” (Department of Education and Science, 2004). The curriculum, which is child-centred and allows for flexibility in timetabling and teaching methods, is divided into several key areas including language, mathematics, social, environmental and scientific education, arts education, including visual arts, music and drama, and finally physical education and social, personal and health education.

2.2.2 Second Level Education

Second level education commences the September following the completion of first level education, at the age of 12 years. Second level education is provided by three main types of post-primary schools, comprising of secondary, vocational and community and comprehensive. This level of education consists of two cycles; a three-year cycle followed by a two-year cycle, each of which concludes with a state examination; the Junior Certificate and the Leaving Certificate Examination respectively. Depending on the school, students may also have the opportunity to complete an additional year, identified as Transition Year (TY),
which follows the Junior Certificate examination. This is an optional programme which does not contain any formal examination. The emphasis and purpose of the year-long programme is to increase development and maturity within the student. Each school devises its own timetable to cater for the needs of their students however this is carried out in accordance with the Department of Education Guidelines and the school and community resources. The programme is designed and delivered by the co-ordinator, core team and teaching staff in consultation with management.

The final two years of second level education prepare the students for one of three state examinations, each of which is related to a specific programme namely the established Leaving Certificate, the Leaving Certificate Vocational Programme and the Leaving Certificate Applied. To date the Leaving Certificate established is the only programme that warrants entry into third level education.

Within second level education students have the option to study their subjects at two (and sometimes three) levels. These levels are identified as higher (honors) and lower (pass) level. The third level, which is only offered in Irish, English and Mathematics at junior cycle and Irish and Mathematics at senior cycle, is identified as foundation level.

**2.2.3 Third Level Education (Higher/Tertiary Education)**

Third Level Education in Ireland is provided by Universities, Institutes of Technology and Colleges of Education, which again are substantially funded by the state. There are seven Universities and fourteen Institutes of Technology located nationwide in Ireland, each of which offer degree programmes at bachelor, masters and doctorate level. Entrance into third level education is decided through the use of a ‘points system’. Students Leaving Certificate exam grades are converted into numerical points. The students are given access to the course depending on the number of points they have. Most degree programmes are of the duration of four years with the majority of students finished their third level education at the age of 22.
2.2.4 Further Education

Further education is available to adults and comprises of education and training which takes places after second level education. It provides second-chance education opportunities for adults who may have not completed second level education or for those who wish to return to work but lack adequate qualifications.

2.3 Student Participation in the Physical Sciences

It is not unknown that there has being a sharp decline in the number of students studying science subjects in the Leaving Certificate and subsequently enrolling in science related courses. Several reports and strategies have been carried out and implemented in recent years in an attempt to increase the number of students opting to study science subjects in schools and colleges, including the Task Force on the Physical Sciences (2002) and the Strategy for Science, Technology and Innovation (Department for Enterprise, Trade and Employment, 2006). Both set out to decrease the ‘swing from science’ and increase interest in science with the aim of motivating students to continue studying science to third level education. Variation in student participation in science subjects is evident in all levels of education in Ireland where participation levels decrease as students proceed from primary to third level education.

2.3.1 Primary Level Participation in Science

“Interest in science must be stimulated at an early stage and fostered throughout the educational system”

(Department for Enterprise, Trade and Employment, 2006)

Science teaching in primary level has undergone radical changes in recent years. Prior to 2003, science was not a compulsory subject in the curriculum and was taught under the umbrella of Environmental Studies. Consequently, under the pressure of the teachers’ tight time schedule science was not a priority. However, following several national surveys and reviews (Curaclam na Bunscoile, 1971 and National Council for Curriculum and Assessment, 1990) the significance and
importance of science for the students’ education was brought to light resulting in the introduction of science as a compulsory subject in 2003.

Recently the NCCA examined the extent of the curriculum’s implementation and reported their findings (Varley, Murphy and Veale, 2008). This study focused on students’ experience of primary science, surveying over 1000 students from third to sixth class. Some of the main findings include the following:

- Primary children are enthusiastic about primary school science.
- Primary children are very positive about hands-on science and appear to have opportunities to engage in it, applying a range of scientific skills as a result. In general, children work collaboratively in small groups when they conduct hands-on activities. The majority of children enjoy working in this way.
- Some pupils do not have regular opportunities to engage in hands-on science.
- Some children may be experiencing teacher demonstration and teacher explanation as dominant features of their primary science learning.
- Reading and writing feature in science lessons and include: copying from the board; reading textbooks; and completing worksheets and workbooks. Pupils’ attitudes towards using these methodologies are not entirely positive.
- Children are very enthusiastic about working on science outside the classroom. They also express positive views about going on science-related trips and having visitors who engage them in scientific work at school. However, these events are not frequent.
- Children are positively disposed towards the notion of using ICT in science. However, children’s actual experiences of using ICT in science lessons appear to be extremely limited.
- The majority of children’s experiences of school science relate to the strands Living things, Energy and forces and Materials.
- Children’s experiences of science within the strand units of forces, and properties and characteristics of materials, appear to be rather limited.
Children’s reports of lessons relating to the strand of ‘environmental awareness and care’ are infrequent in comparison with the other three strands.

In general, primary children are not necessarily relating their school science experiences to the wider world or to future aspirations.

(Varley, Murphy and Veale, 2008, p.8)

It is evident from these findings that the primary students are very “enthusiastic” about science and enjoy it, and are eager to experience it more frequently. However, as a result of limited exposure to science during their primary school years, Irish students’ performance in science is affected. International studies conducted before the introduction of compulsory Primary Science reveal that Irish children aged between the ages of 9 and 13 performed less well in science-related activities than their counterparts in other countries (International Assessment of Educational Progress, 1988). From the twelve countries that participated in this study, Ireland scored tenth in the average science proficiency, with the British Colombia and Korea coming first and second. The study also revealed that Irish girls had the lowest average science score of any group involved in the study.

The activities in the science classroom have significant effects on the student’s achievement levels in science. The aims set out in the primary science curriculum include the development of scientific knowledge, the development of scientific approaches to problem-solving, the encouragement of children to explore scientific ideas and concepts and to enable the child to communicate ideas and present work (Department of Education and Science, 1999). These aims suggest that students must get the opportunity to ‘question’, ‘observe’, ‘predict’, ‘analyse’, ‘investigate’, and ‘evaluate’ within the science classroom and in essence become actively involved in their learning. However, the literature suggests that this does not take place. Prior to the introduction of science as a compulsory subject, 28% of Irish students solved scientific problems and only 14% of those had the opportunity to carry out experiments with other students. This differs significantly to students in British Colombia schools where 59% of students solve scientific problems and 39% of the students carry out experiments with other students (IAEP, 1988). Since 2003, the activities in the science classroom have altered and
now hands-on science activities are dominant in science classrooms; however they are largely teacher directed (NCCA, 2008).

The NCCA (2008) also reported that students’ attitude to primary school science is positive; with 75% of the cohort claiming that they found it interesting. Therefore one can conclude that students entering second level education enter with a high degree of interest in science.

2.3.2 Second Level Participation in Science

Currently within the Irish Education system Science is not a compulsory subject for the Junior Certificate Programme. A Task Force on the Physical Sciences was established by the Minister for Education and Science in 2000 which was designed to address issues concerning the decline in the uptake of science subjects and to make recommendations for appropriate action. One such recommendation stated that science should become a core subject within the Junior Certificate programme (Smyth and Hannan, 2002) however the provision of science as a subject within Irish second level schools still varies.

Although science is not a compulsory subject, it is studied by the majority of students at Junior Certificate level. In 2006 86% of the student cohort sat the Junior Certificate Science exam (DES, 2008), which was an increase of two percent since 2002. A revised junior-cycle syllabus was introduced in 2003 and first examined in 2006. The new syllabus aimed at placing an emphasis on students’ practical experience of science. As part of the new syllabus students’ coursework was allocated 35% of the marks in the examination which include 10% for experiments and investigations specified in the syllabus and a further 25% for additional specified investigations or one investigation of the student’s choice. Since the introduction of the new syllabus the proportion of students taking science at honours level has increased from 63% to 67% (DES, 2008, see Figure 2.2). This increase in the number of students taking science at honours level is encouraging as it provides a good platform for students participating in science subjects in the Leaving Certificate.
Smyth and Hannan (2002) carried out a comprehensive study in Ireland on those who choose to study science in second level education identifying what influenced the students’ subject choice. The issue of gender was very common in their results and they reported that predominately male students study physics while female students choose biology (Smyth and Hannan, 2002). Their work also looked specifically at the uptake of each of the individual science subjects. From the three science subjects, (physics, biology and chemistry), physics has gained the least interest from students. The release of the 2009 Leaving Certificate results emphasised this lack of interest with only 8% of the students choosing physics at higher level (Irish Times, 2009). This represents a downward trend as the predicted number for students taking higher level physics was 5992 in 2009; however only 4694 students sat the higher level paper in it (State Examinations Commission, 2009). The following graph (Figure 2.3) represents the number of students taking Physics, Chemistry, Biology and Physics/Chemistry at Leaving Certificate Level from the years 1992 to 2008.
Figure 2.3: The percentage of students studying the four science subjects in Ireland

It is clear that Biology continues to sustain the highest numbers of students, while the physical sciences still struggle to attract second level students and, as mentioned earlier, these numbers are continuing to decrease. Since only those students who take science subjects in second level education are able to pursue a scientific education and scientific careers, the decline in the numbers of students studying science subjects to the Leaving Certificate raises concerns about the economic wellbeing of Ireland as the demand for science graduates is at an all time high.

2.3.3 Third Level Participation in Science

In Ireland (as in many countries) higher level education has changed considerably. In the last forty years enrolment numbers in tertiary education has grown extraordinarily with the age participation rate rising from 11% in 1965 to an estimated 57% in 2003. This relates to an increase of 21,000 students in 1965 to over 137,000 by 2003 (Organisation for Economic Co-operation and Development, 2004). To facilitate the increase in numbers attending third level education, third level institutions have also increased the availability of courses. Within the seven universities in Ireland there are several opportunities for students
to study science in a variety of fields, including biology and biochemistry, environmental science, physical science, earth science, mathematics, and computing (www.hea.ie).

Despite the opportunities available to students to study science at third level, concerns have been raised regarding the numbers of students who choose to enrol in science degree courses. In 2002, Ireland was above the EU average in terms of the numbers of students enrolled in maths, science and technology courses as a percentage of students in tertiary education (Advisory Science Council, 2006). In spite of this, the numbers of science graduates are decreasing in three of the Irish universities (Figure 2.4).

![Number of students enrolled in science courses in the seven universities in Ireland since 2004.](image)

[UCD: University College Dublin; UCC: University College Cork; NUIG: National University of Ireland Galway; TCD: Trinity College Dublin; NUIM: National University of Ireland Maynooth; DCU: Dublin City University; UL: University of Limerick]

**Figure 2.4:** Number of students enrolled in science courses in the seven universities in Ireland since 2004.

As this thesis focuses on the work of physics students it is fitting to include details of the number of students enrolled in physics courses at the universities in Ireland. Figure 2.5 represents a downward trend as the number of students enrolled in physics courses has reduced in six out of the seven universities since 2004.
From the seven universities in Ireland, only one represents an increase in the student numbers, NUIM. From the six remaining colleges, three have seen dramatic reductions in numbers, NUIG, TCD and DCU.

To exacerbate the problem further, the students who decide to choose science degrees are met with the problem of high non-completion rates. The question of why students’ drop-out rates vary across higher education institutions and disciplines has being the focus of considerable research activity, especially in the USA. One of the most influential theoretical explanations of student attrition is the path analysis model of Tinto (1975, 1987). This model suggests that the students’ social and academic integration into the educational institution is the major determinant of completion. The US literature suggests that first-year withdrawals may be different from others (Smith and Naylor, 2001). Tinto (1987) stressed the effect of the transitional difficulties of adjustment into college life and Porter (1990) showed that about half of all student attrition occurs in the first year.

**Figure 2.5:** Numbers of students enrolled in physics courses in the universities in Ireland since 2004.
2.4 Non-Completion in Higher Education Science Courses in Ireland

The available research in Ireland on non-completion in higher education is quite recent and therefore somewhat limited. In 1999, the Higher Education Authority (HEA) requested the Educational Research Centre (ERC) to carry out a study on non-completion in universities and how it varied by field of study. Information for this study was specific to the seven universities nationwide and included the number of first time entrants who commenced study in 1992-93. This research project ‘tracked’ the students through their undergraduate programme and logged the outcomes in several categories including gender, the number of students who graduated on time and graduated late and those who failed to graduate in the course they commenced. This study proved that Law and Medicine, in contrast to Science, Computer Studies and Engineering, had notably lower rates of non-completion, 88.6% graduated on time in Law courses whereas 65.2% graduated on time in the science domain (includes Agricultural Science, Food science and Technology). The low attainment by or among science students is clearly evident when one highlights that 7.1% did not graduate in their Law course while, in severe contrast, 22.2% failed to graduate in the Science domain (Morgan, Flanagan and Kelleghan, 2001).

Since the publication of this report several initiatives have being designed and implemented throughout the country to combat the problem of low retention rates in undergraduate science degrees. These initiatives range from learning support programmes to faculty specific assistance, to more general provision of study skill seminars. As regard to the science and mathematics interventions, each of the seven universities specifically designed initiatives to assist in the retention of students in this area of study. The initiatives ranged from Mathematics and Science Learning Centres in UL to Pre-Entry Science Programme in UCC and First year Staff-Mentoring Programme in NUI Maynooth (Flanagan and Morgan, 2004). Tinto (2003a) highlighted five conditions to promote persistence within the course. These include expectations, support, feedback, involvement and learning. With the incorporation of these five conditions into the course the attainment of the students can be maximised.
2.5 The Physics Student Population

Having discussed the degree of science participation within the Irish educational system, the author will now specifically look at students who choose to study physics. Traditionally, physics teaching has targeted solely the ‘physicist-to-be’. However, this is no longer the case as the majority of students studying physics in first year are not, and will not, be physics majors at the end of their course. Typically in the United States, no more than one in every 30 university students taking introductory physics will major in the subject (McDermott, 1993). Within the University of Limerick, in the college of Science, ten courses contain physics as a core subject in the first year of the degree but only four of these courses will produce physics majors. From the remaining six degrees the students studying physics do not necessarily want to take it and some may not be interested in the subject.

2.5.1 First Year Physics Students

Each student entering a first year course in physics possesses a system of beliefs and intuitions about physical phenomena derived from extensive personal experience (Halloun and Hestenes 1985; Teaching and Learning Research Programme, 2006). Students enter the physics classroom with misconceptions and preconceived notions not only about physics but also about the schools and how meaningful learning takes place (Hammer, 1989). Guisasola et al. (2002, p. 380) summarised student’s initial thinking and knowledge of science from studies found in the literature. They reported that:

1. Students consider scientific knowledge as a fixed immutable collection of non-related facts and formulae that have little connection to the real world.
2. Their role as students consists of memorizing the facts and formulae and reproducing them during exams. Thus, students tend to be passive learners.
3. Their learning strategies put an excessive emphasis on low-level skills, such as memorization and a critical use of mathematical models, etc.
instead of the high-level ones such as analysis, synthesis and self-evaluation.

4. Usually, students neither use their conceptual knowledge of physics to analyse the problem situation qualitatively, nor plan a possible solution before starting the numerical or algebraically manipulations of equations; they do not reason the strategy to follow in the solution, or question the result obtained.

Together with the students’ experiences and their preconceptions about physics, students develop a cognitive structure which may be valid, invalid or incomplete (Hanley, 1994). The student will formulate his/her existing physics structures only if new information or experiences are connected to knowledge already stored in memory. The problem however, lies in the teaching method. Extensive research has highlighted that the traditional or objective method of teaching does not allow students to “go beyond learning facts, rules, algorithms, and procedures in order to become critical thinkers and problem-solvers” (Marshall, Horton, Igo and Switzer, 2008, p. 576). A classroom based on the objective model tends to resemble a one-person show with a captive but often comatose audience. These classes are usually driven by “teacher-talk” and depend heavily on textbooks for the structure of the course. Nugent et al., (2008, p.1) described the teaching format in undergraduate science courses as “rich in content, (however) they often do not engage the students in active, authentic scientific investigation, nor do they adequately address the problem-solving processes and inquiry skills required to teach science to others”. Teachers within these ‘objective-based’ classes serve as pipe-lines and seek to transfer their thoughts and meaning to the passive student (Hanley, 1994). There is little room for student-initiated questions, independent thought and interaction between students.

A much heralded alternative is to change the focus of the classroom from teacher dominated to student-centred using a constructivist approach. In a constructivist setting, knowledge is not the objective. The role of the teacher is to organise information around conceptual clusters of problems, questions and discrepant situations in order to engage the students’ interest. Hanley (1994) states, that as part of the constructivist approach, teachers must assist the students in developing
new insights and connect them with their previous learning. Ideas are presented holistically as broad concepts and then broken down into parts. The classroom activities are student-centred and students are encouraged to ask their own questions, carry out their own experiments, make their own analogies and come to their own conclusions. This approach facilitates meaningful learning and will therefore encourage conceptual understanding.

2.6 Factors Influencing Students Uptake of Science

The previous section of this chapter highlighted the declining number of students opting to study science at second and third level education in Ireland. The remainder of this chapter will focus on the factors which influence students’ subject choice. The following diagram (Figure 2.6) highlights the several factors that contribute to and affect the uptake of science subjects as shown in the literature.

![Diagram showing factors influencing student uptake of science subjects](https://via.placeholder.com/150)

**Figure 2.6:** Factors that cause and influence student uptake of science subjects

(Adapted from Regan, 2005. p.82)
It is evident from the diagram that there are a number of factors that influence students’ uptake of the science subjects. The author will now discuss some of these factors, including the effect of students’ attitudes, the teacher and teaching strategies, as these are fundamental to this research project. Each factor will be dealt with individually. The author will begin by discussing what an attitude is and how they are formed. The author will then focus on attitudes in science specifically, describing what is known about such attitudes and the influence they have on students’ subject choice and their effect on science achievement. Attention is given to these affective variables, particularly attitude, as they are as important as cognitive variables in influencing learning outcomes, study of science and career choices (Kind, Jones and Barmby, 2007; Osborne et al., 2003; Freedman, 1997; Koballa, 1988a)

2.6.1 Attitudes

Like most abstract terms in the English language, ‘attitude’ has more than one meaning. The word attitude is derived from *aptus*, the Latin word for “fit and ready for action”. This refers to something that is observable, however today’s meaning implies that attitudes are not observable as they are viewed as a “construct” which guides our choices and decisions (Hogg and Vaughan, 2008, p.148). In the past, prior to social psychology, the concept ‘attitude’ was associated with art and was used to describe the physical posture of immobile figures and later the posture of movement among actors and dancers (Fleming, 1967, Cited in Koballa, 1988). Warren and Johoda (1973, p. 9) described this meaning of the word ‘attitude’ as a term that was “used exclusively with reference to a person’s posture….refer to his physical mien”. The term ‘attitude’ evolved somewhat since then and today it is used in a very different context. Attitudes are now concerned with “psychological rather than the immediately physical orientation of a person” (ibid) which refers to the person’s mental state.

The study of attitudes has a long and complex history in social psychology hence various definitions of attitudes can be found in the literature dating as far back as the early 1930’s. However, little agreement among researchers on an explicit definition is recorded (Fishbein and Ajzen, 1975). Gagné and Biggs (1979)
identified attitudes as a type of learning, describing it as an internal state that influences personal action choices (Cited in Good and Brophy, 1990). For each learning type identified, they offered guidelines concerning the different types of instruction that each type of learning requires. Allport (1935) defines an attitude as “a mental and neural state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual’s response to all objects and situations with which it is related” (Cited in Insko, 1967, p. 2). Cook and Sellitz (1964) prefer “to think of attitude as an underlying disposition which enters, along with other influences, into the determination of a variety of behaviours toward an object or class of objects, including statements of beliefs and feelings about the object and approach-avoidance actions with respect to it (Cited in Summers, 1977, p.1). Rosenberg (1956, p. 367) described attitudes briefly as a “relatively stable affective response to an object”. A more recent definition comes from Eagly and Chaiken (1993, p. 1) where they define attitude as “a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour”. Thrustone (1932) defined an attitude as “the effect for or against a psychological object” (Cited in Fishbein, 1967, p.8) where Bogardus’ (1931) definition stated that “an attitude is a tendency to act towards or against some environmental factor which becomes thereby a positive or negative value (also cited in Fishbein, 1967, p.8). All of these definitions describe a response to an object or entity, whether it is a feeling or a belief. In spite of the substantial number of interpretations of the meaning of ‘attitude’, there are “areas of substantial agreement” which were identified by Summers (1970, p. 2) and are listed below.

1. An attitude is a predisposition to respond to an object rather than the actual behaviour toward such abject.
2. Attitude is persistent over time.
3. Attitude produces consistency in behavioural outcroppings.
4. Attitude has a directional quality.

These four aspects of attitude suggest that attitudes are complex and can have crucial consequences towards a student’s learning of an object or subject. In order to fully appreciate what an attitude is one must first identify how an attitude is
developed. The author will continue then to discuss attitudes towards science and physics in particular and identify the effects attitudes can have on achievement.

Many theorists have argued in the past about what is actually required in the construction of an attitude. As attitudes can only come from the learner themselves, they cannot be taught or produced directly through instruction. However, attitudes can be stimulated indirectly through “modelling, persuasion, or manipulation of incentives” (Good and Brophy, 1990, p.34). Several models can be found in the literature describing one, two and three-component models. Thurstone (1931) preferred the one-component model, as he defined an attitude as “the affect for or against a psychological object” (Cited in Hogg and Vaughan, 2008). The psychological object is a “symbol, person, phrase, slogan or idea towards which people can differ as regards positive or negative affect” (Thurstone, 1928 Cited in Hughes 1995, p.67). The two-component model stemmed from Allport’s definition of attitude where he believed that attitudes consisted of a mental readiness to act, which guides evaluation. The final and third model views attitudes as having three components, namely the cognitive, emotional, and action tendency component. This model was evident in a large quantity of research including that of Rosenberg and Hovland (1960) and Himmelfarb and Eagly (1974). These three components together form a person’s attitude towards an object which includes “a cluster of feelings, likes and dislikes, behavioural intentions, thoughts and ideas” (Hogg and Vaughan, 2008, p. 150).

Finally, people often think of attitudes in general terms, for example, “the student has a bad attitude”. The use of the word in this context cannot be ignored because “attitudes always have a referent” (Koballa, 1988, p 117). Koballa continues to define what is meant by a referent stating that “attitudes refer to feelings about or toward some attitude object”. This generality makes the attitude concept of major interest and importance to the science classroom and indeed the science educators.
2.6.1.1 Development of Attitudes

As mentioned above, an attitude is a response to an object; however this response is developed in a sequential manner. Eagly and Chaiken (1993, p.2) outlined the process of attitude formation and described it as follows:

“An attitude develops on the basis of evaluative responding: An individual does not have an attitude until he or she responds evaluatively to an entity on an affective, cognitive, or behavioural basis. Evaluative responding, whether it is covert or overt, can produce a psychological tendency to respond with a particular degree of evaluation when subsequently encountering the attitude object. If this tendency to respond is established, the person has formed an attitude to the object.”

This process of attitude formation relies on evaluative responding, which occurs internally in the person. Attitudes are not directly observable in individuals however they can be inferred from observable responses. As a result, in order to measure a person’s attitudes towards a particular object, verbalisations of feelings and emotions are used (Reid and Skryania, 2002; Adams et al., 2006). Halloran (1970, p.29) acknowledged three main sources of attitudes; direct experience with objects and situations, explicit and implicit learning from other and finally personality development. Gagné and Biggs (1979) believe that attitudes are attained “primarily through exposure to respected models that exhibit the attitudes, rather than through typical instruction” (Cited in Good and Brophy, 1990, p.133).

2.6.1.2 Attitudes towards Science

Science related attitudes are usually subdivided into two groups: attitudes to science and scientific attitudes. Schibeci (1984) clearly distinguished between these two groups stating that “scientific attitude has a predominant cognitive orientation, whereas attitude towards science is predominant affective” (Freedman, 1997, p.343). This section will focus on the affective orientation. Since the realisation of the low numbers of students studying science subjects, and particularly the physical sciences, research groups are now, more than ever, focusing their attention on factors that affect students’ subject choice. The research findings suggest that students’ attitude towards the subject is a significant
factor in their decision. Much research has been carried out in recent years concerning attitudes toward science/physics and the relationship between these attitudes and science achievement (Gungor et al., 2007; Papanastasiou and Zembylas, 2002; Reid and Skyabina, 2002). Several factors have been highlighted as main contributors to the attitudes that students possess towards the science subjects (Halladyna and Shanghnessy, 1982). These factors are related to school and science classes; the individual and even external factors relating to the status and rewards that different countries bestow onto physics-based careers (Woolnough, 1994a). In this section the author will review significant research which has taken place in this area, highlighting the main findings.

In 2003, Osborne, Simon and Collins carried out a comprehensive review of the literature pertaining to studies carried out on students’ attitudes towards science and their implications. In the report ‘attitudes towards science’ are defined specifically as “the feelings, beliefs and values held about an object that may be the enterprise of science, school science, the impact of science on society or scientists themselves” (Osborne et al., 2003, p. 1053). This definition encompasses several components that can affect one’s feelings, beliefs and values. Further examination of the literature emphasizes that there are various other “subconstructs all of which contribute in varying proportions towards an individual’s attitudes towards science” (Osborne et al., 2003, p.1054). These constructs or components include:

- The perception of the science teacher
- Anxiety toward science
- The value of science
- Self-esteem at science
- Motivation towards science
- Enjoyment of science
- Attitudes of peers and friends towards science
- Attitudes of parents towards science
- The nature of the classroom environment
- Achievement in science; and
- Fear of failure on course.
The aim of school science is to “promote enthusiasm for the subject, not only to encourage choice of science post-16 and subsequent careers in science, but also to enhance all students’ interest in scientific issues” (Simon, 2000, p.104). However in practice this is not always the case. Results from numerous studies of attitudes to school science (Hadden and Johnstone 1983; Yager and Penick, 1986; Johnson 1987; Breakwell and Beardsell, 1992; Rice and Corboy, 1995) confirm that positive attitudes peak at, or before, the age of 11 and decline thereafter by significant amounts. The experience of early secondary school leaves many students with negative attitudes towards science and they continue into upper secondary school e.g. Leaving Certificate with little interest in the subject, with decreasing numbers electing to continue with their study of science once they reached a point of choice (Bennett, 2003; Spall et al., 2004; Williams et al., 2003; Reiss, 2004; Owen et al., 2008). This is also indicated within Schibeci’s (1984) five conclusions that summarised science attitude research:

1. gender is related to attitude
2. science programs affect attitudes inconsistently
3. environmental effects are indirect
4. biological and physical science attitudes differ
5. attitudes decline with public school advancement

2.6.1.3 Attitudes towards Physics

The study of affective factors in science and mathematics education can be easily found in the literature however there are few in physics education. None the less, physics education suffers the same problems as science and mathematics education in the area of poor attitudes. As mentioned at the beginning of this chapter only 8% of the student cohort that completed their Leaving Certificate in Ireland in 2009 sat the higher level paper in Physics (Irish Times, 2009). The poor uptake indicates problems that include Irish Physics students’ attitude towards the subject. This may be caused by the negative views amongst physics students as they perceive that the subject is difficult, irrelevant and boring. (Williams et al., 2003). Irish second level students perceive the subject as “heavily content-loaded, very dull and demanding passive reception rather than active involvement” (Woolnough, 1994b, p.369) and only suitable for exceptionally able pupils
(Woolnough, 1994b; Osborne et al., 1998). The decline in students opting to study the physical sciences will have a detrimental effect on Ireland as a knowledge economy in two ways. Firstly, since only those who take science at secondary level education are able (without further remedial courses) to major with a science degree at third level and subsequently pursue a scientific career, the declining numbers of students taking science for the Leaving Certificate will affect the number of scientific careers in Ireland. Secondly, there will be a shortage of science graduates that will become teachers. As a consequence, second level students are often taught by ‘out-of-field’ teachers, meaning that their primary qualification may be in science but they are not fully equipped to teach physics. Thus they “may not teach the subject with the same enthusiasm as a physics graduate” (Williams et al., 2003). Smithers and Robinson (2007) also reported the importance of a teacher with a specialism in teaching physics and found that schools that had a teacher who specialised in physics ‘bucked the trend’ of decline in physics A-level.

In previous work in America and Australia, attitudes towards science classes have been found to be the best predictors of students’ intentions to enrol in science courses in third level (Gardner, 1975; Crawley and Coe, 1990). Williams et al., (2003) also carried out a research study which investigated the reasons why secondary students are not interested in Physics. The researchers used a questionnaire to determine and track Year 10 (age 14) students’ opinions of Physics while using the subject Biology as a scientific comparator. The results of the questionnaire reported that the students questioned found physics less interesting than biology. The analysis of the data also indicated that the students found physics boring and ‘not relevant’ either to everyday life or to other subjects. Finally the data confirmed that the students who found physics interesting did so because they found it easy due to the variety of the topics

The majority of the research in the literature on students’ attitude to physics claims that the students find the subject difficult and dull. However, a study that was carried out by Reid and Skryabina (2002) in Scotland represents quite the opposite. The research identifies that the students in Scotland perceives physics as “rather an ordinary school subject which is open to a very large number of pupils”
In this study, students were asked to complete a questionnaire which was used to explore their attitudes towards physics and to gain an insight into the factors that made physics so popular. The findings confirmed results from other studies (Breakwell and Beardsell, 1992; Simpson and Oliver, 1985) in that it was found that the pupils in primary school preferred science more than the secondary level students and “the erosion of pupils’ attitudes” towards science lessons occurred during the transition from primary to secondary school (Reid and Skryabina, 2002, p.71). The study also explored the factors influencing pupils’ choice of degree course in physics which included 1) the enjoyment of the subject 2) good grades at school 3) likely career opportunity and 4) the teacher at school.

Despite the study carried out by Reid and Skryabina (2002), the literature on physics education suggests that there are several reoccurring reasons as to why students are not choosing physics. These can be summarised as:

- students perceptions of the subject
- enjoyment of the subject
- students feel they will not do well in the exam.

2.6.1.4 Relationship between attitude toward Science and achievement in Science

There are many factors that affect students’ classroom learning including cognitive structure, intellectual ability, classroom practice and the instructional material. The affective and social domains also have significant impacts on classroom learning and it is within these domains that attitudes lie. Attitudes have been highly recognised as one of the most important predictors of individual differences in educational application, learning and achievement (Evans, 1965; Cited in Francis and Greer, 1999). Reviews of the attitude literature in science education contain the results of many studies which set out to explore a very wide range of different correlations of science-related attitudes. These correlations include the relationship between attitude toward science and achievement which were carried out through the use of correlation tests. Most studies have produced small positive correlations ranging from 0.07 to 0.45 (Oliver and Simpson, 1988).
However, an exception to this is found in research carried out by Simpson and Wasik (1978) where a correlation of 0.84 was reported between attitude and achievement.

A more recent study on the relationship of attitudes and achievement was undertaken by Willson, Ackerman and Malave in 2000. This study examined the relationships among science and engineering attitude, physics conceptual understanding and physics achievement for a population of 200 undergraduate engineering students. The results from the study did not support previous findings in that “attitudes did not predict later physics achievement or concept development” (Willson et al., 2000, p. 1117).

### 2.6.2 The Teacher

Another common variable reported in the literature to have an effect on students’ uptake of science subject or course is the teacher. It is fair to say that science teachers know things about science that pupils do not know; it is the role of the teacher to transmit this information and knowledge to their students in a manner that will allow the students to fully understand the content and retain it. However this does not always happen and students are often left more confused and unsure about scientific concepts than before any instruction. The teacher is an essential component in the classroom as s/he functions as the cognitive source of information, the organiser and presenter of knowledge and also as the communicator translating the knowledge into a form appropriate for the students’ age and maturity (Ausubel et al., 1978).

In order to facilitate this role it is essential that the teacher is specialised in the subject area. Several research studies emphasise the importance of a qualified teacher in the subject area as it allows them to impart their enthusiasm for the subject which will encourage the pupils to continue to study the subject (Gill et al., 2009). McDermott (1993, p.295) also noted the importance of the teacher on the students’ understanding, recognizing that teaching in introductory courses is traditionally based on the teacher’s view of the subject and that “most teachers are eager to transmit their knowledge and enthusiasm”. The teachers’ cognitive
understanding also plays a major role in facilitating learning and providing feedback, as they will be unable to provide adequate feedback or clarify misconceptions unless they have a clear understanding and “organized grasp” of the subject being taught (Ausubel et al., 1978, p.502).

An Irish study carried out by Smyth and Hannon (2002) investigated the way in which science education within the classroom itself can potentially influence students’ perceptions and take-up of science. Within this study 35 science teachers were interviewed, 77% had taken a degree concerning chemistry related subjects, 71% concerned with biology related subjects. However, only 29% of the teachers had taken physics as a degree subject. When taking into account which subjects the teachers taught for junior and senior cycle, only 25% of the junior certificate science teachers were qualified in physics. This is in contrast to 77% of the teachers who were qualified in Biology and Chemistry. This lack of expertise in certain areas of the Junior Certificate course affected the teacher’s preferences in teaching, with one teacher commenting that “…because of my Chemistry background, I’m not afraid to do the chemistry practical side. I probably have much more interest in doing them than the Biology practicals but I’m afraid that’s just the way I lean, I suppose” (Smyth and Hannon, 2002, p. 121). Smyth and Hannon (2002, p. 122) went on to establish if there was any relationship between teacher qualifications and student uptake of science and surprisingly there was none found, in all eight schools investigated “patterns of science provision and take-up in the case study schools do not seem to be related to the lack of suitably qualified teachers”.

2.6.2.1 Teaching Science

Scientific knowledge is different to that of everyday knowledge. Leach and Scott (2000) compiled a three-way relationship between everyday knowledge, scientific knowledge and phenomena (Figure 2.7).
They argue that difficulties occur in learning science when a child enters a science classroom with an understanding about a phenomenon or event from their childhood that is interpreted differently in a science classroom. They report that “learning science involves being introduced to, and coming to accept and understand, some of the norms, the ways of thinking, and the ways of explaining used in the scientific community” (Leech and Scott, 2000, p.42).

Teachers play a crucial and very challenging role in the teaching and learning process in which their role is to increase students’ understanding of science and science related concepts. However, often their method of teaching can influence students’ opinions and attitudes towards science as a subject (Simpson and Oliver, 1990; Papanastasiou and Papanastasiou, 2004). Novak, Mintzes and Wandersee (2005, p. 7-8) identified four main tasks that teachers must carry out in order to be an effective science teacher:

1. Understand the major concepts in their field and integrate them into a hierarchical, complex structure.
2. Create an appropriate context for their own teaching; integrating “book knowledge” with other experiences including field trips and courses.
3. Sequence the material and topics in such a way that will encourage meaningful learning, allow new knowledge to be connected with previous knowledge.
4. Plan and implement assessment strategies that support meaningful learning.

In order to facilitate these tasks teachers must implement a teaching style that is appropriate to the students and the teaching objectives of the course. This will not happen by “increasing the number of students’ laboratory activities” or “a trendy emphasis on hands-on activities” (Glynn et al., 1991, p.3); instead the teacher must introduce a “minds-on” approach. This approach requires the students to understand what is meant by important concepts and if, after assessment, they do not represent an understanding they are required to clarify them using their own words in a scientific manner (Glynn et al., 1991). The teaching style implemented in a classroom must be appropriate to students’ ability and their understanding if it is to be successful; this is reinforced by the work of Ausubel and his colleagues on educational psychology (Ausubel et al., 1978, p.499):

“Teaching styles (including group-centered versus teacher-centered approaches, lecture versus discussion) should be adapted to the particular strengths and weaknesses of a given teacher’s personality, background and perception. They should also vary in relation to individual differences in pupils’ personalities, cognitive style, and intellectual abilities, as well as to the nature of the learning material and the particular educational objectives involved in a given learning situation”

The teaching used in a classroom must be tailored to suit the subject. Bennett (2003, p.22) identified four ways in which pupils learn science. These include:

1. transmission of knowledge
2. discovery learning
3. developmental views of learning
4. constructivism.

Through the use of these four methods teachers have the potential to teach students scientific content thus preparing them to study science at higher levels of education and pursuing courses in scientific careers. Teachers must possess several characteristics, however, in order to be effective they must care, listen, understand, know, respect and interact with students (Stronge, 2002).
In order to motivate students to learn science and continue to study the subject, teachers need “to capture the students’ attention” and teach science in such a way as to “connect science with students’ interests, personal lives, societal issues, cultural backgrounds, and other school subjects” (Staver, 2007, p.17). Staver continues by providing several practical techniques to connect science content with student interests:

- Connect science concepts and instruction explicitly to learners’ personal experience
- Use specific examples, analogies, and metaphors
- Plan lessons to emphasize themes of science, technology, and society
- Have students organise data into diagrams, tables and graphs
- Have students use data in tables and graphs (bar, line, and histogram) to identify patterns and make predictions.
- Have students use mathematical operations, fractions, decimals and percentages to calculate results of investigation
- Have students read passages in science texts and trade books and identify major and minor ideas, summarise what they read and make predictions
- Have students develop and role play scenes in which they use scientific thinking and play the roles of scientists.

As science is a practical subject, it is also essential that practical elements be incorporated in the classroom. Within every science curriculum in the Irish education system practical work is identified as a key component and as mentioned earlier, practical work has a major focus in the new Junior Certificate science syllabus, which “emphasises a practical experience of science for the student” (DES, 2003, p.6). It is possible to include practical work in a variety of ways such as practicals using recipe-style formats, investigations and teacher demonstrations.

Several studies have examined the effectiveness of practical work in the science classroom identifying the purpose of it in science lessons (Kerr, 1963; Beatty and Woolnough, 1982; Hodson, 1993). As a result of these studies researchers have
established particular aims of practical work. Kerr (1963) developed ten aims including the promotion of scientific methods, the development of manipulative skills and training for problem solving. Beatty and Woolnough (1982) devised a list of another ten aims which included aspects concerning the methodology employed during practical work. The most recent work on the aims of practical work, (Hodson, 1993) reviewed its effectiveness under four main headings: motivation, acquisition of skills, learning scientific knowledge and the methods of science, and scientific attitudes and suggested five main aims of practical work:

1. to teach laboratory skills
2. to enhance the learning of scientific knowledge
3. to give insight into scientific method, and develop expertise in using it
4. to develop certain ‘scientific attitudes’ such as open-mindedness, objectivity and willingness to suspend judgement
5. to motivate pupils, by stimulating interest and enjoyment.

Owen, Dickson, Stantisstreet and Boyes (2008) carried out an investigation in the UK examining physics students’ attitudes towards different learning activities in an attempt to identify the reason for the ‘swing from physics’. Students were asked to complete a three-section questionnaire and were questioned on aspects of classroom instruction including the popularity of the different learning activities, the frequency of which the students perceived the activities as being used in the classroom and the students’ opinions on the various activities and their use for learning physics. Following analysis of the 13 classroom activities, Owen et al., (2008), reported that the most popular learning activities among 1,288 school students are constructive activities, such as doing experiments. However, within the activities that actually take place in a physics classroom, the most frequent activity (79%) was ‘listening to explanations’ and an astonishing 76% of the students stating that they 'copy down notes' in the physics classroom. The most popular activity, as identified by the students, came in as the seventh most frequent activity with 57% of the student sample stating that they carried out experiments (Owen et al., 2008). These findings are also echoed in the study carried out by Smyth and Hannon (2002) in Ireland. Within this ESRI research study, several reasons were highlighted for the decline in science uptake, one of
which was the absence of practical work. The science teachers believed that the course was not interactive enough for the students, and also the schools lacked adequate resources.

2.7 Conclusion

The factors influencing student uptake and participation of Science and particularly in Physics have been stressed in this chapter. The numbers opting to study physics in upper secondary school and subsequently third level education nationally and internationally are decreasing and several reasons for this have been put forward. However the focus of this thesis is not primarily on the topic of student participation in science. Nonetheless, a review of this research is essential as it provides a clear indication that there are several factors that contribute to students’ subject choice including cognitive, affective and practical variables within the student and the classroom. The key affective variable discussed in this research study is that of attitudes as this is found to have been the best predictor of students’ intentions to enrol in science courses. Research examining students’ attitudes to physics is now new, a substantial amount of research has been carried out internationally which report that students find the subject difficult, dull and often only suitable for the more advanced student. One study which reports conflicting results is that of Reid and Skryabina (2002). This research was carried out in Scotland and examined the students’ opinion of physics. In comparison to the majority of research findings, Scottish students believed that physics is no different to any other school subject and is “open to a large number of pupils” (Reid and Skryabina, 2002, p. 67).

Another variable that influences students subject choice is the teacher and his/her learning styles and it is through the teacher that the student gains their experiences and opinions of the science subject. The information gathered in this literature review provided the author with a framework on which to build and introduce an interactive intervention that was aimed at increasing students’ interest in physics.
Chapter 3

Knowledge Representation and Concept Mapping

3.1 Introduction

Before the author begins to discuss knowledge representation it is important to define knowledge and in particular scientific knowledge. Much research has being carried out on students’ understanding of science concepts and their knowledge structure. In order to identify one’s knowledge and in turn their improvement of knowledge it is essential that the meaning of knowledge is clearly understood. The branch of philosophy that deals with the nature and scope of knowledge is identified as epistemology. In recent years this branch of philosophy has undergone dramatic change. In the past positivism was the leading view where “all genuine knowledge is based on sense experience and can only be advanced by means of observation and experiment” (Cohen at al., 2000, p.8). However, constructivism is now regarded as the dominant epistemological view (Novak, 1991). Within the constructivist view each individual builds on their own knowledge in an active mental process, from concepts already possessed. Constructivism is explained in detail in Section 3.3.1.

Novak (1991, p.48) maintains that knowledge is “made of concepts and concept relationships” making the suggestion that concepts are the units of knowledge similar to the observation that words are made of letters. Every science lesson or laboratory session can contain many concepts and every time a new concept is learned, knowledge increases (Halpern, 1996). These new concepts are used to construct internal knowledge structures thus implying that concept interrelatedness is the essential property of knowledge (Ruiz-Primo et al., 1997). Knowledge is very personal and idiosyncratic because there are many ways in which new concepts learned can be connected to prior knowledge and hence arranged into our knowledge structures (ibid). The characteristics of scientific knowledge stem directly from the meaning of knowledge. Scientific knowledge is “symbolic” in nature and the objects of science are not the phenomena of nature
but they are concepts that are used by the scientific community to interpret nature (Driver et al., 1994, p. 5). The concept is the “relationship between the word (or symbol) and the idea or conception…which enables us to impose some sort of meaning on the world…the means by which we are able to come to terms with our experience” (Cohen et al., 2000, p.13). This implies that there is a relationship between the number of concepts one possesses and their ability to explain the world around them.

“Knowledge, in order to be most useful, must be organised in some way” (Briscoe and LaMaster, 1991, p. 216). It can be represented in many ways, for example, in the form of diagrams and texts. These knowledge representation tools (also known as knowledge diagramming tools or knowledge maps) can have many benefits in the classroom. They enable students to organise and retrieve data, while also allowing them to construct new knowledge and link it to existing knowledge (Luckie et al., 2003). The remainder of this chapter will explain in detail one such tool that is suitable for the teaching of science.

3.2 Concept Mapping

In science education in recent years, the interesting awareness of the importance of learner-centeredness in the teaching-learning situation has generated a lot of attention in relation to understanding how learners learn and how to help them learn about concepts (Jegede et al., 1990, Cited in Chiou, 2008). In an attempt to help students to learn concepts more effectively and to enhance meaningful learning, several strategies have being developed, one of which is Concept Mapping.

The concept map is an alternative way of representing knowledge. It differs from that of written text in that information is not presented in a linear manner (Taber, 1994). Within a written text (book, journal etc.) the material is structured in a specific sequence, which is set out to direct the reader. Attention is drawn to specific key words using italics, bold and underlining. However, within a concept map the content is represented differently, using nodes and linking lines. Unlike a written text there is no specific order in which the map could be read as “it is a
network of ideas that may be sequenced in many permutations” (Taber, 1994, p.276). The advantage of using non-linear modes of knowledge representation tools such as concept mapping was underlined by Fraser (1993) as they “depict the complexity of the relationships between the concepts and ideas (Cited in Freeman and Jessup, 2004, p.153).

Concept Mapping has become a ubiquitous tool in research and educational research. The tool was originally developed by Novak and his research team in the early 1970’s as a means of “externalising internal processes” (Pearson and Somekh, 2003, p.8) and was developed to facilitate the learner to produce maps containing concepts and propositions. Since then the tool has developed further, whereby it is used both in assessment and instruction in several fields and disciplines. The tool offers a situation to allow shared understanding to take place between individuals (Freeman and Jessup, 2004). It is a tool that allows an entire lecture topic or unit to be presented in a graphical format, thus illustrating the holistic relatedness of ideas (Laitch, 2004). This chapter will introduce Concept Mapping, providing information regarding its theoretical background, the elements of a concept map, and its use and applications in the classroom.

3.2.1 Structure of a Concept Map
Concept Mapping is a practical learning tool which falls into the broad family of graphic organising tools that includes mind mapping and spider diagrams. However, the characteristics of Concept Mapping set it apart from the others. The concept map itself has being defined in many ways. Its developers define a concept map as “a schematic device for representing a set of concept meanings embedded in a framework of propositions” (Novak and Gowin, 1984, p.15). Heinze-Fry (2004, p.1) believed that they represent the “conceptual linkages” that people contain in their minds. Iuli and Helldén (2004) and Quinn et al., (2004) include the hierarchical structure of knowledge in his definition. Iuli and Helldén (2004, p.1) states that a concept map “represents knowledge as a hierarchical framework of concepts and concept relationships” with Quinn et al., (2003, p.12), defining a concept map as a “two-dimensional, hierarchical, node-linked diagrams that depict verbal, conceptual, or declarative knowledge in succinct visual or
graphic forms”. White and Gunstone (1992, p.15) describe the purpose of a concept map as a tool that “show(s) how someone sees the relations between things, ideas or people”.

3.2.2 Components of a Concept Map

Each map contains several elements, which as a whole, organise and represent students’ knowledge and understanding of a particular topic. They include concepts, propositions, linking phrases, linking lines and cross-links which when combined differentiate a concept map from other graphic organisers. A brief description of each is described below.

**Concepts** are defined as “perceived regularities in objects or events that are designated by a sign or symbol” (Novak, 1991, p.45) and are “briefly expressed forms of our experiments and the nodal points between the abstract and the concrete (Ingec, 2008). The concepts are usually enclosed in circles and linked together using linking phrases.

**Linking phrases** identify the relationship between adjacent concepts through the use of a “relationship type” (Kremer, 1994).

A **Proposition** is the smallest unit of meaning of a concept map which includes two concepts linked together using a linking phrase, also known as a concept - link - concept triad.

**Linking lines** are usually unidirectional and denote a relation between two concepts (Ruiz-Primo and Shavelson, 1996).

**Cross-links** make explicit relationships between or among concepts in different regions or domains within the concept map. The cross-links are lateral links within a concept map in comparison to a vertical link, which show how a concept in one domain of knowledge is related to a concept in another domain of knowledge, indicating “a synthesis of related concepts” (Heinze-Fry and Novak, 1990, p.461).
3.2.3 Characteristics of a Concept Map

The notable characteristics of a concept map include its hierarchical structure and the use of a ‘focus question’. Every concept map is constructed with reference to a ‘focus question’ which clearly specifies the problem or issue that the concept map should help to resolve (Novak and Cañas, 2006). When learning to construct concept maps, learners tend to deviate from the focus question and build a concept map that may be related to the domain, but which does not answer the question (Novak and Cañas, 2006). In this instance it is essential that the instructor returns to the focus question and ensures that the student constructs a concept map that responds to the question which will lead to a much richer concept map.

As mentioned the hierarchical nature of a concept map is one of its most distinguished features. The concepts are represented in a hierarchical fashion detailing a general-to-specific organisation which agrees with Ausubel’s theory (discussed further in section 3.3) that cognitive structure is organised hierarchically, with more general and inclusive concepts occupying higher levels and more specific, less inclusive concepts situated at the lower levels (Novak and Cañas, 2006). This is conveyed in a concept map where the most inclusive, most general concepts are arranged at the top of the map and the more specific, less general concepts arranged below. Figure 3.1 below is an example of a concept map which answers the focus question “What is Concept Mapping?” and exemplifies the above components and characteristics.
3.2.4 Variations of Concept Maps

There are numerous ways in which students are asked to create concept maps thus creating variations in the mapping process. There are three ways in which the concept-mapping task can vary: task demands, task constraints and task content structure (Ruiz-Primo and Shavelson, 1996). The task demands refer to the demands made on the students in generating their concept map and as mentioned above, can be either constrained or open-ended. The task constraints refer to the restrictiveness of the task which can vary widely. A constrained concept map restricts the students to a list of concepts that they must include in their map (Markham et al., 1994; Barenholz and Tamir, 1992) or they are required to fill in a blank concept map which may or may not contain concepts or linking words. An open-ended concept map supplies the students with a small number of seed concepts that are used to prompt the students; otherwise the students are free to construct their map. The task content structure refers to the topic or theme in which the concept map will be focused on. The response format also holds three
variations: the response mode, the characteristics of the response format and the mapper (Ruiz-Primo and Shavelson, 1996). The response mode simply applies to how the map is constructed, whether it is on paper or on a computer. The characteristics of the response format are specific to the task. If the students are asked to fill-in a blank concept map they are provided with a blank concept map which will contain a list of concepts that the students will be required to insert in the correct order. In general, a concept map task can be categorized along a directedness continuum from high-directed to low-directed based on the information provided to the students (Ruiz-Primo, 2004). Figure 3.2 demonstrates the difference between the response formats required for maps from both scales.

![Figure 3.2: Concept map techniques according to directedness of the mapping tasks (Ruiz-Primo 2004, p. 3).](image)

A description of the different response formats is divided below into both closed (high level of direction) and open-ended tasks (low level of direction).

### 3.2.4.1 Closed Tasks (High Level of Direction)

**Fill-In Concept Mapping:**

Fill-In concept maps are usually used to introduce the Concept Mapping tool and new topics. The process of using this method begins with an expert-created map which is modified by eliminating some of the elements of the map, while ensuring that the integrity of the map is maintained (Kaminski, 2002). The linking phrases
and lines remain, as they will act as a guide for the students which will allow the students to replace the labels in such a way that makes structural sense. The most common use of this method is identified as ‘Select and Fill-In’ Concept Mapping (SAFI) (Schau et al., 1999). This method relates directly to the fill-in maps where the students are provided with a list of concepts that fit the concept map provided (Figure 3.3) and the student’s task is to select and add the concepts from the list provided. The aim of this method is to identify the connected knowledge of the student in a specific topic. Throughout the process the students can clearly see how the introduction of concepts or linking words affects the map as they generate propositions within the domain.

Figure 3.3: An example of a “Select-and-fill-in” concept maps designed to assess students’ connected understanding of science

**Selected Terms Concept Mapping:**

Here the instructor provides a list of concepts to the students at the beginning of the task and the students are then asked to construct a concept map using only the labels provided. The aim of this exercise is to develop the students’ linking ability. The students have the freedom to develop their own structure to the maps within this exercise.
3.2.4.2 Open-Ended Tasks (Low Level of Direction)

Seeded Terms Concept Mapping:
Using this approach, the instructor provides the students with a small number of concept labels. The students are then asked to construct individual concept maps using these concepts as well as including concepts from their own knowledge on the topic. The students arrange the concepts in a hierarchical fashion, representing their understanding of the topic where “they must have an understanding of interconnected groups of propositions to draw an adequate map” (Schau et al., 1999, p.5). Despite the variety of mapping techniques they are all aimed at measuring aspect of the student’s knowledge structure.

3.3 Theoretical Background

The philosophy upon which Concept Mapping is based is constructivism and meaningful learning. Constructivism refers to “a family of theories that share the assertion that human knowledge and experience entail the (pro) active participation of the individual” (Mahoney, 1988, cited in Watts and Pope, 1989, p. 327). The second philosophy stems from David Ausubel's theory of meaningful learning (1968). This work is contrasted with rote learning and falls under the ‘umbrella’ of constructivism where he believed that students are not ‘vessels to fill’ with a lot of notions, but that they can produce and develop their own knowledge with an active process.

3.3.1 Constructivism

Constructivism is not a recent concept; it has roots in philosophy, sociology and education. It has a long history in education and this history provides a large quantity of data relating to its complexity and use in the classroom and lecture halls. Pedagogically, the teacher's role within a constructivist classroom is characterized as that of a facilitator in which they “encourage more student-student interaction that in turn promotes negotiation to reach consensus about the meaning of scientifically acceptable concepts” (Hand et al., 1997). This teaching approach will encourage the student to build “new knowledge upon the
foundation of previous learning” (Hoover, 1996). Hoover continues to define constructivist learning and states that “learning is active rather than passive…if what learners encounter is consistent with their current understanding, their understanding can change to accommodate new experience”. Constructivism promotes dynamic learning as the learners are actively constructing meaning from prior conceptions (Driver et al., 1994; Cited in Wing-Mui So, 2002). Due to this dynamic learning and role reversal of the teacher, constructivist learning differs significantly from the ‘objective’ traditional approach. Driver (1988) outlined the differences as follows:

- Learners are not viewed as passive but are seen as purposive and ultimately responsible for their own learning. They bring their prior conceptions to learning situations.
- Learning is considered to involve an active process on the part of the learner. It involves the construction of meaning and often takes place through interpersonal negotiation.
- Knowledge is not ‘out there’ but is personally and socially constructed, its status is problematic. It may be evaluated by the individual in terms of the extent to which it fits with their experience and is coherent with other aspects of their knowledge.
- Teachers also bring their prior conceptions to learning situations not only in terms of their subject knowledge but also their views of teaching and learning. These can influence their ways of interacting in the classroom.
- Teaching is not the transmission of knowledge but involves the organisation of the situations in the classroom and the design of tasks in a way which promotes scientific learning.
- The curriculum is not that which is to be learned, but a programme of learning tasks, materials and resources from which the students construct their knowledge.

(Cited in Watts and Pope, 1989, p.328)

The elements of the constructivist view of learning listed above reinforce the idea that constructivist learning “is seen as a cognitive approach that locates cognition and understanding within the individual” (Daley, 2004). It also supports the idea that the students do not enter the classroom with no information, instead they
arrive with their own experiences and a cognitive structure based on those experiences and it is only when these cognitive structures are built upon that meaningful learning takes place (Hanley, 1994). If new knowledge conflicts with past experiences, this new information will be difficult to assimilate and the learning will be short-term and worthless (Darmofal et al., 2002).

3.3.2 Theory of Meaningful Learning

Ausubel’s (1968) theory of meaningful learning led Novak and his research team to develop Concept Mapping and resulted in Novak describing the tool as a “major methodological tool of Ausubel’s Assimilation Theory of meaningful learning” (Cited in Colli et al., 2004). Ausubel et al., (1986) believed that the mind is organised in a top-down, hierarchical fashion and that new information can be sorted, added and stored, as either a more general or more specific concept with respect to others, to create meaning (Freeman and Jessup, 2004; Gul and Boman, 2006). This theory contrasted meaningful learning with that of rote learning, stating that meaningful learning involves “an act of relating new knowledge to relevant concepts and propositions that are already known” (Cassata et al., 2004, p. 2). Hay et al., also distinguishes between rote (often identified as surface) and meaningful (deep) learning, where “rote learning is observed where the new material was added superficially without integration, and meaningful learning occurred where new and old material were recombined to make new meanings” (2008, p.300). Ausubel emphasized that meaningful learning does not result in a “bond” between new and old elements of the cognitive structure; however it results in “a modification of both the newly acquired information and of the specifically relevant aspect of cognitive structure to which the new information is linked” (Ausubel, 2000, p.3). In contrast, rote learning results in an “arbitrary and nonsubstantive linkage” between new information and pre-existing elements of the learners’ cognitive structure (ibid). The following figure (Figure 3.4) represents the variation between rote learning and meaningful learning.
Ausubel (2000) believed that in order for meaningful learning to take place the student requires a meaningful learning set as well as the presentation of potentially meaningful material. Novak (1998, p.19) went a step further and identified three essentials that the learner must possess in order for meaningful learning to occur. These include:

1. Relevant prior knowledge: that is the learner must know some information that relates to new material to be learned in some motivational way.
2. Meaningful material: that is the knowledge to be learned must be relevant to other knowledge and must contain significant concepts and propositions.

3. The learner must choose to learn meaningfully. That is, the learner must consciously and deliberately choose to relate new knowledge to knowledge the learner already knows in some nontrivial way.

The process of meaningful learning can be improved by concept mapping. During concept mapping, the learner graphically represents concepts in a hierarchically arranged structure and begins to progressively differentiate among concepts.

3.4 Concept Mapping in the Science Classroom

The process of constructing a concept map is a powerful learning strategy that forces the learner to actively think about the relationship between the terms, making Concept Mapping especially suited to studying science as the learner may perceive that studying science means simply memorizing facts (Dorough and Rye, 1997). The prominent role of Concept Mapping in science education was reflected in an article in a special issue of the Journal of Research in Science Teaching in which 100 references can be found relating to the use of Concept Mapping (AlKunified and Wandersee, 1990). The number has increased exponentially since then, with 1,640,000 hits found in Google Scholar under the term “concept maps science” where it is being used as both an instructional and assessment tool (Boujaoude and Attieh, 2008; Asan, 2007; Vanides et al., 2005; Heinze-Fry, 2004; Liu, 2004; Van Zeale et al., 2004; Stoddart et al., 2000; Santhanam et al., 1998; Novak and Musonda, 1991; Briscoe and LaMaster, 1991; Novak, 1990; Wallace and Mintzes, 1990). Research has also been carried out specific to the physics classroom. The following section will focus on this research explaining why Concept Mapping is suited to physics and how the tool has been incorporated into the physics classroom.
3.4.1 Concept Mapping and the Teaching of Physics

Bascones and Novak (1985) give one definition for understanding physics where they state that it involves “in essence, understanding its theory and related concepts in sufficient detail to make reliable predictions about the outcome of various situations” (p.253). However, the teaching approach which results in this understanding is debated in the literature. Bascones and Novak (1985, p.253) believe “learning physics is equated with developing problem-solving abilities” and achievement in physics measured by the amount of correctly solved problems in a test. In opposition, Shaffer and McDermott (1992) found that students’ successful completion of problem-solving tasks was not a valid indicator of their understanding of the underlying physical science concepts. Similarly, Vosniadou (1996) suggested that core concepts within a discipline have a relational structure and that the relationships among core concepts must be reflected in course curriculum and text-based materials if students are to learn the material (Cited in Romance and Vitale, 1999). Concept Mapping can provide the platform in which the relationships can be clearly identified and analysed. The tool has been used in many elements of the physics classroom; it has been used as a planning tool (advanced organiser) by teachers to identify the concepts and concept relationships within a particular topic. It is also used as a means of collaborative sharing of knowledge. However, the most common use of Concept Mapping has been for assessment purposes (Thomson, 1997), which will be dealt with later in this chapter. The following table (Table 3.1) summarises some of the research studies in physics education which have been carried out using Concept Mapping, both as an instructional and assessment tool.
Table 3.1: Research studies in physics educations which have been carried out using Concept Mapping, both as an instructional and assessment tool.

<table>
<thead>
<tr>
<th>Study</th>
<th>Research Participants</th>
<th>Research Aim</th>
<th>Research Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roth and Roychoudhury, 1993</td>
<td>Senior level high school students</td>
<td>To analyse the process of constructing meaning (Concept Mapping) and the analysis of the products of the cognitive activity (concept maps)</td>
<td>Concept Mapping led to sustained discourse on the topic and improved the declarative knowledge of several students both in terms of the organisation and the configuration of the concepts. However the tool also led to unintended and scientifically incorrect notions becoming ingrained and go unchallenged</td>
</tr>
<tr>
<td>Karenauskaitė and Katilūtė, 2007</td>
<td>Medical students studying physics in 3rd level</td>
<td>To assess the effectiveness of concept maps as a tool for evaluating physics knowledge and student learning</td>
<td>The tool was evaluated positively by the students, which improved conceptual understanding, however the difference between the intervention and comparison groups did not achieve strong statistical significance</td>
</tr>
<tr>
<td>Bascones and Novak, 1985</td>
<td>9th Grade students (Age 14-15)</td>
<td>To study how an instructional system designed according to Ausubel’s Learning Theory enhances physics problem-solving ability</td>
<td>Experimental group (those exposed to concept maps) developed problem-solving abilities earlier in the instruction, however they did not reach the expected score considered as a measure of successful problem-solving</td>
</tr>
<tr>
<td>İnceç, 2008</td>
<td>Pre-Service Physics Teachers</td>
<td>To determine the participants background and current state of knowledge of two areas of physics by comparing and contrasting two different methods; Concept Mapping and an achievement test</td>
<td>There is a weak correlation between the achievement test and the concept maps since concept maps assess the students’ knowledge from a conceptual perspective whereas the achievement tests measure the level of students’ knowledge and his/her ability to apply the knowledge</td>
</tr>
<tr>
<td>Study</td>
<td>Research Participants</td>
<td>Research Aim</td>
<td>Research Conclusions</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Adamczyk and Willson, 1996</td>
<td>Trainee physics teachers</td>
<td>To identify gaps in trainee teachers’ knowledge</td>
<td>Concept Mapping offers an “individualized diagnostic tool” offering trainee teachers the ability to take responsibility for the development of their knowledge and understanding of physics</td>
</tr>
<tr>
<td>Zieneddine and Abd-El-Khalick, 2001</td>
<td>Freshman college students (Age 16-20)</td>
<td>To investigate the effectiveness of concept maps as learning tools in developing students’ conceptual understanding of physics content and explore students’ perceptions regarding their use in the laboratory</td>
<td>The intervention group asserted that Concept Mapping helped them to better understand the physics concepts underlying the laboratory experiments in which they were engaged, <em>(the results however were not statistically different)</em>. Concept Mapping served as a crucial first step in promoting conceptual understanding through revealing students’ naïve conceptions</td>
</tr>
<tr>
<td>Pankratius, 1990</td>
<td>High school physics students</td>
<td>To investigate the effect of the degree of Concept Mapping on achievement in secondary school physics</td>
<td>Mapping prior to, during and subsequent to instruction led to greater achievement as measured by post-test scores</td>
</tr>
<tr>
<td>Austin and Shore, 1995</td>
<td>High school physics students</td>
<td>To assess the degree to which concept maps can assess meaningful learning</td>
<td>Concept mapping can provide a useful means for measuring meaningful learning, interpreted as performance on multi-step problems</td>
</tr>
</tbody>
</table>

Within these research studies both positive and negative conclusions were drawn concerning the use of Concept Mapping within the physics classroom. Roth and Roychoudhury (1993) investigated both the process and the end product of the task, the map, involved in collaborative Concept Mapping within a group of twenty-nine high school physics students. The research involved data sources...
including video recordings, transcripts and concept maps which provided the researchers with significant findings emphasising the positive attributes and negative limitations of the tool. From the data collected Roth and Roychoudhury formulated specific recommendations for the teacher to facilitate the use of concept maps in the physics classroom. These included (p.527):

1. Provide specific instruction to the students to help them establish hierarchies and cross-links.

2. Support students’ efforts for understanding the special significance of general concepts and principles and how the students can organise the knowledge in the scientific field.

3. Provide specific instruction urging the students to reflect on the map, both on the hierarchical structure and the relationships between the concepts.

4. When students are collaboratively constructing concept maps, structure the process by assigning roles to the individuals within the group.

The research carried out by Austin and Shore (1995) examined the use of Concept Mapping as a tool which may be used as an aid in solving multiple-step physics problems. The conventional way to measure students’ understanding of physics has been through the use of single- and multiple-step problems. However, students require a more integrated and connected understanding of concepts to solve multiple-step problems. Within the research study, the students were given a test consisting of single- and multiple–step questions and were required to construct concept maps in the area of electricity that would represent their understanding of the topic, visible through the interrelationships between their concepts and the level of linkage between the concepts. The students were provided with 18 concepts and were asked to link the concepts together in a concept map using as many of the concepts as possible. The concept maps constructed by the students provided a clear picture as to their understanding. Connections within the student maps with no or incorrect linking words “showed a fundamental lack of understanding” (Austin and Shore, 1995, p. 44).

Bascones and Novak (1985) also examined the benefits of Concept Mapping in problem solving. The study aimed at designing an instructional system that
“promoted meaningful learning” (p.253) whereby the course content was sequenced in such a way “that the most inclusive, most general principles and ideas were presented earlier in the instruction to serve as conceptual anchorage for subsequent learning” (p. 254). Concept Mapping and class problem-solving discussions were incorporated into the class time for the experiment group (Ausubelian system) whereas the control group (traditional system) were subject to the teaching that was provided to the students in the past. Following each topic covered in the classroom the students were asked to complete physics problems (one or two at the end of each section) which aimed to examine the students’ cognitive skills. The students were also interviewed following the problem solving to obtain additional information regarding the reasoning patterns the students used when solving the problems. The research findings showed that most students did not reach ‘mastery level’ of problem solving as set out by the scoring system. However, the students that experienced the Ausubelian system of instruction scored higher than the students who were taught using the traditional system and “began to approach the score level of nine points suggested as the criterion level of competence” (p.256).

In conclusion, the research carried out using Concept Mapping in the physics classroom indicates that the tool is suited to teaching physics and can provide the students with improved problem solving skills (Bascones and Novak, 1985; Austin and Shore, 1995), a better attitude towards the subject and allows them to identify their misconceptions and understanding (Adamczyk and Willson, 1996; Zieneddine and Abd-El-Khalick, 2001)

### 3.4.2 Introducing Concept Mapping into the Physics Classroom

To most students Concept Mapping is very new and in order for it to be a success within the classroom and provide the desired outcomes, its introduction is pivotal. The introduction needs to be appropriate to the students in order for them to “appreciate the true value of the technique and adopt it in the long term” (Santhanam, Leach and Dawson, 1998, p.324). Certain aspects need to be taken into account to ensure that the tool is greeted with enthusiasm and interest. The approach needs to be challenging to ignite interest but it should also not be too
demanding on time and effort (ibid, p.324). Novak and Gowin (1984, p.24) are strong advocates that “there is no one best way to introduce Concept Mapping” however, it is essential that the tool is introduced so that it will suit the age group of students you are working with. Novak and Gowin identified specific activities for preparing and introducing concept maps to all age groups; grades one to three (age 6-9), three to seven (age 9 to 12) and finally from grade seven through to college (p.25-34). The following table (Table 3.2) represents some of the activities set out to introduce the tool to the group of students identified as grade seven through to college. This age group is used as it is the same age group as in the author's research study.
Collaborative Concept Mapping is generally used when the tool is first introduced. Students are presented with a new method of learning which can result in high levels of frustration and anxiety. To eliminate some of this anxiety and persuade students to reflect on their thinking, groups are generated to allow them to work together to construct a map. This will also create an environment
that facilitates learning as peers will discuss and debate the contents of the map while contributing to it. In order for collaboration to result in innovative and creative concept maps, extensive practice is required by the students which can result in the students using the tool in a mature rather than naïve way (Correia et al., 2008).

3.5 Concept Mapping and Assessment in Science

It is well known that evaluation has a crucial and essential role in education. In school (as in most places) “so much of what we achieve as learners is controlled in good measure by how our performance is appraised, evaluated and rewarded” (Novak, Mintzes and Wandersee, 2005, p. 1). In most classroom and lecture halls, teachers and lecturers measure students’ achievement using achievements tests which may incorporate true-false, multiple-choice or short problems. However, these assessment methods are often too narrow to determine the extent of the students’ knowledge and can lead to and promote limited measures of understanding (White and Gunstone, 1992). To further complicate the problem, often when a student solves a familiar problem and obtains a correct answer other evaluation techniques can show that the student holds serious conceptual misconceptions (Gunstone and White, 1981; Cited in Novak and Gowin, 1984). These achievement tests measure the level of students’ knowledge and ability to apply the knowledge on different occasions (İngeç, 2008). Their structure are suited more to rote learning as the students do not need to understand the relationships between the concepts as each solution simply requires one or two steps in order to complete (Austin and Shore, 1995), and thus do not validly measure the students’ knowledge (Novak and Gowin, 1984, p.94; Ruiz-Primo and Shavelson, 1996). In contrast to achievement tests, concept maps assess the student’s knowledge from a conceptual perspective (İngeç, 2008) depicting an “array of qualitative aspects of student understanding” (Edmondson, 2005, p.22). Since the introduction of the Concept Mapping tool it has being used for assessment purposes in many disciplines and research studies, both to test students on specific topics and also to “document changes in knowledge and understanding over time” (ibid).
Research and studies carried out using Concept Mapping as an assessment tool require three components: the task, a response format (concept map) and a scoring system which the researcher/teacher uses to evaluate the students’ knowledge (Ruiz-Primo *et al.*, 1997). The student concept maps can be produced in one of two ways; the researcher/teacher can develop the maps from material supplied by the students such as an interview or written response to questions, or the students can construct them themselves. The former method is characteristic of the early research carried out by Novak and Gowin (1984). The task supplied to the students when they are constructing their own maps can be either constrained or open-ended as discussed in section 3.2.4. Variations in the tasks, response formats and scoring techniques can provide the study with different knowledge representations. The following table (Table 3.3) represents different concept maps tasks, response formats and scoring systems, thus emphasising the degree of variation that can be found in Concept Mapping techniques used both in research and practice (Ruiz-Primo *et al.*, 1997).
Table 3.3: Concept Map Components and Variations Identified (Ruiz-Primo et al., 1997, p. 4)

<table>
<thead>
<tr>
<th>Map Assessment Components</th>
<th>Variations</th>
<th>Instances</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASK</td>
<td>• Task Demands: Students can be asked to:</td>
<td>• fill in a map</td>
</tr>
<tr>
<td></td>
<td>• construct a map from scratch</td>
<td>• organize cards</td>
</tr>
<tr>
<td></td>
<td>• rate relatedness of concept pairs</td>
<td>• write an essay</td>
</tr>
<tr>
<td></td>
<td>• respond to an interview</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Task Constraints: Students may or may not be:</td>
<td>• asked to construct a hierarchical map</td>
</tr>
<tr>
<td></td>
<td>• provided with the concepts used in the task</td>
<td>• provided with the concept links used in the task</td>
</tr>
<tr>
<td></td>
<td>• allowed to use more than one link between nodes</td>
<td>• allowed to physically move the concepts around</td>
</tr>
<tr>
<td></td>
<td>• defined the terms used in the map</td>
<td>• until a satisfactory structure is arrived at</td>
</tr>
<tr>
<td></td>
<td>• required to justify their responses</td>
<td>• asked to define the terms used in the map</td>
</tr>
<tr>
<td></td>
<td>• required to construct the map collectively</td>
<td>• required to justify their responses</td>
</tr>
<tr>
<td></td>
<td>• Content Structure: The intersection of the task demands and constraints</td>
<td>• required to construct the map collectively</td>
</tr>
<tr>
<td></td>
<td>with the structure of the subject domain to be mapped</td>
<td></td>
</tr>
<tr>
<td>RESPONSE</td>
<td>• Response Mode: Whether the student response is:</td>
<td>• paper and pencil</td>
</tr>
<tr>
<td></td>
<td>• paper and pencil</td>
<td>• oral</td>
</tr>
<tr>
<td></td>
<td>• on a computer</td>
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<td></td>
<td>• Format Characteristics: Format should fit the specifics of the task</td>
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<td></td>
<td>• Mapper: Whether the map is drawn by a:</td>
<td>• student</td>
</tr>
<tr>
<td></td>
<td>• student</td>
<td>• teacher or researcher</td>
</tr>
<tr>
<td>SCORING SYSTEM</td>
<td>• Score Components of the Map: Focus is on three components or variations of them:</td>
<td>• propositions</td>
</tr>
<tr>
<td></td>
<td>• propositions</td>
<td>• hierarchy levels</td>
</tr>
<tr>
<td></td>
<td>• examples</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Use of a Criterion Map: Compare a student's map with an expert's map.</td>
<td>• Criterion maps can be obtained from:</td>
</tr>
<tr>
<td></td>
<td>• Criterion maps can be obtained from:</td>
<td>• one or more experts in the field</td>
</tr>
<tr>
<td></td>
<td>• one or more teachers</td>
<td>• one or more top students</td>
</tr>
<tr>
<td></td>
<td>• one or more top students</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Combination of Map Components and a Criterion Map: The two previous strategies are combined to score the student's maps.</td>
<td></td>
</tr>
</tbody>
</table>
3.5.1 Scoring Concept Maps

In a recent study, Van Zele et al., (2004) categorised the scoring systems used for concept mapping as either quantitative (i.e. making counts of characteristics) as used by Ruiz-Primo and Shavelson (1996) or qualitative methods (i.e. describing the content and quality of the map to some extent) which was used by Lomask et al., (1992). The scoring system used with Concept Mapping will always depend on the map, as more structured assignments with high levels of directedness will differ in evaluation to those of a more open-ended structure with low level of directedness.

The approaches to scoring structured concept maps generally combine an interest in the precision or content validity of the map (Stoddart et al., 2000). This is performed by counting various map components, such as concepts, links or cross-links. Since 1972, the early scoring systems placed emphasis on “elaborateness”. Novak and Gowin (1984) originally proposed a scoring system in which the number of valid propositions, levels of hierarchy, examples and crosslinks is counted thus developing a quantitative scoring system. Each of these counts is given a weight (Table 3.4) and the weighted counts are added to give a final score (Novak and Gowin, 1984). Each component must be valid in order to be included in the final score. This procedure is generally accepted as the most comprehensive scoring method (Ruiz-Primo and Shavelson, 1996) and has been reported to work quiet well as long as the assignment is well structured and of a ‘closed format’. However, researchers are encouraged to “experiment with their own scoring keys and refinements of scoring criteria” (Novak and Gowin, 1984, p.108).

Table 3.4: Scoring System produced by Novak and Gowin, 1984, p.36)

<table>
<thead>
<tr>
<th>Map Component</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposition</td>
<td>1</td>
</tr>
<tr>
<td>Hierarchy</td>
<td>5</td>
</tr>
<tr>
<td>Crosslink</td>
<td>10</td>
</tr>
<tr>
<td>Example</td>
<td>1</td>
</tr>
</tbody>
</table>

More recently, the scoring systems used show a relative de-emphasis on the count of map components and focuses more on qualitative data (Stoddart et al., 2000).
The approach recognises that the student’s maps are representations of their learning and are compared against an expert’s map. The expert map, also known as a criterion map (Ruiz-Primo et al., 1997) is produced by an expert on the topic which is usually the teacher. When constructing this map, an exhaustive list of possible relationships between concepts is created forming a matrix. This criterion map then provides a benchmark for the “substantial” links students were expected to have after studying a particular topic (Ruiz-Primo et al., 1997).

Other scoring techniques have being implemented within the physics classroom to relate the scores with physics understanding. The first, known as “linkage” is referred to by Novak (1979) as the number of relationships. However, this technique does not take into account the validity of the labels on the links. To counteract this problem, the links have being “coded”. Coding of maps includes a three point scale such that a good link guarantees a code three, connections that represented a lack in appreciation are coded two and links with no labels are awarded a code one (Austin and Shore, 1995).

### 3.5.2 Reliability and Validity of Concept Maps as Assessment

Since the introduction of concept maps in the early 1970’s researchers have raised questions concerning the scoring of concept maps (Rice, Ryan and Samson., 1998). Weak relationships between concept map scores and scores from other measures of achievement are the main concern, perhaps indicating that the concept maps are measuring abilities other than those characterised by “standardized achievement tests or conventional course performance measures” (Novak et al., 1983, p. 638). Ruiz-Primo and Shavelson (1996) provided a thorough analysis of concept maps as assessment devices, where they described the maps as “alternative assessments in science” (p. 569). Within this study Ruiz-Primo and Shavelson presented a comprehensive table reviewing twenty-one research studies that used the tool for assessment purposes, identifying the three components of concept maps and how they were structured and developed in past concept map assessment research. This highlighted the wide variety of different assessment techniques that have been used. The research concluded that they favoured “scoring criteria that focus more on the adequacy of the propositions
over those that focus simply on counting the number of map components (Ruiz-
Primo and Shavelson, 1996, p.595) and suggested that significant research should
be carried out in all areas where concept maps are used as assessment. The
investigation of (a) the reliability of various Concept Mapping tasks, (b) the
validity of inferences drawn from various Concept Mapping tasks, and (c) the
practical application of Concept Mapping to classroom and large-scale assessment
were among the areas recommended for further study (Ruiz-Primo and Shavelson,

Since then many research studies have provided evidence that Concept Mapping
is a reliable and valid mode of classroom assessment (McClure, Sonak and Suen,
1999; Rice et al., 1998; Rye and Rubba, 2002) when the correct scoring system is
used. McClure et al., carried out a research study in 1999 to evaluate the
“psychometric characteristics and practicality of concept mapping as a technique
for classroom assessment” (p.475), where six different scoring methods were
employed. The researchers varied the concept mapping scoring method to
determine if it would affect the consistency of the map evaluation. The research
findings suggested that the selection of the scoring method is likely to have an
effect on the score reliability. The scoring method that yielded the most reliable
scores was the relational scoring method used in conjunction with a master map.
The relational scoring technique was adapted from McClure and Bell (1990)
where the concept map examiners scored individual maps by evaluating the
separate propositions. The propositions were then scored from one to three in
accordance with a scoring protocol set out within the research. To guide the
scoring a master map was also used which was constructed by the professor of the
course.

Rice et al., (1998) also generated a scoring system that was based on the
correctness of the propositions, where high correlations between the concept map
scores and multiple choice tests provided strong evidence of the content validity
of the map scores. Rye and Rubba (2002) also used concept maps as an
assessment tool but the students’ propositions were extracted from student
interviews which were then analysed against an expert-concept map. Again, the
concept map scores in this study correlated highly to students’ total scores on a standardised achievement test.

The majority of the research on Concept Mapping agrees that they are valuable assessment tools. However, Johnstone and Otis (2006, p. 92) suggest that “maps should be treated as very personal learning tools” and consequently are not appropriate for assessment purposes.

### 3.6 Attitudes to Concept Mapping

Despite the large volumes of research carried out using Concept Mapping, few studies examine the students’ attitudes to the tool. The little research that does focus on this aspect and carry out such an analysis report that Concept Mapping is met with positive attitudes by the students (Kareauskaitė and Katiliūtė, 2007; Laight, 2004; Taber, 1994). Within the research carried out by Taber (1994), physics students were asked to draw a concept map as a revision exercise at the start of a new semester following the summer break. The students’ comments regarding the exercise were very positive, which related to both to their feelings about the task (affective) and their own learning (metacognition). Taber (2004, p. 278) reported that the students worked quietly during the assignment “showing no signs of running out of ideas”. Following the analysis of the students notes on the task, it was found that one student (from a group of 13) did not find the assignment “fun” but thought it was “necessary” with the remainder of the class regarded the Concept Mapping task “pleasant” and “interesting” (Taber, 1994, p.280).

Kareauskaitė and Katiliūtė (2007) reported similar findings. Together with examining the physics students’ knowledge and conceptual understanding following exposure to Concept Mapping, the research also looked at physics students’ conceptions of Concept Mapping through the use of a questionnaire which contained both qualitative and quantitative questions. Within this research study, 90.6% of the students evaluated Concept Mapping positively concerning the development of knowledge and its benefit in stimulating understanding (p. 84). The benefit of Concept Mapping in metacognition was also identified with
81.4% of the cohort agreeing that the tool “facilitates and stimulates independent learning” (Karenauskaitė and Katiliūtė, 2007, p 83). Other aspects that were analysed in this research study included the effect Concept Mapping had on learning motivation, constructing one’s knowledge base and in assessing their own learning.

Concept Mapping has also been widely used in medical education also resulting in significant research pertaining to the use of the tool in all areas of health professional education. Laight (2004) examined students’ attitudes to concept maps in relation to preferred learning styles or approaches to learning. The majority (63%) of the students involved in the study reported that pre-prepared concept maps introduced as a teaching and learning activity in large classes were useful to learning. The results were consistent with that of a study carried out by Santhanam et al., (1998) which examined science students’ attitudes of concept mapping. The minority of the students (30%) reported that the technique was “not helpful in any way” (p. 323). However, within Laight’s study “concept maps were anticipated to be good revision aids even amongst those students ostensibly not reporting concepts maps useful” (2004, p. 9).

Research in other disciplines disseminates the same findings. Chiou (2008, p.381) examined accounting students’ perceptions on Concept Mapping, again through the use of a questionnaire. A very high percentage of students (97%) agreed that concept mapping helped them to learn the subject while also allowing them to “integrate and clarify the inter-relationships among curriculum content”, with 95% of the cohort agreeing that the tool “stimulated them to learn and think independently” (ibid).

As teachers are the ‘key agents in the diffusion process of an educational innovation’ (Okebukola, 1992, p.201) it is also important to identify their attitudes towards new tools. However, very little research has addressed this issue. A search of the literature points to one study which was carried out by P.A. Okebukola in 1992. This research study investigated 141 (48 biology, 24 physics, 36 chemistry and 33 mathematics) teachers’ opinions on the use of Concept Mapping and Vee-Mapping (developed by Gowin (1977), a heuristic device to
help people understand the structure of knowledge and process of knowledge construction). The results from the research emphasise that both science and mathematics teachers favoured both tools in terms of their benefits in the areas of meaningful learning and reduction of anxiety levels. The following seven results (specific to Concept Mapping) were generated from the research (Okebukola, 1992, p.204):

1. Concept Mapping was perceived by all the science and mathematics teachers in the sample as easy to use.
2. The teachers found Concept Mapping to be an exciting activity for the class.
3. All the groups of teachers sampled (except the mathematics teachers) disagreed with the view that Concept Mapping is too technical and unnecessary for teaching purposes.
4. Biology, Chemistry and Physics teachers agreed that Concept Mapping has helped to reduce the anxiety levels of the students in the class.
5. Teaching students to make concept maps was not perceived to be difficult by the chemistry, physics or biology teachers.
6. All the groups did not find the strategies too abstract to learn, indicated that their students demonstrated greater understanding of the subject since they started using the techniques and also indicated that they learned to use each of the strategies within an hour of being taught.
7. Mathematics teachers expressed the least favoured attitude towards the Concept Mapping technique.

These results and the results identifying the students’ attitudes towards Concept Mapping indicate that the tool is received within the science classroom with very positive attitudes.

3.7 Conclusion

In this chapter the author examined the foundations of Concept Mapping and the use of the tool in Science and Physics. Various research studies have been carried out internationally both on the use of the tool in teaching and assessment. An overview of the research suggests that the tool is suitable for the teaching of
science as the maps bring to light individual differences in learning; as different people will have different types of concept map, even in the same subject area. A review of the studies that concentrate on the students’ opinions and attitudes of the tool also generate very positive findings.

It is clear from the research that Concept Mapping is an extremely flexible tool and has many applications in the teaching and learning of students. With this in mind, Chapter 4 will report on the problem solving and language ability of science students.
Chapter 4

Problem Solving and Scientific Language Ability of the Novice and Expert

4.1 Introduction

In chapter three the author reviewed the literature on Concept Mapping, discussing its theoretical background and the areas in which it has been used in the science and physics classroom. One of the primary aims of this thesis is to investigate the students’ scientific language and problem solving ability. This chapter therefore, reviews the literature on problem solving and scientific technical language which allows the author to develop a better understanding of the problem solving and scientific technical language ability of the expert and the novice and gain a better appreciation of their individual characteristics. It will also assist the author in formulating appropriate research questions and research design.

The beginning of this chapter will identify the difference between an expert and a novice. The chapter’s first section will focus specifically on problem solving, highlighting the various problems that student’s encounter and the problem solving approaches and strategies that they use. A comparison is then drawn on the approaches used by experts and novices.

The second section of this chapter will concentrate on the language of science and present a broad survey of related literature. This survey will cover relevant research on topics including that of scientific language and the technicality of science language.

4.2 Comparison between an Expert and Novice

When a person is having trouble solving a particular problem or task it is common place to ask for help. In order to get a correct solution one is most likely to consult
an expert in that field; however what makes that person an expert? What is the
distinction between an expert and someone who is new to the material, a novice?
In the past decade much research has been carried out on human information
processes to answer the above questions. In the research the mode of data
collection has been to record verbal accounts given by experts and novices as they
think aloud and problem solve, and to analyse their accounts for similarities and
differences. Although there is no accepted cognitive-psychological definition of
the terms expert and novice (Friege and Lind, 2006) the results from the research
have shown that there are differences in perceptual knowledge, recognition
capabilities and information representation in the long-term memory of both
(Larkin et al., 1980).

that take place in order to progress from a novice to an expert, each of which
possess specific characteristics (Table 4.1).

Table 4.1: Characteristics of the five stages of performance from novice through to
expert

<table>
<thead>
<tr>
<th>Stages of Performance</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice</td>
<td>Uses context-free facts and rules to produce actions based on these facts</td>
</tr>
<tr>
<td>Advanced Beginner</td>
<td>Learns to recognise elements not defined in terms of context-free facts</td>
</tr>
<tr>
<td>Competent</td>
<td>Learns to organise thoughts in terms of plans and goals, which involves choices and decisions</td>
</tr>
<tr>
<td>Proficient</td>
<td>Intuitively recognises a familiar situation and the goal</td>
</tr>
<tr>
<td>Expert</td>
<td>Has the ability to intuitively know the sense of the situation, and from prior knowledge knows what to do</td>
</tr>
</tbody>
</table>

Davis (1989, cited in Dhillon, 1998) identifies a novice as someone who uses
context-free facts during problem solving where an expert has the ability to
intuitively understand the situation involved in the question and uses his/her prior
knowledge to solve what is being asked. Therefore as the problem solver gains experience and the ability to transfer their knowledge during problem solving the transition from novice to expert occurs.

4.3 Problem Solving in the Physics Classroom

Problem solving is central to physics instruction and is an area of difficulty for many students in secondary school science (Bolton et al., 1997; Heyworth, 1998). Successful learning of physics requires students to acquire not only the content knowledge of the subject but also the skills to solve problems using this knowledge. One of the principal goals of a physics course is to produce adept problem solvers who can transfer their knowledge and understanding to real world situations (Walsh, Howard and Bowe, 2007). Within a normal school day students meet and experience problems both during instruction and during homework assignments. The aim of introducing problems during class time is to “illustrate concepts and principles”. They have a different function during homework assignment as they are used to “direct students’ studying” (Gerace and Beatty, 2005) and to reinforce and develop the ideas that are discussed in the classroom.

Within a physics classroom the most common means of teaching problem solving relies excessively on examples and practice. Students are presented with new material and, following this, work through examples often provided in the textbook, which show the application of the new content. The students then are encouraged to practice similar problems for homework. This typical use of problems in a physics classroom has several limitations (Reif, 1995, pp 26-27) as it:

1. reveals little about the problem solving process and how to make good problem solving decisions.
2. can lead students to believe that the solution process resembles the product, however instead the process may actually involve trial and error and subsequent planning to reach the product.
3. can result in bad problem solving habits which are often difficult to break or change.
Such evidence suggests that students require a strategy that will allow them to improve their problem solving skills as it is vital for both in the classroom and everyday life.

### 4.3.1 Anatomy of a Problem

The term “problem” has been used differently by many researchers in the past. Willoughby (1990) defines a problem as “a situation in which a person wants to reach a particular goal, is somewhat blocked from reaching that goal, but has the necessary motivation, knowledge and other resources to make a serious effort (not necessarily successful) at reaching the goal” (Cited in Muir, Beswick and Williamson, 2008). Similarly Yan and Lianghuo defines a problem as “a situation that requires a decision and/or answer, no matter if the solution is readily available or not to the potential problem solver” (2006, p. 612). In order to reach the desired goal the student must be able to integrate several different problem solving strategies. In the last four decades research on problems and problem solving has multiplied. Prior to the 1970’s little attention was given to the analysis of the problem solving process. In 1972 problem solving was researched by Newell and Simon which lead to the publication of their book, *Human Problem Solving* (Anderson, 1993). This research concluded that all problems are composed of the same basic parts or structures (Halpern 1996). In keeping with Newell and Simon’s view Halpern (1996, p.319) identified the problem parts as “anatomical parts” and the concept of the problem solving state was introduced. This refers to the beginning or the end of the problem, “with the solver beginning in the initial state of the problems, traversing through some intermediate states, and arriving at a state that satisfies the goal” (Anderson, 1993). A second structure was also identified from the literature and was known as the *operator* which is defined as “an action that transforms one state into another state” (p.36) and together the problem solving state and operator comprise to form the problem space (Anderson 1993, Halpern 1996). To solve a problem a person must then search the problem space and identify the best path from the initial to the goal state.
4.3.2 Classification of Problems

Within the physics classroom there are two different categories of problem that the students will meet – qualitative and quantitative. Thacker, Kim and Trefz, (1994) identified these as synthesis and analysis problems respectively. The qualitative (synthesis) problem can be solved without any calculations and the students are asked to reason out the solution to the problem using theory. The quantitative (analysis) problem requires calculations in order to obtain the solution. When these two problem types are broken down further several different types of problem are identified. The work of Johnstone (1993) stands out in this area and his research provides a list of eight problem types (Table 4.2).

Table 4.2: Characteristics of the eight problem types identified by Johnstone

<table>
<thead>
<tr>
<th>Type</th>
<th>Data</th>
<th>Method</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Given</td>
<td>Familiar</td>
<td>Given</td>
</tr>
<tr>
<td>2</td>
<td>Given</td>
<td>Unfamiliar</td>
<td>Given</td>
</tr>
<tr>
<td>3</td>
<td>Incomplete</td>
<td>Familiar</td>
<td>Given</td>
</tr>
<tr>
<td>4</td>
<td>Incomplete</td>
<td>Unfamiliar</td>
<td>Given</td>
</tr>
<tr>
<td>5</td>
<td>Given</td>
<td>Familiar</td>
<td>Open</td>
</tr>
<tr>
<td>6</td>
<td>Given</td>
<td>Unfamiliar</td>
<td>Open</td>
</tr>
<tr>
<td>7</td>
<td>Incomplete</td>
<td>Familiar</td>
<td>Open</td>
</tr>
<tr>
<td>8</td>
<td>Incomplete</td>
<td>Unfamiliar</td>
<td>Open</td>
</tr>
</tbody>
</table>

Type 1 and 2 can be regarded as the typical problems usually given in textbooks and end of course examination papers. Type 3 and 4 are very different, with type 3 requiring data while type 4 requires very different reasoning from that used in types 1 and 2. Types 4 to 8 have open type goals and are representative of real life problems.

Yan and Lainghuo (2006) also established classifications of questions, where each division includes two categories (dichotomies) or more:

1. Routine Problems vs. Non-Routine Problems
2. Traditional Problems vs. Non-Traditional Problems
3. Open-Ended Problems vs. Closed-Ended Problems
4. Application Problems vs. Non-Application Problems
5. Single-Step Problems vs. Multiple-Step Problems
6. Sufficient Data Problems, Extraneous Data Problems and Insufficient Data Problems

7. Problems in purely mathematical form, problems in a verbal form, problems in a visual form and problems in a combined form.

1. Routine Problem vs. Non-Routine Problems
A non-routine problem is a problem that “cannot be resolved by merely applying a standard algorithm, formula, or procedure, which is readily available to the problem solvers” (Yan and Lainghuo, 2006, p.613). In contrast a routine problem can be solved easily as the solution path is very evident.

2. Traditional Problems vs. Non-Traditional Problems
Yan and Lianghuo make the distinction that non-traditional problems can consist of four sub-types of problem which include problem-posing problems, puzzle problems, project problems and journal problems. All of these types of problem provide the teachers and instructors with information about the students’ learning and their own teaching and are similar to those exercises found at the end of chapters in school books.

3. Open-Ended Problems vs. Closed-Ended Problems
An open-ended problem can contain several correct answers however a closed-ended problem can only have one correct solution.

4. Application Problems vs. Non-Application Problems
An application problem is similar to a real-life problem, a problem that has applications in everyday life. On the contrary, non-application problems are unrelated to “any practical background in everyday life or the real world” (Yan and Lainghuo 2006, p.613).

5. Single-Step Problems vs. Multiple-Step Problems
As this classification suggests problems that require one step to solve the problem are defined as single-step and those that require more than one step to reach the goal are identified as multiple-step problems. Heyworth (1998) described these questions as basic and composite respectively.
6. Sufficient Data Problems, Extraneous Data Problems and Insufficient Data Problems

This classification refers to the amount of data given to the students in order to solve the question. If they are given more data than required to find the solution the problem is deemed an extraneous data problem. If the data provided in the problem statement is too little then it is an insufficient data problem and if the information given is exactly enough to solve the problem the problem is considered a sufficient data problem.

7. Problem in a Purely Mathematical Form, Problems in a Verbal Form, Problems in a visual form, and Problems in a Combined Form

This category refers to the presentation of the problem statement. The manner in which the problem is presented will dictate to which category it will belong to.

Throughout the course of their lives, whether in the classroom or not, the students will experience all of the above problems. However in the physics classroom the problem situations which students usually have to cope with are mostly problems with a unique solution (Friege and Lind, 2006).

4.3.3 Problem Solving Process

Problem solving is part of everyday life and is considered part of the scientific process of enquiry (Gayford, 1989, cited in Okebukola, 1992). The problem solving process is very much individual and no two students will tackle a problem in the same manner, despite reaching the same solution (Bolton et al., 1997). Research shows that problem solving occurs in stages whereby the solver has to select and apply successful procedures in order to reach the desired goal.

Significant research carried out by Wallas in 1926 established four stages through which one progresses during problem solving. From these four stages one may or may not happen with every task of problem solving. These stages are identified as:
1. Preparation – the time spent in understanding the nature of the problem, the desired goal and the givens.

2. Production – the time during which the problem solver produces the solution paths that define the problem space.

3. Judgement or evaluation stage – the time spent evaluating the solution paths in order to select the best one.

4. Incubation stage – this stage may not always occur and will depend on the questions. When one cannot find the solution path, they stop working on the problem. The time when one is not actively considering the problem is called the incubation stage.

These four stages are echoed in the work of Polya (1973) whereby the problem solver is required to understand the problem, devise a plan, carry out the plan and look back and examine the solution obtained (Muir, Beswick and Williamson, 2008). Barak and Mesika (2007) reduced the stages further and developed a two-stage process which includes an idea-generating stage and an idea-evaluating. The ‘idea generating’ stage comes first where the students collect as many items as possible that relate to the problem. This stage is followed by the ‘idea-evaluating’ where the problem solver analyses ideas and compares them in order to select the optimal solution. Irrelevant to the number of stages of the problem solving process in order to reach the goal state problem solving strategies must be implemented.

4.3.4 Problem Solving Strategies

In solving a physics problem, it is necessary to treat the problem as a decomposable system and design a method of analysis which accounts for the most important, salient features in the problem while ignoring the insignificant factors (Novak and Araya, 1980; Reif, 1995). In order for students to successfully solve the problem they need to be “able to make sense of what the problem is about, what the relevant physics is, and how to interpret the results” (Sabella and Redish, 2007, p.1017). There are several strategies that can help the students work towards the solution and interpret the results. They may not guarantee that the solver will arrive at the correct solution, however learning how to use the
strategies will give them more possibilities which will in turn increase their confidence when they are presented with a new problem (Halpern, 1996). Most of the strategies support the use of diagrams which can help the students to reduce the cognitive load as the solvers’ processing capacity is limited (Dhillion, 1998). The majority of problem solvers will use a combination of the strategies and these will depend on the amount of factual and procedural knowledge and experience of the problem solver (ibid, p.382), however “specific types of problems may yield only to particular techniques” (Bolton et al., 2007, p.177). Table 4.3 summarises commonly used strategies reported in the literature.
Table 4.3: A description of common problem solving strategies

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analogy</td>
<td>Knowledge is transferred from past problem-solving episodes to new problems that share significant aspects with the past problems.</td>
</tr>
<tr>
<td>Brainstorming</td>
<td>The problem solver generates as many solutions as possible without criticism. Criteria are then developed by the solver to judge the viability of the solutions and the best solutions is selected.</td>
</tr>
<tr>
<td>Envisioning</td>
<td>The problem solver generates a series of sequential snapshots that describes what may happen. Domain-specific principles and rules are then applied to obtain a qualitative description of the problem situation. Analysis rules are then applied to solve the problem.</td>
</tr>
<tr>
<td>Forward Strategy</td>
<td>This is when the initial problem description is used to generate the solution using the knowledge base. When knowledge is available, solutions usually show forward and top-down development.</td>
</tr>
<tr>
<td>Generate and Test</td>
<td>This strategy occurs when the problem solver simply generates solutions one at a time and tests them to determine their applicability.</td>
</tr>
<tr>
<td>Problem abstraction</td>
<td>Within this strategy the solver ignores the minor details and focuses on the problem by retaining certain central features, thus allowing the solver to focus on a couple of features at a time.</td>
</tr>
<tr>
<td>Problem decomposition</td>
<td>This is when a large complex problem is broken down into smaller subparts or subproblems and continues until all the subproblems are solved which combine to form the solution of the original problem.</td>
</tr>
<tr>
<td>Heuristic search</td>
<td>This process uses operators to guide the search in the problem space. Problem decomposition is often used during this strategy.</td>
</tr>
<tr>
<td>Working backwards</td>
<td>This is when the solver starts at the goal state and works backwards until they arrive at the quantities specifically given in the problem.</td>
</tr>
<tr>
<td>Means-end analysis</td>
<td>This is when an assessment is made between the current state of knowledge of the problem and the desired goal. This assessment allows the solver to select and apply an operator to reduce the difference. Subgoals are created to eliminate the difference.</td>
</tr>
</tbody>
</table>
4.3.5 Problem Solving Ability of the Expert and the Novice

The previous sections in this chapter look at and discussed the strategies and processes that are available to the problem solver during the problem solving process. The path or strategies that they use can often indicate whether the person is an expert or a novice in that area. This section will look closely at the variation in the problem solving approach used by both.

The literature on problem solving is quite extensive and collectively suggests that experts and novices differ in a number of characteristics including their domain specific knowledge (Friege and Lind, 2006; Sweller, 1988), problem solving process (McDermott and Larkin, 1978), problem solving strategies (Larkin et al., 1980) and in their representation of the problem (Chi, Felrovich and Glasser, 1981). Within the research there is a consensus that experts have a more extensive domain-knowledge base and together with their acquired memory structures they have the ability to memorise and deal with the knowledge more effectively (Friege and Lind, 2006).

Friege and Lind (2006) carried out research to investigate the importance of ‘types’ and ‘qualities’ of knowledge in relation to problem solving. In this study students with good achievements in physics problem solving (experts) and students with fewer achievements (novices) were compared. The findings of the data collected concluded that novices predominantly depend on conceptual knowledge when solving problems whereas experts solve problems using their problem schema knowledge. In related research Chi, Glaser and Rees (1982) reviewed the physics education literature which centred on how physics problems are solved, and in particular how expert physicists solve them in comparison to novices. Their review highlighted three areas in which the empirical research focuses on, namely students’ knowledge structures, students’ prior conceptions of the physical world and finally the solution protocols used by both the expert and the student. Again their findings suggest that there are differences in the manner in which the expert and novice proceed to the solution, where the difference lies in how many steps it takes for each to reach the solution. It is the research carried out by Simon and Simon (1978) that draws attention to this difference. This
research demonstrates that the expert can call to mind the appropriate equations and solve them in one step whereas the novice takes many more (Cited in Chi, Glaser and Rees, 1982, pp.16-17). The following table (Table 4.4) summarises the differences; both quantitative and qualitative in the problem solving process used by both experts and novices (Chi, Glaser and Rees, 1982; Gerace and Beatty, 2005) but also on the strategies they use during problem solving and their domain knowledge (Chi, Feltovich and Glaser, 1982; Friege and Lind, 2006; Larkin et al., 1980; Sweller, 1988).
Table 4.4: The differences; both quantitative and qualitative in the problem solving process used by both experts and novices

<table>
<thead>
<tr>
<th>Problem Solving Variable</th>
<th>Expert</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Quantitative Differences</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning</td>
<td>Do not carry out a large amount of planning for simple problems; however they engage in planning for complex problems</td>
<td>No planning carried out for either complex or simple problems – the solver simply ‘jumps right in’</td>
</tr>
<tr>
<td>Time</td>
<td>Solve problems quickly</td>
<td>Solve problems slowly – subgoals increase time</td>
</tr>
<tr>
<td>Pause Times</td>
<td>Very little pause time</td>
<td>Increased pause time due to equation retrieval</td>
</tr>
<tr>
<td>Procedure</td>
<td>Carries out ‘longer leaps’ during the problem solving</td>
<td>Carries out step-by-step procedure</td>
</tr>
<tr>
<td>Memory</td>
<td>Up to six pieces of information can form a ‘chunk’ and at least four of these chunks can be stored in short term memory</td>
<td>Very few pieces of information forms a ‘chunk’ and only 4-6 chunks can be stored in the short term memory</td>
</tr>
<tr>
<td>Errors</td>
<td>Commit very few errors</td>
<td>Commit errors, in some cases a large number</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Qualitative Differences</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge</td>
<td>Domain specific knowledge in the form of organised schemas</td>
<td>Conceptual knowledge in the form of sparse, isolated facts</td>
</tr>
<tr>
<td>Problem Representation</td>
<td>Superior as it contains a great deal of knowledge, scientific representation is used</td>
<td>Poor problem representation skills, naïve representation is used during problem solving</td>
</tr>
<tr>
<td>Problem Categorisation</td>
<td>Categorise physics problems with a high degree of Inter-subject agreement e.g. solution mode</td>
<td>Categorise physics problems according to surface structures e.g. the inclusion of shared objects in the problem statement</td>
</tr>
<tr>
<td>Solution Paths</td>
<td>Working forward strategy</td>
<td>Working backward strategy</td>
</tr>
<tr>
<td>Metastatements*</td>
<td>Very little comments used during the solving process</td>
<td>Large amount of comments used during the process</td>
</tr>
</tbody>
</table>

*Metastatements are comments made by the subjects about the problem-solving process (Simon and Simon, 1978; Cited in Chi, Glaser and Rees, 1982, p.19).
The table above illustrates that there are a number of variables within problem solving and for each of these variables, experts and novices react differently. For a clear explanation I will discuss a number of these less understood in detail.

**Memory**

The process by which experts and novices store information is very different. Dufresne *et al.*, (1992) proposes that the most salient feature distinguishing experts from novices is that experts possess “highly organised domain-specific knowledge” (p.308) in comparison to the isolated facts that the novice posses. To add to this experts store physics knowledge and particularly equations in tightly connected ‘chunks’ whereas novices stores them individually (Larkin, 1979; Cited in Chi, Glaser and Rees, 1982). Experts have the ability to ‘chunk’ two to six pieces of information; however, a novice has the ability to only store two. If the problem solver has brief exposure of the information or stimulus it will not fixate in the long-term memory and hence must be retained in the short-term memory (Larkin *et al.*, 1980). The short-term memory however has the capacity to store four to six ‘chunks’ of information (ibid, p. 208) which will affect how quickly a problem solver can retrieve and recover information allowing them to progress with the problem solving. The superior recall of information by the experts is “attributed to their ability to group individual units of information into chunks related by some underlying principle or goal structure” (Dufresne *et al.*, 1992, p.308).

**Problem Representation**

Chi, Feltovich and Glaser (1981) provide a detailed account of the representation of problems and advocate that as soon as the solver reads the problem a representation is formed and it is this representation that categorises the problem. As the problem is being solved however the representation of the problem changes and these changes are significantly different for that of the expert and novice (Heyworth, 1998). Through the solving process the solver can progress through four stages of representation (McDermott and Larkin, 1978, Cited in Chi, Feltovich and Glaser, 1981). These four stages include:
• literal representation of the problem
• naïve representation which contains the objects of the problem and their relationships, often accompanied by a diagram of the situation
• scientific representation which focuses on the concepts used to generate equations and finally
• algebraic representation that results once equations are formed.

Differences can occur in the manner in which experts and novices solve problems. Novices often omit the scientific representation, which is often described as the “qualitative thinking” in the problem solving process which “contains abstract entities from formal science” (Heyworth, 1992, pp.19-20), as they lack knowledge and understanding and proceed directly from the initial and naïve representation to the algebraic representation.

The procedure by which novices and experts carry out problems also differs. Walsh, Howard and Bowe (2007) carried out research to determine how students approach problem solving by interviewing 22 introductory students whilst solving quantitative physics problems. The results revealed a hierarchical set of five categories that describes their approaches to solving quantitative problems (Table 4.5). Each category can be described using two components:

1. how do the students approach problem solving?
2. what is the focus of their approach?

The work of Lester and Kehle (2003; Cited in Lester 2007, p. 767) also investigated the distinction between good (expert) and poor (novice) problem solvers and concluded that:

“Good problem solvers know more than poor problem solvers and what they know, they know differently – their knowledge is well connected and composed of rich schemas. Good problem solvers tend to focus their attention on structural features of problems, poor problem solvers on surface features”
<table>
<thead>
<tr>
<th>Category</th>
<th>Characteristic</th>
</tr>
</thead>
</table>
| Scientific                       | • Qualitatively analyses the situation  
• Plans and carries out solution in a systematic manner based on that analysis  
• Discusses the way in which the concepts relate to the problem  
• Refers to concepts to guide the solution  
• Draws diagrams only when they believe it will help them visualise the problem  
• Evaluates the solution                                                                                     |
| Plug and Chug - Structured       | • Qualitatively analyses the situation based on required formulas for the problem  
• Relates the concepts to variables involved and identify the target variable  
• Plans the solution based on the variables and proceeds systematically  
• Refers to concepts to guide the solution  
• Focus throughout solution is how the concepts are related  
• Evaluates the solution                                                                                     |
| Plug and Chug – Unstructured      | • Analyses the situation based on required variable  
• Proceeds by choosing formulas based on the variables in a trial and error manner.  
• Refers to concepts as variables  
• May identify the concepts and equations correctly but may carry out an incorrect methodology and answer the question incorrectly  
• Conducts no evaluation                                                                                     |
| Memory – Based Approach           | •Analyses the situation based on previous examples; perhaps done in the class  
• Proceeds by trying to “fit” the given variables to those examples; recalling from situations encountered in the past  
• Believe that the problem can be solved in the same way as the previously encountered question  
• Refers to concepts as variables  
• Conducts no evaluation                                                                                     |
| No Clear Approach                | • Does not try and approach the problem with any sort of strategy  
• Analyses the situation based on given variables  
• Proceeds by trying to use the variables in a random way  
• Refers to variables as unrelated terms or letters  
• Conducts no evaluation                                                                                     |

*Table 4.5: Categories of Problem Solving Approaches and their Key Characteristics (Walsh et al., 2007)*
From the five categories identified in this research the dominant approach used by the students is the plug-and-chug unstructured method. This method refers to use of trial and error and the students simply select equations based on the variables present rather than on the desired solution. The results gathered from the data indicate that “the majority of students do not approach physics problems qualitatively” (p. 8). This is in contrast to the experts who qualitatively evaluates the problem statement and then construct a representation of the problem (Van Heuvelen, 1991, Cited in Walsh et al., 2007).

4.3.6 Conclusion

Despite the particular function of a problem students will approach and solve a question in the same manner as they are unskilled in the problem solving process. The student will typically read the question and immediately plunge in searching and manipulating equations until they find a combination that yields an answer. They seldom analyze the situation qualitatively nor do they plan a solution and once they arrive at a solution they are usually satisfied and rarely check to see if their answer makes sense. In comparison experts identify the actual problem and comprehend it before attempting to solve it. They deal with both the qualitative and quantitative aspects of the problem and decide on what information is important, what information can be ignored, and what additional information may be needed, even though it was not explicitly provided.

Problem solving is a frequent and crucial component in any science class. It is a skill that students must acquire however most students will not develop this multi-layered skill unless they are trained and supported to do so (Bolton, Keynes and Ross, 1997).
4.4 Language in Science

It is very obvious from the educational literature that a key requirement for successful problem solving is students’ knowledge and in particular their domain-specific knowledge. There are many types of knowledge identified in the research including conceptual, procedural, situational and strategic (Jong and Ferguson-Hessler, 1996). However, a strong link has been identified between knowledge and language. This is evident through the work of Postman and Weingartner (1971) and is apparent from the following extract from their work (Cited in Wellington and Osborne, 2001, p.3).

Almost all of what we customarily call ‘knowledge’ is language, which means that the key to understanding a subject is to understand its language. A discipline is a way of knowing, and whatever is known is inseparable from the symbols (mostly words) in which the knowing is codified. What is biology (for example) other than words? If all the words that biologists use were subtracted from the language, there would be no biology. Unless and until new words are invented. Then we would have a ‘new’ biology! What is history other than words? Or astronomy? Or Physics? If you do not know the meanings of history words or astronomy words you do not know history or astronomy. This means, of course, that every teacher is a language teacher: teachers, quite literally, have little else to teach, but a way of talking and therefore seeing the world.

Traditionally language has been thought to have a passive role in the classroom and is seen simply as a vehicle that transmits thought or reality (Fang, 2005; Ford and Peat, 1988), however in recent years it has been realised that language has a much more important role. Chapter 2 of this thesis discussed in detail the physics student population and the declining number of students studying science and particularly the physical science subjects. Several factors have been put forward as to the reason for this, with the latest one being the students’ understanding and their ability in the language of science (Wellington and Osborne, 2001; Cited in Fang 2005, p. 336). In order for science students to improve their understanding and to learn scientific language they require a shared understanding of the content, whether it is vernacular or non-vernacular language (Brown and Ryoo, 2008; Ford and Peat, 1988). One of the aims of the Leaving Certificate Physics Syllabus is to “develop the ability to observe, to think logically, and to communicate
effectively” (DES, 1999). The fundamental factor that will allow students to reach this aim is the utility of language.

4.4.1 Scientific Literacy

According to the American Association for the Advancement of Science (AAAS) report, Science for All Americans (1989) a person who is scientifically literate is someone who:

“is aware that science, mathematics, and technology are independent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognises both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes”

(Cited in Glynn and Muth, 1994, p.1057).

Wellington and Osborne also believe that knowing and understanding the language of science is an essential component of scientific literacy (2001, p.139) and it is essential that every student is able to comprehend and explain in clear language fundamental science concepts. There are several activities that take place in the classroom including reading, writing and listening, to name a few. All of these activities include the use of science language and the students require a good understanding in order to learn. For example, during problem solving students read and write using science language where it is written language that is used to read the text and spoken language that is used to communicate the path taken from the initial state to the goal state (Lemke, 1989).

The problem that lies in most science and physics classrooms is that the students rarely get the opportunity to use scientific language for learning or clarifying their ideas about science topics (Pearce, 1984). Students are often asked short questions during class time and therefore do not have enough scope to express their ability in scientific language. As a result the teacher is unaware of the students understanding of the concepts and believes the student understands the concepts involved in the simple task. In order to discuss scientific language the author will firstly define what language is and identify the various types.
4.4.2 What is Language?

Language is a symbolic communication system that is learned and is the means by which humans makes sense of text, explain, interpret, learn and solve problems (Lemke, 1989, p.136). Halliday defined language as the “essential condition of learning, the process by which experience become knowledge” (1993, Cited in Fang, 2005). Language itself can be characterised as formal and informal and within the science classroom the ‘new’ language of science is considered the formal language whereas the informal language is the customary language of the students (Lemke, 1989). Huang also identified the distinction between different types of language which occur due to the “broader realms of communication and expressions” present in different social settings (2006, p.391). Likewise, Brown and Ryoo identified variations in language where they differentiated between vernacular and non-vernacular language where vernacular language is seen as ‘everyday’ language that people learn as they communicate with each other and non-vernacular language is “context specific” language which serves a more specialised purpose (2008, p.530). Using this distinction scientific language is considered the new, non-vernacular language.

4.4.3 Scientific Language

Scientific language differs from that of everyday language in that is contains gestures, unique symbols and signs, mathematical formulas, graphic representations and non-verbal markers (Huang, 2006). It is the inclusion of all these elements that combine to form scientific discourse, however for the purpose of this research the focus is on scientific language only. Discourse refers to language in the broadest sense, as it includes “language in all its semantic and representational forms”, which involve diagrams, figures etc. Language on the other hand, is “defined as a collection of words that are used to represent ideas” (Brown and Ryoo, 2008, p.531).

The language of science is “difficult and often obscure” (Childs and O’Farrell, 2003, p.233). Science is constructed through specialised grammar and words which may and may not be completely new to students. Scientific vocabulary can include words we use throughout our lives in everyday language but is adapted to
more specialised purposes in science and as a result will have different meanings within the scientific context (Lemke, 2001; Itza-Ortiz, Rebello and Zollman, 2003). As soon as a student enrols in a science classroom he/she is greeted with a science textbook that provides scientific knowledge in the form of scientific language. The language used in the textbook is often not the language used by the students and can be different to the language even used within the classroom (Lemke, 1989). However, by the end of the course students must be able to read and comprehend the text.

Not only do the students have to deal with a textbook that contains ‘new’ words but they are also faced with new equipment within the science laboratory. The students will be asked to work with equipment and appliances that they will not have seen before including the Bunsen burner, burette, ammeter, resistor and many more. Throughout the course of the school year the students will learn to cope with these new words however research shows that they may not actually understand their meanings i.e. the students fail to understand the semantics of the words (Marshall and Gilmour, 1991; Wellington and Osborne, 2001).

4.4.3.1 The Technicality of Science Language

As mentioned earlier language is a key component of many activities that take place in the classroom including discussions, practical work, demonstrations, pen and paper tasks, reading and listening. Embedded in these classroom activities are the two components of language: the technical component and the non-technical component.

The Technical Component

In order for students to realize the “specialized contents of science” (Fang, 2005), the students must become familiar with a wide range of specialist vocabulary. The technical component of science consists of technical words or terminologies specific to that subject; these may also be referred to as technical terms, scientific terms/terminology, or science. Technical words were originally identified by Gardner (1972) and include such items as physical concepts (mass, force.) names
of chemical elements, minerals, plants, organs, processes, apparatus etc. (p. 7).
The technical/science words can also be everyday words which have new (scientific) meanings in addition to their every day meanings (Sutton 1992; Wellington and Osborne, 2001). In order for a language to be technical it must involve the use of technical vocabulary which holds a “specialized field-specific meaning” (Wignell, Martin and Eggis, 1993; Cited in Fang, 2005).

The Non-Technical Component

The non-technical component of the science teachers’ classroom language is made up of non-technical words. It is this part of the science teachers’ classroom language that may be referred to as the medium of classroom instruction or interaction that is separate from the technical terms. Gardner (1972) used the sentence: gas molecules display random motion; we may predict their behaviour from theoretical considerations: the actual volume of the molecules may be neglected (p. 7), to illustrate examples of non-technical words. The four italicised words: random, predict, theoretical and neglected, though not ‘technical terms’, remain key words in the sentence, with regard to the understanding of the behaviour of the gas molecules. In science education research literature, it is words like these that in particular, have been referred to as non-technical words in the science context (Gardner, 1972; Pickersgill and Lock, 1991; Marshall and Gilmour, 1991; Prophet and Towse, 1999; Wellington and Osborne, 2001).

The groundbreaking research that looked at students’ understanding of science language was carried out by Cassels and Johnstone in 1985 which was entitled “Words that Matter in Science”. In this research study, Cassels and Johnstone examined students’ vocabulary and use of non-technical language within the science context. This work stemmed from their previous research and that of Gardner (1972) which led them to believe that students did not have difficulty with technical language but that they misunderstood non-technical (vernacular) language that was used in the science classroom in a different context (Cited in Wellington and Osborne, 2001, p.11). Following this research three research studies were carried out which replicated that of Cassels and Johnstone, all of which examined students understanding of non-technical science vocabulary.
Pickersgill and Lock (1991) investigated student understanding of 30 non-technical words, employing the same method as that of Cassels and Johnstone. Their research focused on the relationship between students’ verbal reasoning and their understanding of technical words (Table 4.6) and focused specifically on the variation of performance in male and female students. The findings reported that there was no difference between the verbal reasoning of males and females, however there was a positive correlation between the student’s score on the verbal reasoning test and the test which examined their understanding of non-technical words.

Table 4.6: List of non-technical words (Pickersgill and Lock, 1991)

<table>
<thead>
<tr>
<th>abundant</th>
<th>adjacent</th>
<th>average</th>
<th>capable</th>
<th>conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>constituents</td>
<td>contract</td>
<td>convention</td>
<td>converge</td>
<td>converse</td>
</tr>
<tr>
<td>criticise</td>
<td>disintegrate</td>
<td>diversity</td>
<td>emit</td>
<td>factor</td>
</tr>
<tr>
<td>fundamental</td>
<td>incident</td>
<td>liberate</td>
<td>linear</td>
<td>negligible</td>
</tr>
<tr>
<td>percentage</td>
<td>relevant</td>
<td>retard</td>
<td>simultaneous</td>
<td>spontaneous</td>
</tr>
<tr>
<td>stimulate</td>
<td>system</td>
<td>tabulate</td>
<td>valid</td>
<td></td>
</tr>
</tbody>
</table>

Marshall and Gilmour (1991) again using the procedure set out by Cassels and Johnstone, examined students’ comprehension of 45 non-technical words in science classes in Papua New Guinea. The students ranged between those from grade 7 up to university level, aged 12 to 37 years of age. As in the original study, the students understanding of science words were tested in four different formats, each of which represented a different context and a different level of difficulty, namely synonym, sentence, science context and non-science context. The following table (Table 4.7) represents how the students understanding of the word ‘effect’ was examined.
Table 4.7: The four formats used to test the students understanding of the word ‘effect’ (Marshall and Gilmour, 1991).

<table>
<thead>
<tr>
<th>Format</th>
<th>Format Description</th>
<th>Multiple-Choice Question Asked</th>
</tr>
</thead>
</table>
| 1      | A synonymous expression without context | Effect can mean  
  a) Attack  
  b) Result  
  c) Frequent  
  d) Change |
| 2      | The word appears in a sentence describing an everyday event | Which of the following sentences uses the word “effect” properly?  
  a) The teacher could not effect the work of the pupils  
  b) The effect of heating the water was that it boiled  
  c) It took considerable effect to move the large rock  
  d) He thought that his smile would effect everyone |
| 3      | The word appears in a science context stem | If you were asked to find the effect of adding acid to a metal, this would mean you would try to find  
  a) The reason for adding the acid  
  b) What happened  
  c) How long the reaction took  
  d) The quantity of acid used |
| 4      | The word appears in a non-science context stem | Putting the car brakes on had no effect. The means the car  
  a) Stopped  
  b) Did not stop  
  c) Went faster  
  d) skidded |

The results of this study were consistent with that of the previous research. Students performed poorly in their understanding of the words and often confused words with others, especially those words that had opposite meanings, e.g. “simple” for “complex” and “final” for “initial” and words that also sounded the same, e.g. “accumulate” with “accommodate” and “consistent” with “constituent”. The above research studies reinforce the fact that students understanding of
science words are often incorrect and as a result can affect their verbal reasoning of science phenomena.

These research findings have several implications in the science classroom and highlight that there are different types of words that make up ‘scientific language’. Wellington and Osborne group these types of words into scientific, semi-technical and non-technical. To compound the problem further these words often have dual meanings and students are unable to set aside their everyday understanding of the word while in the classroom. Table 4.8 is taken from Wellington and Osborne (2001, p.18) which shows words from all groups of science language and those that have different meanings. It is very clear from this table that the majority of words are specific to Physics which emphasises why it is perceived difficult by many students.
Table 4.8: Science words grouped according to their scientific, non-technical and technical nature (Wellington and Osborne, 2001, p.18)

<table>
<thead>
<tr>
<th>Scientific Words</th>
<th>Semi-Technical Words</th>
<th>Non-technical Words used in Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unique to science</td>
<td>With dual meanings</td>
<td></td>
</tr>
<tr>
<td>Cathode</td>
<td>energy</td>
<td>emit</td>
</tr>
<tr>
<td>anode</td>
<td>power</td>
<td>excess</td>
</tr>
<tr>
<td>electrolysis</td>
<td>work</td>
<td>exert</td>
</tr>
<tr>
<td>refraction</td>
<td>efficient</td>
<td>immerse</td>
</tr>
<tr>
<td>diffraction</td>
<td>conduct</td>
<td>optimum</td>
</tr>
<tr>
<td>ion</td>
<td>reflection</td>
<td>component</td>
</tr>
<tr>
<td>electron</td>
<td>law</td>
<td>displace</td>
</tr>
<tr>
<td>atom</td>
<td>contract</td>
<td>probability</td>
</tr>
<tr>
<td>neutron</td>
<td>theory</td>
<td>impact</td>
</tr>
<tr>
<td>velocity</td>
<td>field</td>
<td>continuous</td>
</tr>
<tr>
<td>charge</td>
<td>circuit</td>
<td>definition</td>
</tr>
<tr>
<td>cycle</td>
<td>charge</td>
<td>diverge</td>
</tr>
<tr>
<td>filament</td>
<td>cycle</td>
<td>converge</td>
</tr>
<tr>
<td>substance</td>
<td>substance</td>
<td>gain</td>
</tr>
<tr>
<td>impulse</td>
<td>impulse</td>
<td>random</td>
</tr>
<tr>
<td>weight</td>
<td>weight</td>
<td>flow</td>
</tr>
<tr>
<td>mass/massive</td>
<td>mass/massive</td>
<td>detect</td>
</tr>
<tr>
<td>beam</td>
<td>beam</td>
<td>principle</td>
</tr>
<tr>
<td>pitch</td>
<td>pitch</td>
<td>principal</td>
</tr>
<tr>
<td>friction</td>
<td>friction</td>
<td>particle</td>
</tr>
<tr>
<td>potential</td>
<td>potential</td>
<td>contract</td>
</tr>
</tbody>
</table>
4.4.4. Conclusion

Despite the centrality of science to our lives many students fail to understand the words associated with it because they are very different to that of the language used by students in their everyday lives. Science language uses both technical and non-technical words that are combined to form very different meanings from those in the everyday ordinary life.

The evidence presented and discussed in this section implies that students often have minimal understanding of scientific language. The two main issues that contribute to this are:

1. the students do not have the opportunity to discuss and practice their scientific language in the classroom because most tasks and questions they complete require short answers and hence do not require them to clarify their ideas about the science content.

2. science students find it extremely difficult to differentiate between the scientific words, both technical and non-technical, that have dual meanings.

In the next chapter the author explains the methodology underlying her research to examine the use of Concept Mapping in an undergraduate setting as well as its purpose in generating qualitative and quantitative problems that were used to examine physics students’ scientific technical language.
Chapter 5

Research Methodology

5.1 Introduction

Research is defined by Jones (1996) as a systematic process of collecting and analysing the data set with the goal to develop explanatory concepts which in turn will aid in our appreciation of individual behaviour and social processes. In the context of this research study the author is investigating undergraduate physics students’ use of and opinions of the Concept Mapping tool while also examining the students’ use of scientific language and problem solving skills.

As this investigation is diverse it is necessary to select a research design that best reflects the situation and thus can serve as the best possible tool for investigating the issue. This chapter provides the rationale for the selection and implementation of the research design. Theoretical and procedural issues concerning the research process are also examined, while discussing in detail each stage of the research process.

5.2 Research Design

Research design can be thought of as the structure of the research in that it holds all the elements of the study together. The design selected must take into account the research questions posed and adequately answer the questions. Different research problems will lead to different research designs, which in turn result in the collection of different types of data and different interpretations of those data (Leedy and Ormond, 2005). Due to the enormity of this task it is pivotal that time is allocated at the onset of the study to ensure a suitable research design is developed, which is “appropriate to the subject matter and interests at stake” (Toulmin, 1996, p.204; Cited in Reason and Brad).
To ensure that the research design is appropriate for the study it is important to first identify the ‘gap’ in the human knowledge structure in the area in question. The author identified a lack of research investigating Irish students’ use of Concept Mapping and also research which investigated students’ use of technical language used in problem solving, in both qualitative and quantitative problems. This formed the focus of the thesis. To facilitate this investigation the researcher decided that a specific type of research (mixed-method research) must be employed to answer the research questions. This is discussed in detail later in the chapter (Section 5.7.4 and Section 5.7.5). Before the author continues to discuss the research design and identify the research questions she will firstly give a brief description of the type of research employed in this study and discuss the rationale for choosing it.

5.2.1 Action Research

Action research is a form of applied research that focuses on finding a solution to a local problem in a local setting (Leedy and Ormond, 2005) and rejects the notion of an objective, value-free approach to knowledge generation (Brydon-Miller, Greenwood and Maguire, 2003). The process of action research has a long and complex history because it is not a single academic discipline but an approach to research that has emerged over time from a broad range of fields commencing with that of Lewin in the early 1940’s during his work of social psychology. Argyris and colleagues summarised Lewin’s concept of action research in the following points (Argyris, Putman and Smith, 1985, pp. 8-9):.

1. It involves change experiments on real problems in social systems. It focuses on a particular problem and seeks to provide assistance to the client system.
2. It involves iterative cycles of identifying a problem, planning, acting and evaluating.
3. The intended change in an action research project typically involves re-education.
4. It challenges the status quo from a participative perspective, which is congruent with the requirements of effective re-education.
5. It is intended to contribute simultaneously to basic knowledge in social science and to social action in everyday life.

Since then ample definitions of action research can be found in the literature, however one of the most suitable to this study is provided by Oberg and McCutcheon (1987) who define action-research as “any systematic inquiry, large or small, conducted by professionals and focusing on some aspects of their practice in order to find out more about it, and eventually to act in ways they see as better or more effective” (Oberg and McCutcheon, 1987, p.117). Within the many definitions found in the literature, basic themes can be distinguished; collaboration through participation; acquisition of knowledge; and change. The key idea of action research is that it uses a scientific approach to study the resolution of important issues together with those who experience these issues directly (Coghlan and Brannick, 2005). In any action research study it is first essential to understand what is happening and to evaluate it, then to introduce change and evaluate the new situation (Bassey, 1999). This framework encourages what is identified as a ‘spiral of steps’ which was first developed by Lewin in 1946. Within this framework each step contains the components of an action research study.

This iterative process allows the author to understand and establish the context of the study while also promoting the development of steps to facilitate the acquisition of solutions to the research questions. An additional characteristic, which supported the use of action research within this study, was that it is situational, in the sense that it is concerned with identifying a problem within a specific context and attempts to solve the problem within that context. The following diagram represents the ‘spiral of steps’ associated to this research study.
Figure 5.1: Action Research “Spiral of Steps” employed in research study.
5.3 Description of the Study

The research project presented in this thesis incorporated a five-phased approach. The specific characteristics of each will be discussed in detail while also highlighting their contribution to the overall design of the project (Figure 5.2).

**Phase 0**: Prior to any data collection a comprehensive review of the literature was carried out in order to gain an in-depth knowledge of the area. Aspects including the uptake of Physics in Irish schools and universities, the use of Concept
Mapping within science classrooms, as well as literature concerning problem solving and scientific language were reviewed and examined. This literature review led the author to develop a pilot study to test the use of Concept Mapping in the University of Limerick, Phase 1.

**Phase 1**: The pilot study took place during the autumn semester of the academic year (AY) 06/07 and data was collected from four first year groups of students, all of which were completing physics modules. This phase provided essential feedback concerning the potential use of concept maps in physics classrooms within the University of Limerick. This phase informed Phase 2, allowing for an investigation utilising concept maps as both an instructional and assessment tool.

**Phase 2**: This phase is identified as the exploratory phase and involved the collection and subsequent analysis of qualitative and quantitative data collected from a cohort of students (N = 88) enrolled in the physics module “Light and Sound” during the spring semester of 06/07. This research phase centred on the use of concept maps in the physics classroom which allowed the author to analyse the tool, the students’ attitude towards it and finally the effect Concept Mapping had on their learning of physics.

**Phase 3**: Due to the success of Concept Mapping in the Physics classroom, the author developed the study further. During this phase the students’ concept maps were used to generate both qualitative and quantitative word problems. Large scale interviews were carried out providing data from both students and experts.

**Phase 4**: The final phase focused on the analysis of the qualitative and quantitative data collected from both the experts and novices during Phase 3. The author then compared the language and problem solving ability of both.

**5.4 Theoretical Perspective**

The theoretical perspective that guides this research study is based on the synthesis of two theoretical positions. This first position emerges from Ausubel (1968) who proposes that learning takes place by the incorporation of new
concepts and propositions into existing concept and propositional frameworks held by the learner, alternatively known as the individual’s knowledge structure (Novak and Cañas, 2006). The second position emerges from Vygotsky’s constructivist theory, also known as social constructivism. The social constructivist theory maintains that meaningful learning can take place when people are clearly taught how to use psychological tools including language, diagrams and problem-solving approaches and are then given the opportunity to use these tools to create an understanding of some phenomenon (Snowman and Biehler, 2000).

5.4.1 Ausubel’s Theory of Meaningful Learning

“Meaningful learning by definition, involves the acquisition of new meanings. New meanings, conversely, are the end products of meaningful learning. That is, the emergence of new meanings in the learner reflects the prior operation and completion of a meaningful learning process”

(Ausubel, 2000, pg 67)

According to Ausubel there is a clear distinction between rote and meaningful learning. Rote learning occurs when “new knowledge is arbitrary and non-substantively incorporated into students’ cognitive structure” (Novak, 2002, p.549) whereas meaningful learning involves the learner consciously integrating new knowledge to prior knowledge already possessed.

Novak and Cañas (2006) identified three conditions that must be in place in order for meaningful learning to take place.

- The new material (concepts and propositions) to be learned must be conceptually clear and presented with language and examples relevant to the learner’s prior knowledge.
- The learner must possess relevant prior knowledge.
- The learner must choose to learn meaningfully. Teachers can motivate students to learn meaningfully by using instructional and evaluation strategies that facilitate the relation of new concepts to concepts already in memory.
Due to the diverse range of student abilities within a classroom or lecture hall, each student will vary in the quality and quantity of relevant knowledge they possess and in their levels of motivation to learn meaningfully. Also, within any instructional strategy learning can vary from being almost rote to being highly meaningful, from reception learning to discovery learning. Novak and Gowin (1984) illustrated this as a matrix and identified that reception learning and discovery learning are on a scale distinct from that of rote learning and meaningful learning. The initial matrix has since been revised (Novak and Cañas, 2006).

Reception learning is the method in which most school children and adults acquire new meanings, however the major problem with reception learning is that students develop a rote learning set in learning potentially meaningful subject matter
This can be as a result of teachers overlooking the fact that students become very skilful at using abstract terms without understanding the underlying concepts. The students may also lack the ability to learn meaningfully and believe that rote learning is the only possible way.

This framework recognises that meaningful learning will not take place without both careful planning and implementation of instructional tools within a classroom, or high levels of student motivation. The theory depicts the importance in providing tools that will facilitate meaningful learning which allow students to associate new concepts and propositions to ones already developed in their cognitive structure. This is a key issue identified by the author during the planning and implementation of Phase 2 (exploratory study) and Phase 3 (development of concept mapping study) of this research project. Ausubel also identified the significance of the role of language in meaningful learning and stressed that language is an important facilitator of meaningful reception as it clarifies meanings, making them more defined and transferable (Ausubel, 2000). Ausubel continued by stating that “without language, meaningful learning would probably be only very rudimentary” (ibid). This again is a key issue which the author took on board during Phase 3.

5.4.2 Vygotsky’s Constructivist Theory

“Learning is active rather than passive. Learners confront their understanding in light of what they encounter in the new learning situation. If what learners encounter is inconsistent with their current understanding, their understanding can change to accommodate new experience. Learners remain active throughout this process: they apply current understandings, note relevant elements in new learning experiences, judge the consistency of prior and emerging knowledge, and based on that judgment, they can modify knowledge.”

(Hoover, 1996, p.1)

The underlying concept of social constructivism is that the emphasis is placed on the social context of learning rather than on stages of development and learning styles which are the dominant features of cognitive constructivism, as summarised in Hoover’s definition of learning. Within Vygotsky’s constructivist theory the
teacher plays a vital role in the students learning where they are identified as ‘facilitators’ of learning as opposed to ‘transmitters’ of knowledge. The constructivist teacher does not take the role of the “sage on the stage”, rather they act as “guides on the side” providing students with opportunities to test their understanding (Hoover, 1996, p.1).

The most significant bases of the social constructivist theory were developed by Vygotsky [1896-1934] (1962), identified as the ”Zone of Proximal Development” (ZPD). Essential in this theory are the three categories in which Vygotsky placed students thinking and problem-solving skills. The first category is when students/learners utilise skills allowing them to perform problem-solving independently, without any help. The second is where students can perform skills with the help of an adult (teacher) and the final category is where students cannot solve the problem even with help. Within the second category are the skills that are in the ZPD. If a child uses these skills with help from others, such as teachers, parents, and fellow students, they will develop skills that will allow them to perform the tasks independently in the future.

Teachers that incorporate constructivism into their classroom/lecture can allow students the opportunity to “think scientifically” (Polman, 2000; Cited in Wilhelm, Thacker and Wilhelm, 2007, p. 20). Studies have shown that physics students’ conceptual understanding is disappointingly weak using traditional methods in comparison to those using constructivist methods (Leonard et al., 1996) or as Hake (2000) defines as Interactive Engagement methods. Interactive Engagement (IE) Methods are those designed at least in part to promote conceptual understanding through interactive engagement of students in hands-on (always) and hands-on (usually) activities that yield immediate feedback through discussion with peers and/or instructors. In comparison traditional (TM) Methods are those identified as passive-student lectures, recipe labs, and algorithmic-problem exams. Traditional courses as those reported by instructors make little or no use of IE methods.

The Department of Education emphasises the importance of “self directed learning and independent thought, a spirit of inquiry, critical thinking, problem
solving, self reliance and initiative” (Department of Education and Science, 1999, p.2). Although this is a description of what is detailed in the Leaving Certificate Physics syllabus, the author believes that similar opportunities should be afforded to University students. With this in mind the author set out the following research aims and questions.

**5.5 Research Aims and Questions**

The work presented in this study stemmed from the author’s reflections on her own experience of learning Physics in university. The study was further encouraged by the rapid decline in the number of Irish students graduating with a science degree, particularly within physics degrees. Each phase of this research study was guided by research aims and questions which are summarised below.

**Phase 1 – Pilot Study**

The aims of the pilot study are to:

- Establish if Concept Mapping is a feasible instructional tool within the University of Limerick setting.
- Examine the students’ reaction to Concept Mapping.

**Phase 2 – Exploratory Phase**

Having recognized that the students of the pilot study responded positively to the Concept Mapping tool, the purpose of this phase was to introduce Concept Mapping on a large scale into a Physics module. The exploratory phase of the research addressed the following research questions:

- Does Concept Mapping have an effect on students learning of Physics? If so, to what extent?
- Does experience of Concept Mapping improve students’ attitudes towards Physics and what issues concerning the use of the tool are identified after one semester experience?
- What elements are essential for the training of undergraduate physics students in Concept Mapping?
- How effective and valid are concept maps as a form of assessment?
Phase 3 – Concept Mapping Development

The final phase of data collection was predominantly qualitative as the focus of the study was now firmly on the use of scientific technical language used by the students during problem-solving in semi-structured interviews. As this phase of research was carried out during one academic semester, the author was restricted to interviewing 10 students. Six experts were also interviewed using the same problems to compare the use of technical language used by students and that of experts. For the purpose of this study experts are defined as anyone who has completed a physics degree and is either in the process of getting or has qualified with a PhD in physics.

The research questions that guided Phase 3 of this study include:

- Can solutions to theoretical qualitative physics problems be used to categorise levels of scientific language? If so how many categories of language are used when answering physics problems and what are the characteristics of each category?
- Is there a significant difference in the level of language used by experts and students when problem solving?
- Is performance in physics word problems affected by the level of scientific language proficiency?
- In what way, if any, did the lecturer’s use of language and problem solving ability impact on the students’ proficiency in scientific language and problem solving ability?
- What issues in relation to students’ attitudes and beliefs concerning concept mapping and the use of the tool in a science classroom come to light following a year’s experience of the tool?
- Does having experience in concept mapping encourage pre-service teachers to use the tool in their own teaching? If so, in what aspect of teaching do they incorporate it and what are their conceptions concerning Concept Mapping following its usage?

Phase 4 – Analysis of Data Set

The analysis of the data collected from the interviews was carried out during the final Phase of this longitudinal study (observation of the same group of students
over a long period of time). The interviews were transcribed verbatim and the students’ problem solving and scientific language ability was analysed and categorised.

5.6 Research Method

The research method depends upon the nature of the research questions. Having decided on the research questions it is crucial that the research method utilized is adequate and appropriate to investigate them fully. Due to the diverse nature of the study one research strategy or method will not address the varied research questions so as a result the author employed a mixed methods research approach. For many years the advocates of quantitative and qualitative research paradigms have engaged in debates protesting the benefits of each. Following several papers on the strengths and weaknesses of both paradigms a third paradigm has being identified as mixed methods research. It is believed that taking a non-purist or mixed position allows researchers the ability to design a research method that offers the best chance of answering the specific research question (Johnson and Onwuegbuzie, 2004). The combination of qualitative and quantitative research paradigms not only contributes to the gain of their individual strengths but also compensates for their particular faults and limitations (Brewer and Hunter, 1989) while allowing for greater opportunities for both verification and discovery (ibid). This design method represents the highest degree of mixing paradigms (Creswell, 1994). The paradigms are mixed in all stages of the study; the introduction, the literature review, the purpose statements and research questions. In order to fully understand the mixed methods approach it is necessary to discuss these research paradigms individually and to highlight their individual differences.

5.7 Qualitative and Quantitative Research Paradigms

Qualitative and quantitative research paradigms are often defined on the basis of the beliefs or assumptions that guide the investigation. These assumptions are related to the views they hold concerning the nature of reality (ontology), the relationship of the researcher to what is been studied, the role of values in the study, and the process of research itself (methodology). They are two distinct
paradigms that result in two contrasting cultures; one concerned with ‘deep, rich observational data’ and the other with ‘hard, generalizable data’ (Sieber, 1973).

5.7.1 Qualitative Research

In order to understand qualitative research I will begin by giving a definition of the research method provided by Denzin and Lincoln (2005, p.3) which identifies the ever-changing nature of qualitative inquiry.

“Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible. These practices transform the world. They turn the world into a series of representations, including field notes, interviews, conversations, photographs, recordings and memos to the self. At this level, qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative research study things in their natural settings, attempting to make sense of, or interpret, and phenomena in terms of the meanings people bring to them”.

In general the qualitative paradigm, also known as the interpretative, constructivist, or postpositivist approach, is used to answer questions about the complex nature of phenomena, with the intention of describing and understanding the phenomena from the participant’s point of view.

5.7.2 Quantitative Research

The quantitative research paradigm, also known as the traditional, experimental or positivist approach is used to answer questions concerning relationships among measured variables with the purpose of explaining, predicting, and controlling phenomena (Leedy and Ormond, 2005).

There are several quantitative research methodologies evident in the literature including experimental research, correlational research, casual-comparative research and survey research. The basic premise of quantitative research is that there is a reality “out there”, independent of us, waiting to be discovered (Kane and O’Reilly–De Brún, 2001). The study is usually carried out under experimental settings rather than in natural settings and this can present a problem and affect
the validity of the results as it is unlikely that you will come across the same conditions except when the exact conditions are set up. In general within a quantitative study the variables are clearly defined, are measurable, and the results can be converted to numbers. The characteristics of qualitative and quantitative research approaches can be distinguished by asking questions concerning the purpose, process, data collection, data analysis and reporting of the findings involved in each approach. These characteristics are highlighted in Table 5.1
Table 5.1: Characteristics of qualitative and quantitative research. (Leedy and Ormond, 2005).

<table>
<thead>
<tr>
<th>Question</th>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the purpose of the research?</td>
<td>To explain and predict</td>
<td>To describe and explain</td>
</tr>
<tr>
<td></td>
<td>To confirm and validate</td>
<td>To explore and interpret</td>
</tr>
<tr>
<td></td>
<td>To test theory</td>
<td>To build theory</td>
</tr>
<tr>
<td>What is the nature of the research process?</td>
<td>Focused</td>
<td>Holistic</td>
</tr>
<tr>
<td></td>
<td>Known variables</td>
<td>Unknown variables</td>
</tr>
<tr>
<td></td>
<td>Established guidelines</td>
<td>Flexible guidelines</td>
</tr>
<tr>
<td></td>
<td>Predetermined methods</td>
<td>Emergent methods</td>
</tr>
<tr>
<td></td>
<td>Somewhat context-free</td>
<td>Context-bound</td>
</tr>
<tr>
<td></td>
<td>Detached view</td>
<td>Personal view</td>
</tr>
<tr>
<td>What is the data like, and how is it collected?</td>
<td>Numeric data</td>
<td>Textual and/or image-based data</td>
</tr>
<tr>
<td></td>
<td>Representative, large samples</td>
<td>Informative, small sample</td>
</tr>
<tr>
<td></td>
<td>Standardised instruments</td>
<td>Loosely structured or non-standardised observations and interviews</td>
</tr>
<tr>
<td>How is that data analysed to determine their meaning?</td>
<td>Statistical analysis</td>
<td>Search for themes and categories</td>
</tr>
<tr>
<td></td>
<td>Stress on objectivity</td>
<td>Acknowledgement that analysis is subjective and potentially biased</td>
</tr>
<tr>
<td></td>
<td>Deductive reasoning</td>
<td>Inductive reasoning</td>
</tr>
<tr>
<td>How are findings communicated?</td>
<td>Numbers</td>
<td>Words</td>
</tr>
<tr>
<td></td>
<td>Statistics, aggregated data</td>
<td>Narratives, individual quotes</td>
</tr>
<tr>
<td></td>
<td>Formal voice, scientific style</td>
<td>Personal voice, literacy style</td>
</tr>
</tbody>
</table>

5.7.3 Commonalities among the Paradigms

Although I have just highlighted the many differences between the qualitative and quantitative research methods, there are several similarities between the research
paradigms also. Both paradigms use empirical observations to address research questions (Johnson and Onwuegbuzie, 2004) and both “describe their data, construct explanatory arguments from their data, and speculate about why the outcomes they observed happened the way they did” (Sechrest and Sidana, 1995). Furthermore throughout each research method, researchers minimise bias and any other possible sources of invalidity (Sandelowski, 1986).

Although the quantitative and qualitative purists would contend that accommodation between paradigms is impossible (Guba, 1990) through the identification of these similarities and the weaknesses and strengths of both the qualitative and quantitative paradigms it is possible to conclude that a mixed-method approach is a useful paradigm. The mixed-methods research paradigm can help to bridge the gap between the quantitative and qualitative research as it will exploit the strengths and curtail the weaknesses of both.

5.7.4 Mixed-Methods Research Paradigm

Before the author discusses the characteristics of a mixed-method paradigm it is important to distinguish between the terms methodology and methods as they are often used synonymously. Methods include a range of approaches, procedures and instruments used to gather data. On the other hand, methodology is a more generic term that refers to the inquiry process (Gill, 2006) and the theoretical perspective for the research project. Therefore within the mixed-method research paradigm the emphasis is on the techniques that are used to carry out the research (Bogdan and Biklen, 2007).

The literature is replete with mixed-methods research typologies (Creswell, 1994; Morgan, 1998; Patton, 1990; and Tashakkori and Teddlie, 1998), and with these there are several configurations which the method can take, mixed-model and mixed-method (Johnson and Onwuegbuzie, 2004). The mixed-model technique involves mixing qualitative and quantitative approaches within and across the stages of the research. Alternatively, the mixed-method technique involves the inclusion of a quantitative Phase and a qualitative Phase in the overall research study (ibid). The mixed-model design can be further differentiated into a ‘within-
stage’ mixed-model design and an ‘across-stage’ mixed-model design. These designs differ according to the integration of paradigms in the study. Within the mixed-method research paradigm the researcher must also decide on two other dimensions:

1. The time order
2. Paradigm emphasis

1. Time order
Time order or orientation refers to whether the qualitative and quantitative phases of the study occur at approximately the same time (i.e. concurrent) or whether these two components occur one after the other (i.e. sequential) (Collins, Onwuegbuzie and Jiao, 2006). The decision of time order is crucial for any research methodology as it affects whether one set of results will inform another. A sequential design allows for one Phase to inform another however a concurrent design will not as both phases are running at the same time.

2. Paradigm emphasis
When conducting mixed-method research the researcher decides which research method is the principal data-gathering tool (Morgan, 1998). It is not always possible to identify whether the qualitative or quantitative method is dominant and in some cases both approaches have equal weight. There are several purposes or rationales for conducting mixed methods research. Greene, Caracelli and Graham (1989) identified 5 major purposes (Table 5.2)
Table 5.2: Purposes of mixed methods research

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangulation</td>
<td>Seeks convergence, corroboration, correspondence of results from different methods</td>
</tr>
<tr>
<td>Complementarity</td>
<td>Seeks elaboration, enhancement, illustration, clarification of the results from one method with the results from the other method</td>
</tr>
<tr>
<td>Initiation</td>
<td>Seeks the discovery of paradox and contradiction, new perspectives of frameworks, the re-framing of questions or results from one method with questions or results from the other method</td>
</tr>
<tr>
<td>Development</td>
<td>Using the findings of one method to help inform the other method</td>
</tr>
<tr>
<td>Expansion</td>
<td>Seeking to expand the breadth and range of inquiry by using different methods for different inquiry components</td>
</tr>
</tbody>
</table>

Since then Bryman (2006) defined a more comprehensive scheme for the justification of using a mixed-methods approach (see Bryman, 2006, p.105 – 107). The scheme is quite large but it aims to depict all the possible justifications for employing mixed-methods.

5.7.5 Mixed-Method Design Employed

As mentioned earlier the aim of any research study is to carefully create a research design that successfully answers the research questions set out in the study. With this in mind, the researcher identifies the design used in this study as a mixed-model research method that incorporated the across-stage approach. The qualitative and quantitative phases were run both concurrently and sequentially with equal emphasis on both paradigms.

The goal of mixed-methods research is not to replace the qualitative or quantitative paradigms but rather to use the strengths of both and construct a
design suitable for your research questions. The use of mixed-methods research facilitated the investigation of different research questions thus generating more diverse findings.

5.8 Validity and Reliability

If this research is to be significant and enhance the sum of what we know about students’ use of Concept Mapping and their use of technical language when problem solving then it must have meaning beyond this study of undergraduate students. This issue is generally discussed in terms of validity and reliability.

Quantitative research is saturated with statistical measures that allow for an objective determination of validity and reliability. However, the validity and reliability of a qualitative study is much more subjective, and hence open to different interpretations. Statistics are not always useful. To overcome this qualitative researchers have found ways to establish validity and reliability within their studies (Wolcott, 1990; Maxwell, 1992).

5.8.1 Validity

A study or method is said to be valid if it actually measures what it claims to measure. Validity refers to the issue of whether an indicator (or set of indicators) that is devised to gauge a concept really measures that concept (Bryman, 2008). To encompass both qualitative and quantitative methods Hammersley (1992) provided a broad definition of validity. He states that “an account is valid or true if it represents accurately those features of the phenomena that it is intended to describe, explain, or theorise” (Hammersley,1992, p.69). Validity is strengthened through the selection of a suitable research methodology together with the selection of appropriate research tools (Ní Riordáin, 2008). In qualitative research, the level of validity depends on the impartiality of the researcher and the span and profundity of the data obtained (Cohen et al., 2000). Throughout this research study the author used a wide variety of data (concept maps, questionnaires and interviews) as the basis of description, explanations and theories. All questionnaires and interviews were piloted before distribution to the students.
There are several different types of validity that exist in relation to research including internal, external, ecological and content validity. The types of validity that are relevant to this study are discussed below.

**Internal Validity**

Internal validity is associated with the sample under study and relates mainly to the issue of causality. It is concerned with the question of whether a conclusion that incorporates a causal relationship between two or more variables holds true (Bryman, 2008). The author ensures this by guaranteeing that the analysis was carried out according to the literature and by seeking advice during the analysis from experts in the qualitative and quantitative fields. The following methods were also used during the interviews to ensure validity of the data collected:

1. The students were encouraged to ‘think aloud’ (Chi, 1994; Cited in Walsh, Howard and Bowe, 2007, p. 3) during the interviews so to record the problem solving behaviour of the participants. The transcripts were then used to compare the train of thought and problem solving knowledge of the participant.
2. During the problem solving, pen and paper were provided to the students to explore their problem solving strategy.
3. The interviewer also recorded observations throughout the interview process so as to record information that was not verbalised.

**External Validity**

External validity is concerned with the results and whether or not they can be “generalized” beyond the specific research environment (Bryman, 2008). In order to provide evidence of a generalisation researchers introduce the *sampling model* approach. Within this approach the researcher identifies the sample he/she will generalise to and carry out the research. Finally, if the sample is a representative of the population the researchers can generalise the results to that population. Here the researcher identifies the particular characteristics of the participants involved in the study e.g. undergraduate physics students in the University of Limerick. The purpose of the research study is to identify students’ opinions on the Concept Mapping tool and also their use of scientific technical language and thus transfer the findings to similar groups of students.
It should be noted that the issue of generalisability depends on applying the research in a similar setting to a broader population. That is, in the context of this research study, are the results generalisable to other college physics modules, with similar experience of concept mapping? As each physics course has unique features, such as the lecturer, teaching assistants, textbook, and student population, it is impossible to reproduce the study. It would prove more beneficial to think in terms of translating the results to a comparable situation rather than in terms of generalizing the findings to the same context and content (Goetz and LeCompte, 1984).

5.8.2 Reliability

Within research the word reliability can often have similar meaning. In order to access the reliability of a measure of a concept, the methodology employed and procedures must be replicable by someone else (Bryman, 2008). This implies that if one were to carry out the same research, utilising the same methodology for data collection and analysis, there would be a high level of correlation in their results. Within this research, reliability was supported through the use of the mixed-methods research paradigm, which included several methods of data collection and analysis. The author also introduced practices to reduce error in the study including the piloting of questionnaires and interviews. The interviewer was also trained prior to the interview in order to prevent any errors inadvertently being introduced to the study.

5.9 Ethics

Within any research study the researcher has a responsibility not only to their area of study in its “search for knowledge and quest for truth but also for the subjects they depend on for their work” (Cohen et al., 2000, p. 56); the wellbeing of the research participants is top priority. Therefore when carrying out any study the researcher must bear in mind the repercussions and “effects the research has on the participants and act in such a way to preserve their dignity as human beings” (ibid). Standards for research ethics must be agreed upon ensuring that as
researchers we take into consideration the concerns of the participants and
generate trust between the researcher and those researched. Hence before this
research begun approval was sought through the University of Limerick Research
Ethics Committee. The research study was then designed such that:

- Participants in the study were strictly voluntary
- The participants had the right to withdraw from the study at any
time during the research study.
- All participants received an information sheet detailing the purpose
of the study and what was required of them during the course of
the study.
- All participants signed a consent form before participating in the
research.
- Participant confidentiality was guaranteed through the provision of
pseudonyms developed by the students and used throughout
dissemination of results.
- The data is used only for research purposes and presented as
combined data rather than that of individual students.
- The data is stored according to the University of Limerick’s ethics
regulations.

5.10 Researcher Distance

Within every research study the worry of biases, opinions and subjectivity
affecting the reported results comes into play, especially when the data must ‘go
through’ the researcher’s mind before they are put on paper. As stated previously
this research came about from the author’s own experience of her undergraduate
study and because of this the researcher comes to this research with her own
biases and assumptions. To overcome these biases and to “objectively study the
subjective states of their subjects” (Bogden and Bilken, 2007, p. 33) the
researcher employed the mixed-method approach. This approach allowed for
variety in data collection tools. Leedy and Ormond (2005) recommended several
other strategies to minimise the extent to which one's prior expectations and opinions enter into the final analysis of the data. These include:

- Get multiple and varying perspectives on any single issue or event.
- Make a concerted effort to look for evidence that contradicts your hypotheses.
- In the final research report, acknowledge any biases you have, so that the readers can take them into account when reading the report.

Throughout this project these recommendations were acknowledged and taken into account to establish researcher distance and objectivity.

5.11 Research Study

As outlined at the beginning of this chapter the study was carried out in five phases. The aim of the study was to identify physics undergraduate students’ opinions on the Concept Mapping tool and also their role in examining and assessing physics student’s use of technical scientific language when problem-solving. As mentioned earlier in section 5.7 due to the diversity of the research questions a mixed-model methodology was employed incorporating both qualitative and quantitative research paradigms. Throughout each phase the author also employed across-stage and within-stage research approaches. Prior to Phase 1 a comprehensive review of the literature was carried out (Phase 0) and subsequently it was discovered that no research had been carried out in Irish universities similar to this. Each phase will now be discussed individually, emphasising and discussing the steps involved.

5.11.1 Phase 1: Pilot Study

5.11.1.1 Research Aims and Objectives:
The aim of the pilot study was to introduce Concept Mapping to undergraduate physics students and to evaluate its feasibility within the University of Limerick setting.
With this study several objectives were outlined. They included:

1. To train students how to construct a concept map ensuring all components of a map are present.
2. To help students connect knowledge, both prior and new.
3. To encourage students to summarise information graphically in the form of a concept map.

5.11.1.2 Significance of the Study
Concept Mapping is a very flexible instructional tool which has being implemented in many disciplines, however, to date there is very little application of this tool in Irish third level institutions. An adaptation of Concept Mapping has being implemented in the University of Limerick under the term ‘topic maps’ in the Department of Mathematics and Statistics; however its use was not evaluated but rather utilised during data collection.

Due the success of Concept Mapping worldwide, a pilot study was undertaken in the hope of determining whether the introduction of Concept Mapping would enhance student learning and to provide significant guidelines for the future implementation of Concept Mapping in Irish science classrooms.

5.11.1.3 Learning Context and the Profile of the Participants
This pilot study was carried out during the autumn semester in the academic year 06/07. Four groups, resulting in a cohort of 44 students, participated in the research. The cohort consisted of two first year groups and two second year groups; with groups from both the Science Education degree and Applied Physics degree offered in the university. All groups were enrolled in a physics module at the time of the study (Table 5.3).
Table 5.3: Groups of Students that participated in the pilot study

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>Module Name</th>
<th>Module Number</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applied Physics</strong></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Year</td>
<td>Principles of Physics</td>
<td>PH4141</td>
<td>N = 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantum Mechanics</td>
<td>PH4403</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Year</td>
<td></td>
<td></td>
<td>N = 11</td>
</tr>
<tr>
<td><strong>Science Education</strong></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Year</td>
<td>Introduction to Physics</td>
<td>PH4511</td>
<td>N = 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electricity and Magnetism</td>
<td>PH4301</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Year</td>
<td></td>
<td></td>
<td>N = 10</td>
</tr>
</tbody>
</table>

During the first meeting with each group the author ran a training session on Concept Mapping, which included a ten minute PowerPoint presentation (See Appendix A) detailing the components and characteristics of the tool. The students also examined and discussed concept maps detailing concepts in science and non-science related areas. Subsequently, the students were given written instructions including five seed concepts and thirty minutes to construct a concept map on their understanding of the given ‘key’ concept which was related to their physics module.

Students mapped their understanding of the key concept twice during the course of the semester (at weeks 2 and 13). These concept maps were examined for structural complexity and content validity. At this stage of the research study the students did not experience any teaching using the Concept Mapping tool throughout the semester.

5.11.2 Phase 2: Exploratory Study

As mentioned Phase 2 the author modified and implemented an adaptation of the pilot study, developed from the findings gathered from Phase 1.
5.11.2.1 Research Aims and Objectives

1. To introduce Concept Mapping to physics classes in a first year undergraduate course.
2. To initiate the use of concept maps as ‘advance organisers’.
3. To assess students’ understanding of Physics utilising Concept Mapping.
4. To evaluate the use of Concept mapping through questionnaires and interviews.

5.11.2.2 Significance of the Study

Following the analysis of the students’ concept maps it was found that Concept Mapping is a valuable tool in the science classroom and can be of great benefit to students when implemented carefully. In order to highlight the full benefit of this tool an exploratory study was carried out with several modifications.

5.11.2.3 Learning Context and the Profile of the Study Participants

The selected first year undergraduate physics module, Sound and Light; PH4202 defined the context of this investigation. The module contained aspects including simple harmonic motion, sound and light waves and physical and geometrical optics (See Appendix B).

The cohort of the students (N = 88) included a wide variety of abilities and included those from two courses, Bachelor of Science in Biological Science Education and Bachelor of Science in Physical Science Education. The students’ timetable for this module consisted of 2 lecture sessions (one hour each), one lab session (two hours) and one tutorial a week (one hour). It was during this one hour tutorial session that the author was in direct contact with the students and data was collected. The purpose of the tutorials was to provide students with time to ask and answer questions concerning material that was covered during the lectures. Throughout the tutorials the students worked in groups of two or three. The formation of the student groups was carefully designed so as to encourage cooperative learning and maximise their learning potential.
Forming the Groups:
There are many different approaches in forming groups for classroom benefit. For the purpose of this study the author decided on forming heterogeneous groups because there are a number of advantages associated with doing so. Groups composed of students with diverse backgrounds, abilities and interests (a) expose students to multiple perspectives and problem-solving methods and (b) generate more cognitive disequilibrium (needed to stimulate students’ learning and cognitive development) (Johnson, Johnson and Holubec, 1994). The method that was used to assign the groups can be described as “stratified random” (ibid, p. 3.7) and the characteristic, which the author used, was the level of Physics experienced by each student. With this it ensured that every group has at least one student who had completed Leaving Certificate Physics.

The groups were assigned to triads as the author felt that small groups increase the visibility of students’ efforts and thereby make them more accountable. Also with increasing group size, there is a decrease in face-to-face interaction among team mates and hence a reduced sense of intimacy (Johnson et al., 1994).

Assigning Roles:
To promote well functioning groups, roles of responsibility were assigned prior to any work being carried out. Some typical roles in groups include the following:

- Chair: The chair keeps the group moving forward and helps to finalise strategies to solve the problem. The chair also helps to ensure that everyone is involved, and that each member of the group has a task to do.

- Scribe: The recorder or scribe keeps records of assignments to be done and strategies, which have been chosen to solve problems, as well as ideas and issues the group have discussed at meetings.

- Timekeeper: The timekeeper is responsible for keeping the schedule to enable the group to meet deadlines.

Other roles appropriate to a physics environment include accuracy checker, safety officer, experimental designer and experimenter (Raine and Symons, 2005).
The roles were rotated weekly which discouraged students from sticking to roles that came to them easily and gives them additional experience in those that they find challenging. The chair of each group was determined during the first tutorial very simply by posing the question as to who has the most siblings. This was very random but as the students discussed the size of their families they became more relaxed and at ease with each other. The chair of each group then allocated the remaining roles within their group. Observation of group interactions indicated that after roles were assigned groups worked productively. The issue of dominance and conflict avoidance did not arise as a problem. With time, the groups adjusted well to their roles and they generally worked efficiently.

The student groups remained constant over the course of the study so as to develop a familiarity among them. In order to maintain functioning groups throughout the tutorials ground rules were established. The ground rules were discussed and agreed by the entire group. It is thought that this would be particularly helpful for students who were new to collaborative learning (Symons and Raine, 2005). The use of group ground rules, roles of responsibilities, documenting the activities of the group and individuals within the group and peer pressure within the group all provided ways to help group members to avoid conflict (Duch et al., 1998).

5.11.2.4 Integration of Concept Mapping into the Classroom

The exploratory phase differed greatly from the pilot study with the author having direct contact with the students on a weekly basis during the tutorial sessions. The following list gives an indication of the alterations made following from the analysis of Phase 1.

- An intensive training course on concept mapping was administered prior to the module.
- The training was delivered by the same researcher to all groups of students to minimize variability. The training lasted 50 minutes and had 3 major parts:
  - Introduction of concept maps via a PowerPoint presentation
Construction of concept maps (both in groups and individually) and finally
A discussion permitting students to ask questions.
- Concept maps are used as ‘advanced organisers’ to introduce new subunits in tutorials.
- The students construct three maps throughout the semester, at weeks 3, 8 and 11.

5.11.2.5 Preparing the Students

As stated above, the students were given intensive training on Concept Mapping prior to constructing any maps similar to that carried out by Zieneddine and Abd-El-Khalick, 2001 and Vanides et al., 2005). Experience has shown that virtually all college students can learn to construct a simple concept map in a single 50-minute class period, while gaining practice and confidence with the technique (Wallace et al., cited in Quinn et al., 2004). The training session took place during the tutorial session in week two of the spring semester ’07. As stated above this training session took place in three stages.

1. Introduction of concept maps: this PowerPoint presentation was very similar to that used during the pilot study. It was fifteen minutes in duration and formed a basis for the students. It answered certain questions including:
   - What are Concept Maps?
   - What are Concept Maps used for?
   - What are the components of Concept Maps?

2. Construction of concept maps (both in groups and individually): the second stage of the training involved the students constructing concept maps. Four aspects of Concept Mapping were highlighted in this stage of the training:
   i) identifying a relationship between a pair of concepts
   ii) creating a proposition
   iii) recognizing good maps
   iv) redrawing a map.
Initially the students constructed maps in groups of two and three. Students were given instructions to ‘fill-in’ a concept map within the theme of the ‘water cycle’. This was a non-hierarchical map which was used to demonstrate that different structures of concept maps exist. The students were given the entire list of concepts suitable for the map and asked to complete it within their groups. Following from the group construction the students were asked to individually construct a map, using the key concept ‘Living Things’. The students were not made aware of which structure to construct but were given a list of concepts to assist them in their maps. Subsequent to the group and individual construction of maps a class map was drawn on the board with each student coming to the board and contributing a proposition. This exercise highlighted that every student had a different understanding of the topic and each student map will represent their own understanding.

3. The final and concluding stage to the training session was a discussion. This time allowed students to ask questions about the tool now that they have had first time experience with it.

5.11.2.6 Concept Maps used as Advance Organisers

During this twelve week study the author used concept maps as ‘advance organisers’. This methodology was used following a study carried out by Willerman and Mac Harg in Illinois in which they discovered that “concept mapping used as an advance organiser can sufficiently improve eighth-grade science achievement” (Willerman and Mac Harg, 1991, p.705). Prior to this study there has being several studies carried out on the effect of advance organisers on student learning with conflicting results. However a meta-analysis review carried out by Stone (1982) “found that advance organisers that used principles and important terms from new material to be learned were also effective” (Cited in Willerman and Mac Harg, 1991, p. 706).

In this study the author provided the students with concept maps prior to beginning a new topic as part of instruction. The concept maps, which were constructed by the teacher, were presented to the students and accompanied with
an explanation of the relationship between the concepts, identifying their linkage. The aim of this was to explain the terms which are familiar to the students and subsequently giving them the opportunity to recognise the relationships between the concepts. A map on waves which was used as an advanced organiser can be found in the appendix (See Appendix C).

The use of concept maps as advance organisers have several implications for science teaching and especially this study. The maps provided the students with a visual tool showing the relationship between concepts, while also presenting the science content that models the construction process (Dorough and Rye, 1997). It was a relatively easy tool which required very little equipment, (overhead projector and transparencies). Also the maps supported the students as they then had a complete map available to them throughout the topic, which they used as a reference.

5.11.2.7 Data Collection
The students within this study were provided with all relevant information concerning the project prior to data collection. All information sheets were discussed and consent forms signed and collected during week 1 of the semester (See Appendix D and E). There were three methods of data collection utilised in this phase of the study; concept maps; questionnaires and interviews resulting in both qualitative and quantitative data. The time orientation of these data collection instruments were given considerable thought and as a result they were introduced sequentially. The author decided on this model to allow the data collected from one tool to inform the other.

Concept Maps
As previously stated, the students constructed three maps throughout the course of the 12 week study, during weeks 3, 8 and 11 respectively to provide both qualitative and quantitative measures of understanding and also to represent the students’ development of ideas over time (Edmondson, 2000). The level of direction provided varied with the three maps. The material provided to the
students to assist in the construction of the first map consisted of instructions and
guidelines (See Appendix F). The students were also provided with a list of ‘seed’
terms which formed a basis for them. The second map contained instructions and
guidelines, however they were not provided with any ‘seed’ concepts. The final
and third map only contained the instructions. For each map the students were
encouraged to begin the construction of the map by generating a full list of
concepts that they believed were important to the focus question. Throughout this
phase of the study the students were asked to answer the same focus question
“what is light?” for all three maps so as to examine the development of their
knowledge over the 12 week period.

For the construction of the maps the students were provided with an A3 size sheet
of white paper and were encouraged to draw the map with a pencil. They were
encouraged to include as many concepts as they felt explained their understanding
of the key concept. The students were given fifty minutes to complete each
concept map however in most cases the time participants spent constructing the
maps ranged between 25 and 40 minutes.

Following the evaluation of the first two maps, the author decided to construct
another class map with each individual student supplying a proposition. The
author did this to reinforce the idea that all students will have a different
understanding and that students should not hesitate to include terms when
constructing the maps. One volunteer recorded a copy of the map as it was
constructed and the author emailed a copy of the final class map to all students.
The map was developed using the programme CmapTools.

Questionnaires
The second method of data collection employed the use of questionnaires. The
author believed it was necessary to introduce questionnaires into this study as they
produce quantitative data which can have “conventional uses in qualitative
research” (Bogdan and Biklen, 1992).

The post-questionnaires (See Appendix G) were self-administered in week 11
following the students’ experience with Concept Mapping. The author decided to
do so because it would ensure high response rates and also would not consume any more of the student’s class time so close to the end of semester exams. This method of data collection also permits the author to provide any necessary explanations and gives the benefit of a degree of personal contact (Oppenheim, 1996). The questionnaire developed by the author was divided into four parts; the student’s personal information, the Concept Mapping training session, the implementation of the Concept Mapping tool and finally the impact of Concept Mapping.

The author designed the questionnaire while keeping in mind the definition of questionnaires given by Davidson (1970) (Cited in Cohen and Manion 1994):

> It (the questionnaire) is clear, unambiguous and uniformly workable. Its design must minimise potential errors from respondents……and coders. And since people’s participation in surveys is voluntary, a questionnaire has to help in engaging their interest, encouraging their co-operation, and eliciting answers as close as possible to the truth”

Best (1981) also set out recommendations when designing questionnaires in order to make them attractive to the students. With these two frameworks in mind the author designed a well-structured questionnaire by:

1. Including warm-up questions. These are questions which are simple to answer, and such questions make it less likely that the respondent will disengage from the questionnaire.
2. Including a coherent structure. This was carried out by developing a logical order to the questions within the questionnaire.
3. Not overcrowding the questionnaires with questions and text, while ensuring that questions were not split over pages.
4. Including open and closed ended questions.

Rubin (1994) suggested that if a questionnaire is quick and easy it is more likely to be properly completed than a complex, long questionnaire. Similar to Rubin, Moore (2000) noted that the longer the questionnaire, the less likely people are willing to complete it. Moore believes that “the golden rule is to keep open questions short and simple” (Moore, 2000).
The closed ended questions were mainly designed according to the Likert scale. This was used in Part 4 of the questionnaire where the author was seeking to find information regarding the impact of Concept Mapping on the students. The author used this method primarily due to the advantages associated with it. These included:

- The method is entirely based on empirical data.
- This method produces more homogenous scales and increases the probability of a unitary attitude being measured.

(Best, 1981)

Questionnaires have several advantages, they are impersonal and avoid interviewer bias (Oppenheim, 1992) while also wide-reaching and flexible (Brace, 2004). The aim of the questionnaires was to establish and clarify key issues concerning the study participants and the concept mapping tool, which can be summarised by the following questions.

1. What are the characteristics of the study participants (age, gender, previous experience with physics)
2. Do the students feel that Concept Mapping is beneficial in the physics classroom?
3. What impact did the training session have on the students? Did the students feel the training session was beneficial?
4. Did the use of the tool alter the students view on physics in any way, positively or negatively?

All the questions, except the responses to open questions, were numerically coded and inputted into SPSS for analysis in the conventional manner (Coakes and Steed, 2001; Miller et al., 2002) while the responses to the open-ended questions were transcribed verbatim. Quotations from pupils are included in the findings to exemplify the types of responses received.

Interviews

Interviews were used in conjunction with the questionnaires to collect data concerning student’s attitudes towards the tool and also to examine the student’s
maps. All three maps developed by the student were available during each interview and their structure was discussed.

This method of data collection was voluntary and resulted in five interviews each approximately 10 minutes in length. The interviews were conducted during the last week of the semester. These student interviews provided an opportunity for the students to express their own views with greater spontaneity (Oppenheim, 1992) on the Concept Mapping tool and on their maps they constructed throughout the semester. The interviews were carried out to help the author determine the reasoning behind the construction of the students’ maps. There are several advantages in carrying out these interviews as they allow the students to describe their maps in their own words. They also allow the author to probe for more details and explore unexpected themes that may arise from the concept maps.

5.11.2.8 Data Analysis

Concept Maps
The concept maps were analysed using a criterion map which was constructed by the author designed specifically to include the important concepts associated with the module and the module objectives. Maps from 20 students were chosen randomly which resulted in a total of 60 maps analysed. The sample group contained equal male and female participation. The 60 maps examined for this research study are available in Appendix H.

Questionnaires
Initially all questionnaires were checked for completeness, accuracy and uniformity (Moser and Kalton, 1976). Following from this the data was coded and then analysed. Closed-ended questions were coded and analysed using SPSS whereas with open-ended questions the responses were transcribed verbatim and recorded.

Interviews
The interviews were recorded using an IC recorder with each lasting approximately 10 minutes in length. After the interviews were carried out each
recording was transferred to Voice Editor 3 (voice editing software) and was transcribed and saved as a word document. In order to fully become familiar and understand the data the author read and re-read the interviews looking for patterns and themes (Hammersley and Atkinson, 1983). The transcripts were analysed noting not only the literal statements but also non-verbal and paralinguistic communication.

5.11.3 Phase 3: Development of Concept Mapping Study

The research carried out in Phase 3 was concerned with the students’ use of technical language in physics. The students from Phase 2 remained on in the study with a loss of 11 students due to non-completion in the course. The data collection instruments again included concept maps, questionnaires and interviews. The main difference in this study was the adaptation of the interviews as they now focused on problem-solving.

5.11.3.1 Research Aims and Objectives

As mentioned above the aim of this phase of research was to identify undergraduate physics students’ use of scientific technical language when problem solving. With this in mind the objectives of the study included:

1. To develop scientific problems from students’ misconceptions identified in concept maps.
2. To assess students’ use of scientific technical language used during problem solving
3. To develop categories of scientific language
4. To determine if there is a difference in the scientific language used by experts and novices
5. To identify if there is a relationship between students’ scientific language ability and their problem solving ability
6. To examine if the lecturer’s use of language affects their students use of language
5.11.3.2 Significance of the Study

In the past, concept maps have being used effectively for several purposes including eliciting knowledge, examining student’s conceptual understanding and assessment. However they can also be used in identifying the gaps in students’ knowledge and the quality of students’ responses (McPhan, 2008). With this in mind the guiding focus of this phase is whether or not concept maps can be used in conjunction with semi-structured interviews to identify and examine students’ use of scientific technical language. To analyse students’ use of scientific technical language written ideas at various times throughout a semester alone would not provide enough information. Semi-structured interviews containing physics problems were introduced and student’s verbal statements from the interviews and written ideas sourced from the maps provide two different and complementary views of their knowledge structure.

5.11.3.3 Learning Context and Profile of the Students

The students in Phase 2 carried through into Phase 3 as they moved from first to second year of their undergraduate course. The cohort was now enrolled in Electricity and Magnetism (PH4304) (See Appendix I for the module outline). Through the transition from year one to year two, there was a reduction of 11 students due to non-completion within the course. The author was again the teaching assistant for the tutorials however concept maps were also introduced during the lectures, used as advance organisers to introduce the topic and also as a revision aid to summarise content.

5.11.3.4 Data Collection

The data collection process within Phase 3 was very similar to that executed during Phase 2. As the student participants were now aware of the construction of concept maps no training was provided. However, during the first tutorial of the semester the author highlighted the key components of concept maps to reiterate their importance during the construction of maps. As in Phase 2 concept maps, questionnaires and interviews were the instruments used for data collection in a sequential manor.
Concept Maps
As with Phase 2, the students were asked to construct three concept maps which were constructed and collected during the tutorial session in weeks 3, 7 and 11. Data was collected at various points within the course to increase the likelihood that the maps would have an instructional effect (Stoddart et al., 2000). The focus question of the maps changed to coincide with progress of the module; the students were asked to create a map using “what is electricity?” for maps 1 and 2 however for map 3 they were asked to answer the focus question “what is your understanding of electrical current” [Concept Map instructions for each map can be found in Appendix J]. It was essential to change the key concept because of the large amount of content within the module.

Interviews
As mentioned above, the underlying difference between Phase 2 and Phase 3 data collection of this research study is the execution of the interviews. The author felt that, in order to maximise the use of concept maps as a tool to examine students’ use of scientific technical language, it must be used in conjunction with interviews. The interviews were used to examine the students’ cognitive structure and to ascertain not only the concepts and propositions that they held but also how these concepts were explained and used by the student.

Within this study there were two types of interview carried out; student interviews and expert interviews. The students that participated completed two interviews; one after map 2 and one following map 3. The expert interviews were carried out at the end of the research in autumn 2008. For the purpose of this study an expert is defined as someone who is in the process of, or who has completed a PhD in the area of physics.

Interview Participants
The group of students (N = 77) were given detailed information concerning the interviews and were encouraged to volunteer to participate. Ten students volunteered to participate, six females and four male students. All of the students
had completed the Irish Leaving Certificate Exam, which typically consists of six subjects, taken either at Higher (honours) or Ordinary (pass) level. In total there were six experts interviewed; four from the University of Limerick (UL) and two from Dublin Institute of Technology (DIT). The UL experts were all presently working or studying in UL, three were completing their PhD’s with the other lecturing. Both experts from DIT had graduated with a PhD and one was lecturing, one being a visiting professor from Maine University in USA. Prior to the interviews the participants were informed that the aim of the data collection was to determine what language they used during problem solving and to capture their train of thought as they attempted to solve the problem.

Interviewers

The interviewers used during this phase of research were sourced in the Physics Department in the University of Limerick. The affect of interviewers’ attributes on respondents’ replies has been under investigation in the past though the literature on the issue does not provide definitive generalisations; however it is almost certain that the characteristics of the interviewers have an impact on replies (Bryman, 2008). Two female postgraduate students were designated for the purpose of interviewing the students. Prior to interviewing the students the interviewers were provided with detailed information on how to carry out the interviews in an appropriate manner, (See Appendix K) ensuring that the interviews were carried out using a consistent and standardised approach to increase validity (Fraenkel and Wallen, 2003). Procedures highlighted measures for encouraging students to answer questions and to probe inadequate answers.

The author interviewed the experts following the completion of the student interviews. Again the interviews were scheduled during a time that was suitable for the interviewee. The experts were questioned on the same problems that the students received, however they completed both sets of questions together. The author followed the structure of a structured interview as it allows for “schedule” and results in a closed situation (Cohen and Manion, 1994).
Interview planning

There are several important aspects involved when planning an interview. These include selecting the content, selecting material, sequencing the interviews, organising questions, conducting and evaluating the interviews (Novak and Gowin, 1984).

Selecting the content
For the purpose of this research study the propositions used in the student concept maps formed a basis for the interviews. The author examined the student concept maps and generated a concise list of student errors and incorrect propositions. These were then used as guides to develop physics problems that would further examine students understanding and “to ascertain whether or not these misconceptions exist and if so, how they are related to other ideas in the student’s mind” (Novak and Gowin, 1984, p.125)

Selecting the material
In order to sustain the student’s interest throughout the interview, it is necessary to provide props, activities or demonstrations from which one may then proceed with questions (Novak and Gowin, 1984). To ensure that students were motivated and interested throughout the interview, the author reviewed the questions generated and introduced props and activities that would serve as visual and tactile references. These included visual diagrams and experimental apparatus.

Sequencing Interviews
Both interviews were voice recorded and consisted of a sequence of eight and six physics problems respectively (See Appendix L). Generally the problems became progressively more complex and proceeded from familiar areas of the subject to more broad areas. The majority of the questions were open-ended as to reduce the possibility of the students giving yes/no answers or a simple statement. Generally the questions were presented in verbal form however some were presented in a combined form, including both visual and verbal components. The interview did not have a time limit and ended when the student could not contribute any more information. Retrospectively, the interviews lasted on average 40-45 minutes,
however this varied. In some instances students were unable to solve or answer a problem however this did not affect the research results as it was the students’ use of technical language that was under investigation and not the student’s ability to solve the problems.

**Organising questions**

The questions were organised using the Newman Research Method (1977). Newman (1977) maintained that a person must proceed through several “successive hurdles” when attempting to answer a standard written mathematics question (White, 2005). These include reading (decoding), comprehension, transformation, process skills and encoding. Failure to succeed in any one of these stages or hurdles would most likely prevent the person from progressing to the next stage, therefore preventing them from gaining the correct answer (Newman, 1977). To help determine at which stage the person found difficulty Newman used five prompts in the form of questions which were asked during interviews following the student’s completion of the questions. Each question was associated with one of the five steps involved in answering mathematical questions.

<table>
<thead>
<tr>
<th>Prompt Used</th>
<th>Stage In Answering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please read the question to me. If you don't know a word, leave it out.</td>
<td>Reading</td>
</tr>
<tr>
<td>Tell me what the question is asking you to do.</td>
<td>Comprehension</td>
</tr>
<tr>
<td>Tell me how you are going to find the answer.</td>
<td>Transformation</td>
</tr>
<tr>
<td>Show me what to do to get the answer. &quot;Talk aloud&quot; as you do it, so that I can understand how you are thinking.</td>
<td>Process Skills</td>
</tr>
<tr>
<td>Now, write down your answer to the question.</td>
<td>Encoding</td>
</tr>
</tbody>
</table>

Newman also introduced a classification to errors which included a ‘careless’ category. The interviewer identified at which stage the initial error was made by the person and if during the interviews the students error was caused by unknown factors, it was categorised as ‘careless’.

Within this research study the author adapted the Newman Research Method for the interviews. The interviewers were given Newman’s questions to ask during
the interview. At the onset of each question the students were also asked to state their initial thoughts on what the problem involved. Finally at the end of each problem the students were asked to rate their confidence in their answer encouraging the students to qualitatively analyze their answers. The questions were given to the interviewers as guidelines however they were asked and encouraged to use the questions throughout the interview. The focus of the interviews was to decipher the students’ use of scientific language however the Newman Method was appropriate as it identifies the stage of problem solving which the students find difficult.

During the problem solving students were provided with paper, pencils and calculators to help them during the problem-solving process and were encouraged to use them throughout the interview.

**Conducting the interviews**

When conducting the interviews several arrangements were made to ensure that the interviews would cause little disruption to the student’s timetable while also guaranteeing the interviews provided results. Several steps were carried out to guarantee this including:

- Arrangements and timetables for the students were finalised two weeks in advance.
- The interviews were carried out early in the day, where possible during a time that was suitable for the students. The author felt it was important to arrange the interviews early in the day as this is when students are more alert and motivated.
- A maximum of three interviews were scheduled for any one day as it was important that the interviewer was vigilant and thorough during each interview.
- The interviews were carried out in the Science Learning Centre room, which was small, quiet and familiar to the students. [The Science Learning Centre (SLC) is a centre set up in UL to provide students with support in their learning of science through tutorial support and the provision of a drop-in-centre]. The interviewers set out to provide a calm
and relaxed atmosphere by introducing themselves at the beginning of each interview and relaxing the students.

- The author ensured that the interviewers were thoroughly familiar with the questions asked and the materials covered. This allowed them to ask appropriate follow-up questions if necessary.

- The interview was not rushed and students were given 10-15 seconds to provide a response to the question before and prompt questions were introduced. The interviewers were also advised not to pause for too long waiting for a response as this will ‘freeze’ the students and affect their answering. The students were given an hour slot for each interview to ensure there was sufficient time.

- In a situation where the students didn’t know or forgot an answer the interviewer rephrased the question. If this still did not provide the students with help in answering the interviewer moved on to another question.

- The interviewer was instructed not to ask any questions that “steered students towards understanding”. Phrases such as “I see”, “tell me more about that” were used to gather more information and acknowledge the student’s response.

- The student’s own language was used to rephrase questions or probe further. If the interviewer insists on the “right” word, he/she may inhibit further expression of concepts or propositions.

- Each interview ended on a positive note whereby the interviewer thanked the students for their cooperation and assistance during the interviews.

**Evaluating interviews**

The data collected from the interviews was qualitative in nature and thus qualitative analysis was used. All interview transcripts were analysed noting patterns and themes and identifying different levels of language and problem solving ability. The participant’s problem solving ability of quantitative problems was analysed using the categories identified by Walsh, Howard and Bowe (2007) (Section 4.3.5). The participant’s language ability was also analysed using a method of categorisation which is discussed in detail in Chapter 7.
**Questionnaires**

Within Phase 3 the entire cohort of students (N = 77) were asked to complete two questionnaires; a post-concept mapping (PCM) questionnaire and a post-teaching practice (PTP) questionnaire (See Appendix M and N respectively). This PCM questionnaire consisted of three parts; personal information, concept mapping and the impact of concept mapping. It was administered during the last week of the semester, however due to poor attendance only thirty-four students (44%) completed it.

The PTP questionnaire was administered following the return of the students from their teaching practice. The students were asked whether or not they used Concept Mapping during their six week block and if so, when and what were their opinions of the tool from the perspective of a teacher.

**5.11.4 Phase 4 – Analysis of Data**

The analysis of the data is defined as Phase 4 in this research study. This final stage of the research involved the analysis of the combined data collected during Phase 3, including that of the concept maps, interview transcripts and questionnaires. The data collected consisted of both qualitative and quantitative data and required tools to investigate both aspects to allow the author to merge of results and draw conclusions.

As mentioned earlier a criterion map was used to examine the students’ concept maps. The concept maps constructed by the students in Phase 3 formed the basis of the interview questions. The qualitative data generated was analysed to determine the use of scientific technical language and problem solving ability of the participants. The questionnaires provided the author with responses, both qualitative and quantitative, concerning key issues involved with the implementation and impact of Concept Mapping in a physics classroom and their affect, if any, on student learning. The analysis is described in detail in Chapter 7.
5.12 Summary

In this chapter the author provided a detailed overview of the research methodologies employed in this research and explained her methodological decisions. The theoretical perspectives employed in the research were presented, as well as the research approach adopted. A five-phase mixed-model research design was implemented sequentially and concurrently in order to address the specific research questions. A detailed outline of each phase is discussed to assist in an understanding of this investigation, identifying that each Phase was informed from the previous phase. A detailed discussion of the research paradigms is given together with a discussion on issues relating to researcher distance, ethics, validity, reliability and generalisability. The next chapter presents the research findings from Phase 1 and Phase 2 of this research.
Chapter 6

Results – Phase 1 and Phase 2 (Students Opinion of Concept Mapping and its use in the Physics Classroom – Analysis of the Findings)

6.1 Introduction

The aim of this chapter is to examine the students’ experience and opinions of Concept Mapping. To date, no such study has been undertaken in Ireland and consequently these findings provide significant data on the use of the tool in Irish universities and classrooms. In this chapter the various results from the pilot study (Phase 1) and the exploratory study (Phase 2) are outlined. Students of the University of Limerick were asked to construct Novakian maps using the criteria set out during the training session provided at the onset of the semester. The maps collected, together with student questionnaires and semi-structured interviews were evaluated and analysed to determine their benefits, if any, for Irish students.

6.2 Pilot Study – Phase 1

As discussed in Chapter 5, the students constructed two maps throughout Phase 1 of the study, both at the onset and conclusion of the module. During the 12-week semester the students did not receive any instruction using concept maps, however, they were trained on how to use the tool during their first tutorial in week 2 of the autumn semester of the academic year 06/07. The first map was constructed in week two, on the same day the training was provided, with the second map constructed during week 12 of the same semester. Table 6.1 represents the student attendance during the physics tutorials when the maps were drawn. Due to exam pressure a high proportion of students failed to attend the last tutorial and hence did not complete the second map, which affected the results of this study significantly.
Table 6.1: Number of students that constructed concept maps during the pilot study in each of the four groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of Students that Constructed Maps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 2</td>
</tr>
<tr>
<td><strong>First Year:</strong></td>
<td></td>
</tr>
<tr>
<td>Introduction to Physics</td>
<td></td>
</tr>
<tr>
<td>PH4511</td>
<td>12</td>
</tr>
<tr>
<td><strong>First Year:</strong></td>
<td></td>
</tr>
<tr>
<td>Principles of Physics</td>
<td></td>
</tr>
<tr>
<td>PH4141</td>
<td>10</td>
</tr>
<tr>
<td><strong>Second Year:</strong></td>
<td></td>
</tr>
<tr>
<td>Electricity and Magnetism</td>
<td></td>
</tr>
<tr>
<td>PH4301</td>
<td>7</td>
</tr>
<tr>
<td><strong>Second Year:</strong></td>
<td></td>
</tr>
<tr>
<td>Quantum Mechanics</td>
<td></td>
</tr>
<tr>
<td>PH4403</td>
<td>11</td>
</tr>
</tbody>
</table>

As mentioned above the students constructed two maps, however, the author was unable to evaluate them for structural complexity and content validity as intended due to their structure (Figure 6.1). The student maps did not represent the characteristics of Concept Mapping as certain elements of the map were missing or presented incorrectly. The students failed to generate concept-link-concept triads and therefore it was difficult to identify the students’ understanding of the concepts and their relationships. Figure 6.1 represents a map constructed by a second year science education student who was asked to construct a map pertaining to the focus question “what is electric current?” This map is included as a representative of the work received from the students at this stage.
Figure 6.1: Concept map constructed by a second year student during the pilot study

This map was drawn verbatim using IHMC CmapTools (Institute for Machine and Human Cognition CmapTools) software in order to present it clearly. The map indicates that the student was confused about the structure of the map and was unable to generate correct linking phrases. This is turn limited the number of propositions in the map. Also sentences are used rather than concepts to signify knowledge preventing scoring to take place.

Where students did construct good maps at the beginning of the module (pre-maps), by the time the second map was constructed (post-map) they had forgotten the technique (Figure 6.2 and 6.3). This result may have been avoided if concept maps were used throughout the course of the semester during instruction as advance organisers or for revision purposes. Figure 6.2 and Figure 6.3 are the two maps constructed by a second year student during the pilot study. The author would like to acknowledge that although all student maps were examined and
analysed from the pilot study, they are not available in the appendix as it would not benefit the research report in any way. The maps are available in print version upon request.

Figure 6.2: Pre-map constructed by a second year student during the pilot study
Figure 6.3: Post-map constructed by a second year student during the pilot study

It is clear from these two maps that the student was unsure of the method involved in constructing concept maps. The pre-map shown (Figure 6.2) is hierarchical in nature and does represent the concepts the student holds in this domain. However, the map lacks linking phrases and therefore it is impossible to identify the relationships that the student holds between the concepts, and consequently it is difficult to identify the depth of the student’s understanding. The structure of the post-map (Figure 6.3) is however, very far removed from the ideal structure of a Novakian concept map. It is not hierarchical and lacks further relationships
between the concepts. As a result of these errors in construction no quantitative results were collected from Phase 1 but several findings were recorded.

6.2.1 Conclusions drawn from Phase 1

The evaluation of the student maps led the author to believe that the students require a more intensive training session which will allow them to practice drawing and constructing concept maps prior to data collection. The students within this group had very little experience using concept maps prior to constructing their maps. Following the analysis of maps constructed during the pilot study several findings were reported and used to inform Phase 2 (exploratory study) of this research study. These include:

1. The method of introduction and training can influence students’ perception of Concept Mapping and its potential benefit in the classroom. Intensive training is required to ensure students are fully aware of the method of construction. It is also advised that during the training session students construct maps in groups and individually on topics not specific to the topic that is being taught.
2. Continuous implementation of Concept Mapping throughout the semester is required to aid in the understanding of the maps.
3. Concept maps should be used by the teachers as ‘advanced organizers’. This method will clearly assist the students in realising the potential of the maps and will also aid the students in identifying the relationship between concepts.
4. The sessions during which the concept maps are constructed must be allocated early in the semester to avoid poor attendance due to exams.

6.3 Exploratory Study – Phase 2

Although the students in Phase 1 were unable to construct ideal concept maps, they responded very positively to the approach. With this in mind the author developed the exploratory study with the aim to introduce Concept Mapping on a
larger scale into a first year physics module. In this section the author will begin with a brief explanation of the methodology employed, followed by a detailed account of the results collected from all three data collection tools used in this Phase of the study, which include concept maps, questionnaires and interviews. The following concept map (Figure 6.4) summarises the methodology and the timeline of the Phase.

**Figure 6.4**: Concept Map detailing Phase 2 of research study

As evident in the above concept map the student cohort (N = 88) constructed three concept maps throughout the semester and also completed a questionnaire during the final week of the term. Five students also volunteered to be interviewed on the tool and its use in the physics classroom.

The results of this Phase will be presented according to two themes which encompass the research questions set out in Phase 2; student learning of physics...
and students opinions of Concept Mapping. The research aims, questions and methodology are outlined in the following table (Table 6.2).

Table 6.2: Summary of Research Questions, Research Methods and Data Analysis employed in Phase 2.

<table>
<thead>
<tr>
<th>Phase 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics</td>
<td></td>
</tr>
<tr>
<td>Research Approach</td>
<td>Mixed Methods</td>
</tr>
</tbody>
</table>
| Research Questions| • How do concept map scores correlate with progression through a specified module?  
|                  | • What elements are essential for the training of undergraduate physics students in Concept Mapping, as seen by the students?  
|                  | • Does experience of Concept Mapping improve students’ attitudes towards Physics and what issues concerning the use of the tool are identified after one semester experience?  
|                  | • Are concept maps valid assessment tools in third level education? |
| Research Method  | • Concept map – specific to the module Light and Sound. The students were asked to construct three concept maps which answered the focus question “what is light?”  
|                  | • Student questionnaire – the students were asked to complete a post-questionnaire to evaluate their opinions on the tool and its use in the classroom.  
|                  | • Student interviews – five students volunteered to be interviewed on their maps and their construction. |
| Analysis         | Qualitative – Criterion map  
|                  | Quantitative – SPSS (Version 15) |
6.3.1 Students’ Learning of Physics

Research question addressed:

- How do concept map scores correlate with progression through a specified module?

The answer to this question lies in the interpretation of the data presented in Table 6.3. This table represents the concept map scores from the three maps constructed by the selected twenty students, presented here as a percentage of the total grade.

Due to the large cohort in this study a sample of maps was chosen to facilitate appropriate analysis and evaluation. Twenty student maps were chosen to include a sample of the mixed abilities in this group. The twenty students were chosen as a representative of the student cohort. The author included students who were present and absent from the training session to determine its effect on the students’ opinions of the tool and the construction of their maps. The concept maps constructed by these 20 students are available in the appendix (Appendix H). The remaining maps are not included due to the enormity of the task and limited time available to the researcher as each map is drawn using the CmapTools software. Hardcopies of the maps constructed by the students are available upon request.
Table 6.3: Concept map scores of the three maps constructed by the students

<table>
<thead>
<tr>
<th>Student</th>
<th>Gender (F/M)</th>
<th>Present at the training session</th>
<th>Map 1 Result (%)</th>
<th>Map 2 Result (%)</th>
<th>Map 3 Result (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>F</td>
<td>Yes</td>
<td>5.6</td>
<td>7.5</td>
<td>11.32</td>
</tr>
<tr>
<td>B</td>
<td>M</td>
<td>Yes</td>
<td>7.5</td>
<td>16.03</td>
<td>41.0</td>
</tr>
<tr>
<td>C</td>
<td>F</td>
<td>Yes</td>
<td>26.4</td>
<td>35.8</td>
<td>67.9</td>
</tr>
<tr>
<td>D</td>
<td>F</td>
<td>No</td>
<td>3.7</td>
<td>20.75</td>
<td>30.18</td>
</tr>
<tr>
<td>E</td>
<td>F</td>
<td>Yes</td>
<td>5.6</td>
<td>18.86</td>
<td>30.18</td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td>Yes</td>
<td>10.37</td>
<td>16.0</td>
<td>27.0</td>
</tr>
<tr>
<td>G</td>
<td>F</td>
<td>Yes</td>
<td>13.2</td>
<td>15.0</td>
<td>20.75</td>
</tr>
<tr>
<td>H</td>
<td>M</td>
<td>No</td>
<td>11.32</td>
<td>43.4</td>
<td>51.8</td>
</tr>
<tr>
<td>I</td>
<td>M</td>
<td>Yes</td>
<td>13.2</td>
<td>24.5</td>
<td>37.7</td>
</tr>
<tr>
<td>J</td>
<td>M</td>
<td>No</td>
<td>12.3</td>
<td>15.0</td>
<td>39.6</td>
</tr>
<tr>
<td>K</td>
<td>M</td>
<td>Yes</td>
<td>21.6</td>
<td>40.5</td>
<td>41.0</td>
</tr>
<tr>
<td>L</td>
<td>F</td>
<td>No</td>
<td>15.0</td>
<td>21.6</td>
<td>43.4</td>
</tr>
<tr>
<td>M</td>
<td>M</td>
<td>Yes</td>
<td>9.4</td>
<td>11.32</td>
<td>42.5</td>
</tr>
<tr>
<td>N</td>
<td>M</td>
<td>Yes</td>
<td>5.6</td>
<td>3.6</td>
<td>24.5</td>
</tr>
<tr>
<td>O</td>
<td>F</td>
<td>Yes</td>
<td>5.6</td>
<td>10.37</td>
<td>16.0</td>
</tr>
<tr>
<td>P</td>
<td>F</td>
<td>Yes</td>
<td>6.6</td>
<td>8.4</td>
<td>24.5</td>
</tr>
<tr>
<td>Q</td>
<td>F</td>
<td>Yes</td>
<td>13.2</td>
<td>16.9</td>
<td>36.7</td>
</tr>
<tr>
<td>R</td>
<td>M</td>
<td>No</td>
<td>9.4</td>
<td>9.4</td>
<td>30.18</td>
</tr>
<tr>
<td>S</td>
<td>M</td>
<td>Yes</td>
<td>15.0</td>
<td>19.8</td>
<td>33.0</td>
</tr>
<tr>
<td>T</td>
<td>M</td>
<td>Yes</td>
<td>9.4</td>
<td>9.4</td>
<td>39.6</td>
</tr>
</tbody>
</table>

These student concept maps were scored using a criterion map which was developed specifically for the Light and Sound module (PH4202). The criterion map (Figure 6.5) was constructed by the author and included concepts specific to the aims and objectives of the module. The criterion map contained fifty-three propositions in total and student maps were scored against this map. Colour coding has been used in the map to highlight the many strands of information students could have introduced into their maps.
Figure 6.5: Criterion map used during Phase 2 to evaluate student concept.
The student maps were graded against the criterion map in conjunction with a scoring system. Total proposition accuracy was based on an evaluation of the quality of propositions that students constructed. Each map’s total accuracy was the sum of individual propositions scores, represented as a percentage of the total number of correct propositions. Individual propositions were scored using a three-point scale (Table 6.4).

**Table 6.4:** Three-point coding system used for scoring student concept maps

<table>
<thead>
<tr>
<th>Proposition Accuracy</th>
<th>Score Awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect</td>
<td>0</td>
</tr>
<tr>
<td>Partially correct</td>
<td>0.5</td>
</tr>
<tr>
<td>Scientifically correct</td>
<td>1</td>
</tr>
</tbody>
</table>

The students chosen are identified using letters of the alphabet to preserve confidentiality. From the sample of twenty students, 25% were not present during the training session which took place prior to the construction of maps in week 2 of the spring semester 06/07. The highest score was awarded to a female student who was present at the training session and she received a score of 69.7% on her third and final map. The lowest score awarded to a third map was 11.32%. Having said this however, this map (constructed by student A) contained concepts specific to biology which were scientifically correct but no points were awarded to these as they were not physics concepts. Overall, however the average scores increased from map 1 to map 3.

The author uses two graphical techniques to represent the data; boxplots and concept maps. In its basic form, the boxplot presents five sample statistics - the minimum, the lower quartile, the median, the upper quartile and the maximum - in a visual display. The length of the box represents the middle 50% of scores and is known as the interquartile range. The lines that extend from the box are called whiskers. The whiskers are of length 1.5 times the interquartile range. Outliers (values outside the whiskers) are identified by the subject number in the plots. Figure 6.6 represents the percentage achieved for all three maps constructed by the students.
Further analysis of the scores identifies that the scores differed with student sex with males achieving higher scores in the first and third maps. Females achieved higher in the second map however (Figure 6.7).
Hypothesis tests were carried out on student scores using SPSS. A 5% level of significance was used for all tests and no adjustment was made for multiple testing. The data for the map results were not normally distributed, therefore non-parametric tests were used. The t-test is a particularly useful and widely applied statistical test however it is based on normally distributed data. Non-parametric tests are distribution free. The two tests carried out in this analysis are the Friedman Test and the Wilcoxon Test. As with many non-parametric tests, these tests use the ranks of the data rather than their raw values to calculate the test statistic. The Friedman test is used when one has repeated measures on the same sample of subjects. This is appropriate here as the student maps were measured three times throughout the course of the semester. The results of the Friedman Test indicate that there is a statistically significant difference in the student concept map scores across the three time points (map 1, map 2 and map 3), \( n = 20 \), \( p < 0.005 \). Inspection of the median values show an increase in student map scores from map 1 (Median = 9.88) to map 2 (Median = 16.01) and a further increase at map 3 (Median = 34.85).

The Wilcoxon test for paired data was used to determine if there was a statistically significant change in the student map scores as the semester progressed. Paired testing was carried out three times (Table 6.5), each resulting in statistically significant difference, \( p < 0.001 \).

**Table 6.5**: Wilcoxon Signed Rank Test: Paired testing between all three map scores

<table>
<thead>
<tr>
<th></th>
<th>Map 2 – Map 1</th>
<th>Map 3 – Map 1</th>
<th>Map 3 – Map 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Z</strong></td>
<td>-3.506</td>
<td>-3.920</td>
<td>-3.920</td>
</tr>
<tr>
<td><strong>Sig (2 -tailed)</strong></td>
<td>&lt; 001</td>
<td>&lt; 001</td>
<td>&lt; 001</td>
</tr>
</tbody>
</table>

### 6.3.1.1 Student Concept Maps

Student concept maps are also used to represent the students’ understanding of physics following their experience of Concept Mapping. To assist analysis a sample of three student maps will be presented to identify the individual student’s progress. Each map is drawn verbatim using *CmapTools* and each will be
followed by a brief description. Again to maintain student confidentiality the students are identified using letters of the alphabet. The following three maps correspond to student A, B and C in Table 6.3. The maps (Figure 6.8 to Figure 6.16) have being colour coordinated to highlight the student’s incorporation of physics in the maps. The yellow colour highlights where students included their knowledge from other disciplines, e.g. biology. The students profile will be highlighted in each case to identify the student’s gender and underline the student’s background in physics.

**Student A**

**Profile:**
This is a female student who did not study physics in Leaving Certificate level. She was present for the training session at the beginning of the semester. When asked what she understood by the term concept maps in the questionnaire, she replied that they “consist of many different terms and words connected to a topic which shows your understanding of that topic”.

**Map No. 1**

![Concept Map Image](image)

*Figure 6.8: Student A Map No. 1 (Phase 2)*
Figure 6.8 represents the first map constructed by student A which was based on the focus question “What is Light?”. It is clearly evident that the student included several concepts specific to biology. During the construction of the initial maps, the author did not restrict the students in any way to include only physics concepts as the maps are a representation of the students own understanding of the topic. However, within the physics concepts that this student included, all the propositions are correct.

**Map No. 2**

![Light Diagram](image)

*Figure 6.9: Student A Map No. 2 (Phase 2)*

Again in this map (Figure 6.9), student A included several concepts that are related to biology to describe her understanding of the concept ‘Light’. However the student’s physics knowledge has increased and the student incorporated concepts such as refraction, convection and heat.
The final map drawn by student A (Figure 6.10) again shows an improvement from the first two. The student includes formula and units, showing the relationship between theory and the mathematical component in Physics. However, the student still continues to include concepts from biology. The propositions in this map reflect the depth of the student’s understanding of light at the end of the semester.
**Student B**

**Profile:**
Student B is a male student who did not study physics at Leaving Certificate level. He was present for the training session during week 2 of the semester. When asked to explain his understanding of concept maps, he described them as “a brief description of a topic and can be used instead of an essay to explain a topic. They help you link definitions to each other.”

**Map No. 1**

![Concept Map](image)

**Figure 6.11: Student B Map No. 1 (Phase 2)**

Map 1 (Figure 6.11) constructed by student B again includes several propositions relating to Biology; however the propositions that the student includes which refer to physics are all correct.
Following the construction of the second map of student B (Figure 6.12) it is clearly visible that the student’s physics understanding has increased. He continues to include concepts in biology and also introduces several new concepts relevant to the physics course that he is studying. When evaluating this map one can see that the students’ understanding has altered since constructing the first map. The student wrote on the first map that “light travels in straight lines” but then changed this to “light travels in waves”. When drawing the first maps the students had no material covered in the lectures concerning light, however prior to constructing the second map the students were introduced to sound and waves.
This material may have confused the student and altered his opinion on the mode in which light travels.

Map No. 3

Figure 6.13: Student B Map No. 3 (Phase 2)

The third and final map constructed by student B (Figure 6.13) includes a large quantity of physics concepts with a small number of concepts concerning biology still evident. The student’s knowledge is very concise and includes several formulas. There are six levels present within this hierarchical map which again suggests the student has a good depth of understanding within this domain. The student has again re-examined his opinion of how light travels and has amended his understanding to include that “light travels in straight lines”.

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**Student C**

**Profile:**
Student C is a female student who has studied Physics at Leaving Certificate level. She was also present at the training process and when asked to give a brief description of concept maps using her own words to describe them she replied by saying, “you start with a key word and then elaborate in a map form using arrows and linking words to tell the story of what you are trying to explain”.

**Map No. 1**

![Figure 6.14: Student C Map No. 1 (Phase 2)](image)

One can instantly see that student C has a good understanding of ‘Light’ at the onset of the module (Figure 6.14). The student focused her map on Physics
concepts and in comparison to the majority of the students did not include concepts from any other domain to represent her understanding. This student also included a crosslink which, according to the literature, represents a higher level of understanding, connecting information from different areas within a topic.

Map No. 2

Figure 6.15: Student C Map No. 2 (Phase 2)

The second map drawn by student C (Figure 6.15) shows the development of the students’ understanding. This student introduced concepts such as concave and convex while also including units. Disappointingly, however, the student did not elaborate on waves even though it was the material that was discussed during the lectures at the time of construction.
The final map constructed by student C (Figure 6.16) signifies the extent of what concept maps can represent. This student map scored the highest grade from the entire sample of maps evaluated. Several equations are integrated within this hierarchical map and crosslink’s are also included.
These maps agree with the statistical data in that the students’ understanding improved throughout the semester. In the initial map students included aspects of Biology to describe their understanding of light but as the study progressed students became more confident and familiar with physics and included concepts representing their growing knowledge of physics. The author believes that the students included concepts from the biology domain as they are enrolled in a biological science degree programme and will have discussed light in a biology context during their initial modules of the programme. It is also important to point out that the majority of the students studied Biology in senior cycle in second level education and not physics.

6.3.1.2 Summary of Findings

The progression of the students understanding is clearly evident from the three maps constructed throughout the course of the semester. The criterion map, developed by the author, outlines the desired outcomes of the Light and Sound module as it includes concepts specific to the objectives set out in the course outline in relation to Light. The concept maps generated by the students signify the students’ improvement in understanding and also an improvement in the construction of Novakian concept maps as they advance towards the end of the module. The students however, included very few cross-links in their concept maps which may reflect in part a limitation of the training session and the use of concepts maps as advance organisers. It may also represent what Novak, Gowin and Johansen (1983) identified as “students tendencies not to integratively reconcile concepts but rather to learn material as discrete chunks” (p.632). Statistical analysis of the concept map scores indicates a statistically significant difference in the scores, from map 1 to map 3. The tool facilitates the representation of the students understanding of physics in a manner that is visually appealing and allows the author to identify the areas within the domain the students are struggling with.
6.3.2 Student’s Opinion of Concept Mapping

As this was the first time Concept Mapping has been introduced in third level education on a large scale in Ireland the opinions of the students was of great interest to the author. To facilitate this, students were asked to complete a questionnaire following their experience with the tool (See Appendix G). Emphasis was placed on the effect the tool had, if any, on the students’ learning of physics. With this in mind the questionnaire was divided into four sections which questioned the students on:

1. Their background in Science, in particularly Physics
2. The suitability of the training session they received
3. The Concept Mapping tool in the classroom
4. The impact of Concept Mapping on their learning of Physics

6.3.2.1 Student Profiles

For anonymity purposes students were asked not to write their names on the questionnaires. The questionnaire was administered to the entire class and on the day it was distributed 63 students (n = 63) were present. The questionnaire contained open-ended questions and also questions based on the Likert scale.

From the cohort that was surveyed, 68% were female and 32% were male. Students were asked about their past experience with physics and whether or not they studied physics at Leaving Certificate level. From those present on the day the questionnaire was administered, it was found that 25% of the student cohort studied Physics at Leaving Certificate level.
6.3.2.2 The Importance of the Concept Mapping Training Session

Research question addressed:

- What elements are essential for the training of undergraduate physics students in Concept Mapping, as seen by the students?

Part two of the questionnaire focused on evaluating the appropriateness and suitability of the training session. This training was held during week two of the semester and full attendance was not achieved, with 82% of the cohort present. Those who were present were asked to rate the components of the session. The components included a brief PowerPoint presentation; group, individual and class construction of maps whereby the author used non-physics topics when introducing the tool and finally a classroom discussion. The results indicate that the class construction of the maps was deemed very important by the students with 39.7% rating it as a very important factor and a further 28.6% deeming it as important in the introduction of the tool (Figure 6.17).

![Figure 6.17: Students’ opinions on the class construction of maps during the training session of Concept Mapping](image)

Figure 6.17: Students’ opinions on the class construction of maps during the training session of Concept Mapping
This was followed closely by the group construction of a map; with 36.5% of the cohort believing it was a very important aspect of the training session (Figure 6.18). Having this said, a percentage of students reported that it was less important than other aspects of the training session (Figure 6.18).

![Bar chart showing student opinions on group construction of maps during training session of Concept Mapping.]

**Figure 6.18:** Students’ opinions on the group construction of maps during the training session of Concept Mapping

The students also believed that the use of non-physics topics was an important element of the training session with 57.2% of the cohort identifying it as *very important* or *important*. Although this was the first time students were introduced to the tool, they felt that the PowerPoint presentation was not the most significant element. A small 17.5% of the group agreed it was very important.

A final feature of the training that was evaluated through the use of the student questionnaire was the timing and duration of the session. Students were also asked whether or not they believed the time allocated to the training was sufficient to understand the use of the tool. The result of this question was very
reassuring as 95% of the student cohort who completed the questionnaire and were present at the training session believed it was sufficient time to train them on the use of the tool.

6.3.2.3 Summary of Findings

It is vital that students undertaking work using concept maps receive an intensive training course on the tool. This training course can take several shapes, however certain elements must be included in order to provide the students with a shared understanding of the tool that will facilitate the construction of the maps. The training course provided to the students in this research included 5 main aspects comprising a presentation, construction of maps (individual, group and class) and finally a discussion. The students believed the length of the training was appropriate and sufficient for their needs. Individual aspects of the training were also analysed. The construction of a map, with the help of the entire class, was deemed most important in the training and the presentation in the training was found to be less important than the construction of the maps. The involvement of non-physics topics and concepts in the maps was reported to be an important element; however few students identified it as a very important aspect. Overall however, the five elements incorporated into the training session to help the students understand the aspects involved in Concept Mapping were believed to be important and fitting to the training session

6.3.3 Students Opinions of the tool

Research question addressed:

• Does experience of Concept Mapping improve students’ attitudes towards Physics and what issues concerning the use of the tool are identified after one semester’s experience?

The third element of the questionnaire dealt with the tool itself and its effects on student attitudes towards Physics. Students were asked whether their attitude towards the subject was affected by their experience with Concept Mapping.
Figure 6.19 illustrates that the tool had a positive effect on students’ attitudes towards Physics. Those whose attitude disimproved explained by saying that they found the semester difficult and were losing interest in the subject. One student stated that “despite working harder at it I can still not understand it (physics) and as a result I am losing interest in it”.

Students were then asked if they found Concept Mapping beneficial in a physics classroom. The response to this question was very consistent with students acknowledging that they felt it is a very valuable revision and study aid.

Sample responses include:

“Yes it makes you think about everything you know on a certain topic. It encourages people to generate words first and then connect them”

“Yes it summarises what you have learnt and is a form of revision exercise testing your understanding of a topic”

“Yes because it shows how the theory and formulae are related”
When answering this question, students also suggested ways in which they think concept maps may be used in the classroom. One student recommends that “a big poster of a concept map should be put on walls of labs and classrooms for students to see throughout the year”.

To reinforce the benefits of Concept Mapping in the classroom, concept maps that supported the material covered in the lectures were used as ‘advanced organisers’ during the semester. Students felt that this was of benefit to them as the maps allowed them to see from the onset what would be dealt with in the tutorials allowing them to have a reference from the beginning of each topic.

However some students were worried about the amount of time spent on the maps throughout the semester and felt that this would have an impact on their grade of the final exam. They believed that more time should have being spent on tutorial and exam questions. Sample responses to question 16 which asked students their opinion on using concept maps as advance organizers include:

**Positive**

“Yes because the information was broken down into simple terms and it made it easier to understand”

“Yes as it helped to highlight what information would be needed when dealing with specific questions”

“Yes because they allowed me to see where the formula came from”

“Yes because by having the ideas on a map, it was easier to approach the tutorial questions”

“Yes because they gave an idea of what was expected”

“Yes because they acted as references and each week the concept map grew”

**Negative**

“I would have preferred to have covered more exam papers”

“I feel that too much time was spent on the maps and we should have spent more time on the paper because it is worth 70% of the final grade”
“No really, I think it is important to spend more time on the maths in physics as anyone can learn definitions and formula to put into concept maps but it is applying these formula that pupils need help with”

The final aspect of the questionnaire focused on the impact Concept Mapping had on student’s learning. Figure 6.20 illustrates the students’ responses. This question used a five point Likert scale to evaluate the student’s level of agreement with the following statements:

Do you feel by constructing Concept Maps that you are able to:

A = Understand the theory more easily
B = Identify physics concepts
C = Link prior to new knowledge
D = Answer problems more easily
E = Summarise material efficiently
F = Represent your knowledge clearly in simple English
G = Organise your knowledge into general and specific domains
H = Identify your misconceptions more easily
I = Make valid connections among concepts

Figure 6.20: Students opinions on the effect Concept Mapping had on their learning of Physics
The results indicate that, after completing the Physics module which utilised the Concept Mapping tool, the students felt that they were able to link prior and new knowledge more efficiently (55.6% strongly agreed with this statement). A high percentage, 55.6%, also agreed that they were able to make valid connections among physics concepts at the end of the semester.

The author also investigated whether the introduction of this tool altered students’ decisions on which subject to continue studying for their degree. At this stage of the research the students were drawing close to the end of year one of their degree course at which they had to decide whether to choose Physics or Chemistry for the remainder of their degree. From those who completed the questionnaire almost 5% were Physical Science students who did not have the option of choosing as their degree was in both Physics and Chemistry. The majority of the students, 69%, stated that their experience of Concept Mapping did not alter their decision. However, 27% of the students changed their choice from Chemistry to Physics following the positive experience of the tool. Following the implementation of Concept Mapping almost 54% of the students intended to study physics for the remainder of their Science Education course. In previous years the number of science education students who choose physics has been lower. In the previous academic year, 05/06, 34% of the students selected physics as their minor subject, with the remaining 66% selecting chemistry.

6.3.3.1 Students Analysis of Concept Mapping - Interview Analysis

Five students volunteered to take part in interviews to discuss their experience with Concept Mapping. The main focus of the interview was to discuss the student maps in detail, following the framework of Newman (1977), allowing the author to determine at what point during the construction of the maps the students met difficulty. The interviews also questioned the students on their opinions of the teaching of Physics in University of Limerick (UL) which is not included in the chapter. This section will provide extracts of the conversation that will underline the problems faced by the students when constructing the maps.
Concept Mapping - Construction of Concept Maps

The remainder of the student’s interview focused on the individual concept maps constructed by the students. In the interview the students were asked to discuss their maps and suggest ways that they would change them, if given the opportunity. Probing questions were also used by the interviewer to determine where students found difficulty in the construction. The following transcripts are two student accounts of their maps and are representative of the type of data collected from all five volunteers.

**Student G**

Student G did not study physics at Leaving Certificate level. She scored 7, 8 and 11 respectively in her three maps.

**Interviewer** Can you describe your maps for me?

**Student** I drew all three maps and they explain the topic of light. They are very basic but everything that I wrote down I understand. I didn’t want to include formulas that I couldn’t connect up.

**Interviewer** What would you change about your maps?

**Student** Looking at my maps now I can see straight away that there are several things I would change and do differently. I think the place I need to start is on the list of concepts. I don’t have enough and I remember when I was drawing the maps I was getting annoyed when I couldn’t remember any more.

**Interviewer** How do you think you can improve on your list of concepts?

**Student** I think the best way is to ask myself questions on the topic like; what is it? Where does it come from? What does it do? All these small questions will give words that can be put into the map.

**Interviewer** Is there anything else you would change?

**Student** Am….I would introduce more symbols and units. The only place I did this was in the third map and it was only for the speed of light and for wavelength. I was more relaxed for the third map because I had seen and drawn a few maps at that stage. When I asked myself questions and thought back on the lectures I remembered more information and words.
Interviewer  Looking at your second map you can see that you included very little on waves. Can you explain why you did this?

Student  I found it hard to remember the terminology used. When I was drawing this I was frustrated because we had just covered the material in the lecture but I couldn’t remember the three types of waves so this stopped me from including everything else I knew. I thought that I needed these words so the map wouldn’t make sense. I know now I should have found a way to include the other words I knew like wavelength and frequency.

Interviewer  Yes I can see from your list of concepts you compiled before drawing the map that you have wavelength and frequency mentioned. Why didn’t you include them into your map?

Student  Yes at the time I was not sure about how to link them in. I should have started a new strand. I couldn’t think of simple English to connect them.

Analysis

From the above extract it is clear to see that this student was fully aware of the problems that prevented her from constructing better maps. She felt that she started off wrong by not composing a long list of words. By compiling this list the students get more relaxed and focused on the task at hand. Another prominent factor that affected this student’s map is her reluctance to include several strands of information within the map. She was thrown when she couldn’t remember the three types of waves and because of this she could not continue to include any other terms and concepts to define waves. It is clear from this that the students’ ability in recalling information can upset the construction of the map and limits the number of propositions included.
Student L

Student L did study Physics at Leaving Certificate level and scored 8, 11.5 and 23 respectively in the three maps.

Interviewer Before we discuss the maps can you tell me what do you think you had to do when you are asked to draw a concept map?

Student Basically I think we are asked to draw a map that will include as many terms as possible that are connected to the concept light. I think it’s another way to write an essay on a topic.

Interviewer Looking at your three maps now do you think you successfully did that?

Student It took me a while to do it properly, I think by the time I drew the third map that I did a good job.

Interviewer Yes I think you did too. Can you describe your three maps for me and tell me what you think of them.

Student The three maps I drew explain the concept light. The first one I drew contained bits on biology because I remembered that from the Leaving Certificate. But the other two contained all physics.

Interviewer Did you have any problem in drawing these maps?

Student The main problem I had was connecting the terms. I know the words in my head but found it difficult to put them into the map. I think this was because I was trying to use big words. When you look at my third map I linked up all the concepts with simple small words but it still makes sense.

Interviewer Yes it did contain a lot more concepts. You included some formula into the maps too, what prevented you form including more?

Student There are two reasons for that really, I couldn’t remember some but I didn’t know where to put them. I could talk about them on their own no problem but didn’t know where to fit them in.

Interviewer If you were to use Concept Mapping in teaching, what directions do you think is the most important when drawing the maps?
Student I think personally everyone should make a list before they draw the map because it allows you to plan your map, and when you are making the list you are more focused on the words and not the map.

Analysis Again it is evident in this student’s interview that the same issues are arising. The students are finding it difficult to link their information and are conscious of the final structure and appearance of their map. The student also believes that by making a list you will generate more terms and concepts rather than creating the map directly. Having completed the map, when the students were left with concepts that they could not introduce they began to get frustrated because they knew the concepts however they were unable to identify and show their relationship to concepts already included in the map.

6.3.3.2 Summary of Findings Concept Mapping is a tool that can affect students’ cognitive and affective behaviours in the science classroom. The students’ attitude towards the tool and its effect on their attitude toward physics was examined in the end of term questionnaire. A large majority (61.9%) stated that their attitude improved following experience of the Concept Mapping tool. The students who believed that their attitude disimproved (7.9%) made reference to a module that they were completing simultaneously which may have impacted on their opinion.

An in-depth analysis was carried out on the students’ perceived use of the tool in the classroom and its benefits to their learning of physics. Nine aspects of teaching and learning science were identified and the students were asked to indicate their level of agreement as to whether or not Concept Mapping assisted in them in the physics classroom. According to the data collected 55.6% of the student cohort strongly agreed that the tool helped them in linking prior to new knowledge. This is a key aim of the Concept Mapping tool which facilitates meaningful learning. The two aspects of learning that the students disagreed with was the benefits of the tool in identifying misconceptions (19.1%) and their
ability to help them answer problems easier (19.1%). Overall, however, the students agreed that the tool has many benefits in the physics classroom including their ability to understand the theory easier and making connections among scientific concepts. This is supported further by the number of students who altered their subject choice for the degree (27%).

The use of semi-structured interviews further facilitated the analysis of the students’ conceptions of the Concept Mapping tool. Several elements concerning the construction of maps became more obvious as a result of these voluntary interviews. Students were very conscientious that the concepts and propositions that they include into their concept maps are correct. They omitted material that they could not connect up which would subsequently identify their lack of understanding or misconceptions. Encouragingly, following the construction of the maps the students reflected on the process and began to identify techniques that would enhance their maps. These included asking questions on topics like “what is it? Where does it come from? What does it do?” (Student G) and “make a list before they draw the map because it allows you to plan your map, and when you are making the list you are more focused on the words and not the map” (Student L).

### 6.3.4 Concept Mapping as an Assessment Tool

**Research question addressed:**

- Are concept maps valid assessment tools in third level education?

An analysis of the concept map scores in the three maps developed by the twenty students and their end of term exam results was undertaken to gain insight into the use of Concept Mapping as an assessment tool. Table 6.6 reveals the map scores and end of term exam results for the twenty students involved in the analysis of the results.
Table 6.6: Student map scores for all three maps collected during Phase 2 and the corresponding students’ end of term exam results

<table>
<thead>
<tr>
<th>Student</th>
<th>Map 1 (%)</th>
<th>Map 2 (%)</th>
<th>Map 3 (%)</th>
<th>End of Term Exam (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.6</td>
<td>7.5</td>
<td>11.32</td>
<td>93.5</td>
</tr>
<tr>
<td>B</td>
<td>7.5</td>
<td>16.03</td>
<td>41.0</td>
<td>42.0</td>
</tr>
<tr>
<td>C</td>
<td>26.4</td>
<td>35.8</td>
<td>67.9</td>
<td>42.0</td>
</tr>
<tr>
<td>D</td>
<td>3.7</td>
<td>20.75</td>
<td>30.18</td>
<td>62.5</td>
</tr>
<tr>
<td>E</td>
<td>5.6</td>
<td>18.86</td>
<td>30.18</td>
<td>69.0</td>
</tr>
<tr>
<td>F</td>
<td>10.37</td>
<td>16.0</td>
<td>27.0</td>
<td>72.5</td>
</tr>
<tr>
<td>G</td>
<td>13.2</td>
<td>15.0</td>
<td>20.75</td>
<td>84.0</td>
</tr>
<tr>
<td>H</td>
<td>11.32</td>
<td>43.4</td>
<td>51.8</td>
<td>45.0</td>
</tr>
<tr>
<td>I</td>
<td>13.2</td>
<td>24.5</td>
<td>37.7</td>
<td>36.0</td>
</tr>
<tr>
<td>J</td>
<td>12.3</td>
<td>15.0</td>
<td>39.6</td>
<td>73.0</td>
</tr>
<tr>
<td>K</td>
<td>21.6</td>
<td>40.5</td>
<td>41.0</td>
<td>48.5</td>
</tr>
<tr>
<td>L</td>
<td>15.0</td>
<td>21.6</td>
<td>43.4</td>
<td>43.5</td>
</tr>
<tr>
<td>M</td>
<td>9.4</td>
<td>11.32</td>
<td>42.5</td>
<td>49.0</td>
</tr>
<tr>
<td>N</td>
<td>5.6</td>
<td>3.6</td>
<td>24.5</td>
<td>23.5</td>
</tr>
<tr>
<td>O</td>
<td>5.6</td>
<td>10.37</td>
<td>16.0</td>
<td>46.0</td>
</tr>
<tr>
<td>P</td>
<td>6.6</td>
<td>8.4</td>
<td>24.5</td>
<td>38.5</td>
</tr>
<tr>
<td>Q</td>
<td>13.2</td>
<td>16.9</td>
<td>36.7</td>
<td>56.5</td>
</tr>
<tr>
<td>R</td>
<td>9.4</td>
<td>9.4</td>
<td>30.18</td>
<td>33.0</td>
</tr>
<tr>
<td>S</td>
<td>15.0</td>
<td>19.8</td>
<td>33.0</td>
<td>59.5</td>
</tr>
<tr>
<td>T</td>
<td>9.4</td>
<td>9.4</td>
<td>39.6</td>
<td>52.5</td>
</tr>
</tbody>
</table>

An examination of Table 6.7 shows that students scored very poorly in maps one and two. Further examination draws attention to the fact that the student scores are generally (four exceptions) lower in the final map than they are in the end of term exam which took place three weeks following the construction of the map. Pearson’s correlation coefficient was used to measure the strength of the association between map results and end of term results. No statistically significant correlations (Table 6.7) were found but the correlation between map 3 and end of term results was a moderate negative one ($r = -.38$).
Table 6.7: Pearson product-moment correlation coefficient for student map scores and end of term exam results

<table>
<thead>
<tr>
<th>Map</th>
<th>Pearson Correlation</th>
<th>Sig. (2-tailed)</th>
<th>Term exam (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map 1</td>
<td>-0.113</td>
<td>0.637</td>
<td></td>
</tr>
<tr>
<td>Map 2</td>
<td>-0.102</td>
<td>0.668</td>
<td></td>
</tr>
<tr>
<td>Map 3</td>
<td>-0.381</td>
<td>0.097</td>
<td></td>
</tr>
</tbody>
</table>

A scatterplot representing this correlation is shown in Figure 6.21. The students’ scores in map 3 are on the horizontal axis with the end of term exam results displayed on the vertical. The graph indicates that as scores in map 3 increase, end of semester results tend to decrease.

![Figure 6.21: Scatterplot of the student scores for map 3 and their end of term exam results](image)
6.3.4.1 Summary of Findings

The use of concept maps as an assessment tool is widely reported in the literature since they were first developed in the early 1970’s. Issues concerning their validity as an assessment tool are argued in many of these papers. This research project examined the use of the tool in third level education and investigated if there was any relationship between the students’ scores achieved in their maps and those achieved in the end of term exam. Analysis of the data indicates that some students who attain high grades in a map constructed close to the completion of a degree module (map 3) achieve lower grades in their final exams. This can be due to several reasons, including the lapse of time that occurs between covering course content and the terminal exam. It may also be due to the structure of the exam paper, which may be assessing mathematical skills and manipulation of variables. In comparison, the concept maps are assessing something different which is their understanding of concepts and essentially meaningful learning.

6.4 Phase 1 and Phase 2 Research Conclusions

The findings of this study suggest that there was an increase in the students’ understanding and subsequently meaningful learning, as represented in the concept maps, as they progress through the first year physics module Light and Sound. Meaningful learning will not take place unless a connection is made with prior and new knowledge. The student maps clearly depict that the students are connecting the concepts they learned prior to the module to concepts that are new to them as a result of the module. When the maps were scored by the author it was evident that the students’ understanding of Light increased during the study. The median scores increased from 9.8% in the first map to 34.84% in the third and final map. The student feedback on the tool also revealed that the student’s attitude towards physics improved with 61.9% stating so. This agrees with several studies carried out on the tool (Valadares et al., 2004; Moneira, 1985).

In order to implement the tool in the classroom several components are used. These included an intensive training session, the construction of maps throughout the period of study, the use of maps as advance organizers and finally the
administering of a questionnaire to evaluate the effectiveness of the tool. As reported in the questionnaires the students felt that the training provided was appropriate and supplied them with sufficient information on the tool. Within the training several components were used to prepare the students on the tool. However the group, individual and class construction of the maps were deemed most important. Students felt that the construction of the maps was more important than the PowerPoint presentation and the use of non-physics topics when introducing the maps. Some students felt that a copy of the PowerPoint should have being made available to them during the training so they could take down further notes if necessary. The students also responded well to the construction of the three maps throughout the semester and high attendance was achieved. Students also commented on the degree of directedness they received when constructing the maps. A portion of the cohort found it easier to construct maps when they were given sample concepts to begin their map. This was again mentioned in the interviews when students found it difficult to compose a list of concepts to include in the maps. When the author introduced concept maps on the topics dealt within the tutorials the students commented that they allowed students “see the big picture” on the topic. They also provided a reference for the students which they used when answering questions and for revision.

The final component used in this Phase of the study was the questionnaire which allowed students to comment on the tool and the effect it had on their learning of physics. This questionnaire provided the author with several significant findings one of which highlighted the impact Concept Mapping can have on student retention. Following the students experience with the tool students altered their subject choice for their following year and 54% on the cohort are intending to continue studying physics in their Science Education course. This was an increase of 20% from the previous year.
Chapter 7

Students’ Problem Solving Ability and their use of Scientific Technical Language

7.1 Introduction

The nature and characteristics associated with Concept Mapping lends itself to many diverse avenues of investigation. Having successfully reported the benefits of the tool within the physics classroom during the exploratory study (Phase 2) the author synthesised the research findings and expanded the study further into a second year physics module with the aim to evaluate the students’ use of scientific language using concept maps and physics word problems. Consequently Phase 3 (development of Concept Mapping to analyse students’ use of language and problem solving ability) and Phase 4 (analysis and discussion of data collected) focus heavily on the area of students’ use of language and the relationship, if any, between students’ use of language and problem solving ability. As this is a longitudinal study, the student cohort in this study was identical to that in Phase 2 (exploratory study, Section 5.12.2). Due to the size of the research group the results in this Phase of research focuses specifically on the work of ten students which represent the student sample. These students were again chosen as a representation of the student cohort. Data collected through the use of the questionnaires from the entire group is used in the evaluation of Concept Mapping.

This chapter will begin with a brief account of the methodology employed in Phase 3. As outlined in chapter 5 both students and experts were interviewed in an attempt to collate and assess the individual’s use of language during problem solving. All sixteen participants will be introduced and identified prior to the reporting of results. A detailed report of the findings from all modes of data collection including concept maps, interviews and questionnaires will follow. The results of this Phase (Phase 3) will be described in two sections. Section A is concerned with the qualitative data collected from the student concept maps and
the transcript interviews. Here the author will discuss the individual levels of language, how they were generated, and their usage by both the experts and the students in problem solving. Section B will focus on the quantitative data collected from two questionnaires which were administered at different intervals towards the end of the research study. The use of both sections is consistent with a mixed-methods approach. Each section will address one or more of the research questions which will be identified at the start of each section.

7.2 Methodology employed – Phase 3

The following concept map (Figure 7.1) summarises the methodology employed and data collection tools used during Phase 3. The methodology undertaken in the individual sections (relating to both qualitative and quantitative data) is discussed in greater detail later in this chapter.

Figure 7.1: Concept Map detailing the particulars of Phase 3 of the Research Study
7.3 Subjects involved in the Study

As discussed in detail in chapter 5 the student participants involved in this Phase of research were completing a second-year physics module, Electricity and Magnetism (PH4301). The entire group, \( N = 77 \) were involved in Phase 3 of this research study and completed two questionnaires. However the qualitative data (concept maps and interviews) is primarily concerned with the analysis of data collected from ten student volunteers (six females and four males). These students volunteered to carry out two semi-structured interviews at separate intervals during the course of the 12-week study. The student interview transcripts for both interviews are available in Appendix O. The ten volunteers had varied levels of physics experience, both formal and informal. The students were not required to meet any specific criteria concerning their experience with physics prior to taking part in the study, however, their past experience and prior knowledge was recorded at the beginning of the first interview (Table 7.1).

<table>
<thead>
<tr>
<th>Student</th>
<th>Sex</th>
<th>Leaving Certificate (LC) Physics</th>
<th>LC Grade</th>
<th>Grade from previous Physics module, Light &amp; Sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>No</td>
<td>n/a</td>
<td>C3</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>No</td>
<td>n/a</td>
<td>C1</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>Yes</td>
<td>A1 (Pass)</td>
<td>B3</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>No</td>
<td>n/a</td>
<td>C3</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>No</td>
<td>n/a</td>
<td>B3</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>No</td>
<td>n/a</td>
<td>B1</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>No</td>
<td>n/a</td>
<td>C3</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>Yes(^*)</td>
<td>C1 (Hons)</td>
<td>C3</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>No</td>
<td>n/a</td>
<td>D2</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>No(^*)</td>
<td>n/a</td>
<td>C3</td>
</tr>
</tbody>
</table>

\(^\d\) Repeat Student of Module PH4301

\(^*\) This student did sit the Leaving Certificate exam for the combined Leaving Certificate subject Physics/Chemistry and was awarded a B2 in the higher level paper.
The expert interviews were also carried out in Phase 3 in an attempt to examine if any differences occurred in the use of language and problem solving ability of the experts and students. As discussed in chapter 5 (section 5.12.3.4) an expert is defined as “someone who has completed a physics degree and is either in the process of getting or has qualified with a PhD in physics”. In total six experts were interviewed. The experts were interviewed once, at a time that suited them and included the questions the students received from both interviews. The expert interviews lasted approximately 40 minutes, with one lasting twenty-five. This expert (expert 1) was called away unannounced and was unavailable to complete the questions. A brief account of the expert’s education and current occupation is described in Table 7.2. The transcripts of the expert interviews are available in Appendix P).
### Table 7.2: Profiles of the Experts Interviewed in Phase 3

<table>
<thead>
<tr>
<th>Expert</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Holds a Ph.D. in experimental surface physics with subsequent research expertise is in physics education at the introductory and advanced levels. Taught in modules including physical science for pre-service elementary teachers, first-year physics for physics and engineering students, quantum mechanics for physics students, and an integrated content and research methods module for postgraduates in a secondary science and mathematics teacher preparation programme.</td>
</tr>
<tr>
<td>2</td>
<td>Female</td>
</tr>
<tr>
<td></td>
<td>Graduated with a Science Education degree and currently completing a PhD in the area of Physics Education. During the course of the PhD this expert has taught in a diverse range of Physics modules, including Mechanics &amp; Heat and Light and Sound. This expert lectured the students during the third Phase in this research for the Electricity and Magnetism module.</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Graduated with a degree in Applied Physics and undertook a PhD researching a computational model of earthquakes. Currently involved in research in electromigration, molecular dynamics simulation of metals, and the dynamics of a sheared granular system. Lectured in a number of areas including computational physics, C programming, thermal physics, sound &amp; light, mechanics, and modern physics.</td>
</tr>
<tr>
<td>4</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Graduated with a degree in Applied Physics from the University of Limerick (UL) and currently undertaking a PhD in physics in sensor technology. This expert has extensive experience in teaching undergraduate students including those enrolled in General Physics, Introduction to Physics and Thermal Physics modules.</td>
</tr>
<tr>
<td>5</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Graduated with an honours degree in Applied Physics and currently undergoing a PhD in Semiconductor Physics. Due to transfer soon to PhD level from master’s level. Tutored physics modules over the past two years, including Mechanics &amp; Heat, Introduction to Physics (beginner physics module), Introduction to Physics 2, Solid State Physics and Electricity and Magnetism. Has also lectured, tutored and set an exam paper for another module: Physics for Engineers 1.</td>
</tr>
<tr>
<td>6</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Gradated from DCU (then NIHE Dublin) with BSc (applied physics) and then did a PhD in Colorado State University in the area of chaos and nonlinear dynamics. Lectured in several third level institutions around the world in some of the following modules: Introductory physics (all areas); Classical mechanics; Thermal physics; Statistical mechanics; Quantum mechanics; Condensed matter; Renewable energy technologies; Introductory astrophysics; Optics; Electromagnetism.</td>
</tr>
</tbody>
</table>
7.4 Section A – Data collected from Concept Maps and Interviews

Due to large amount of data collected in Phase 3 of the research, the data is presented in two sections. The research aims, questions and methodology addressed in Section A are outlined in the following table (Table 7.3).

**Table 7.3**: Summary of Research Questions, Research Methods and Analysis undertaken in Phase 3, Section A

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Phase 3 Section A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Approach</td>
<td>Phenomenography</td>
</tr>
</tbody>
</table>
| Research Questions | • Can solutions to theoretical qualitative physics problems be categorised into levels of scientific language? If so how many categories of language are used when solving physics problems and what are the characteristics of each category?  
• Is there a significant difference in the levels of language used by experts and students when solving qualitative word problems?  
• Is performance in physics word problems affected by the level of scientific language proficiency? If so, to what degree does language proficiency have an effect on problem solving ability?  
• In what way, if any, did the lecturer’s use of language and problem solving ability impact of the students’ proficiency in scientific language and problem solving ability? |
| Research Method | • Concept Map – specific to the module Electricity & Magnetism. In the first two concept maps the students were asked to expand and graphically represent what they understood by the term ‘Electricity’ and in the final map they were asked to construct a map on ‘Electrical Current’.  
• Physics word problems – these word problems were designed using the content supplied by the students in their concept maps. The propositions found in the student maps formed the basis of the interview questions. |
| Analysis | Quantitative – SPSS (Version 15) |
7.4.1 Methodology Employed

This section, section A, will focus on the qualitative information generated from the maps generated from the students during their Electricity and Magnetism course. It was through the analysis of these maps that the author generated the interview questions. Throughout the 12-week semester the cohort of students within the physics module constructed three concept maps; at weeks 3, 7 and 11 respectively. As mentioned previously the key concepts did not remain constant for all three maps. This was due to the broad nature of the module and it was essential to alter the key concept in the final map to determine if students were retaining information as the module proceeded.

Following the examination of the concept maps (See Appendix O) it was evident that students were unsure of certain areas of the topic and were confused by other aspects within the domain. This was met with limited knowledge in certain areas also. The students’ errors and inaccuracies identified in the maps, in the form of propositions, were noted. The author also identified the topics that the students did not expand on within the maps. From these lists the author generated both qualitative and quantitative physics word problems that students would be asked to solve during a semi-structured interview. Two student interviews were carried out at separate intervals, at week 8 and week 11 of the semester and students were asked to volunteer to take part. As the study progressed the level of direction varied with the concept maps. Initially the students were provided with instruction, probing questions and seed terms to assist them in the construction of the maps, however, when the students were asked to construct the final map they were provided with only instructions.

The expert interviews contained the identical questions posed to the students to determine if there were any similarities in the experts’ and students’ use of scientific language and problem solving skills. Following the transcription of the interviews, categories of scientific language were developed. Subsequently, statistical analysis was carried out to examine if there was a relationship between students’ and experts’ proficiency in scientific language and also the ability in problem solving.
7.4.2 Data Analysis

This section focuses on the qualitative data collected from the student concept maps and the student and expert interviews. As in Phase 2, a criterion map (Figure 7.2) was used to examine and analyse the students’ concept maps. The maps in this Phase of research were not scored but rather examined to identify the areas in which students were having difficulty. The recognition of these areas of difficulty and confusion was followed by the development of qualitative and quantitative word problems with the view to carry out students and expert interviews. In total 14 questions were developed (See Appendix L) including eight theoretical and six mathematical problems. The qualitative data (language) gathered from the student and expert interviews were analysed to identify distinct categories of responses. The interviews were transcribed verbatim from the voice-recorder and used in conjunction with the students’ written solutions to ensure that all data was accounted for. The author developed the categories initially and categorised the students’ and experts’ responses accordingly. Within these responses three levels of scientific language were identified; scientific, intermediate and instinctive. These three categories are defined in detail in the section 7.4.3. Two other responses were also acknowledged from the student interviews, one of which was related to “incorrect responses” and the final category was given the identification “no response”.

As discussed above the students’ problem solving ability was also analysed through the use of the interviews. The students and experts mathematical problem solving ability was assessed using categories that described students’ approaches to problem solving (Walsh et al., 2007). All quantitative data was coded and imported into SPSS (Version 15) for analysis. Fisher’s Exact Test was applied to compare the categorical variables associated with the students’ and experts’ use of language as the sample size was small. Pearson’s Correlation was employed for assessing the relationship between the use of language and performance in problem solving physics questions. The correlations are reported along with the significance of each correlation.
Figure 7.2: Criterion Map used to analyse the student concept maps generated during Phase 3 of the research study
7.4.2.1 Student Concept Maps

The primary aim of asking the students to construct concept maps was to allow the author to clearly identify the students understanding of the topics ‘Electricity’ and later ‘Electric Current’. In total three maps were constructed by each student. An example of the three maps constructed by one student is given below (Figures 7.3, 7.4 and 7.5). The maps gathered from the students were often difficult to read therefore for this report all student maps have been redrawn verbatim using CMaps.

Figure 7.3: The first concept map drawn by a student enrolled in the Electricity and Magnetism module
Figure 7.4: The second concept map drawn by a student enrolled in the Electricity and Magnetism module
Figure 7.5: The third concept map drawn by a student enrolled in the Electricity and Magnetism module
A critique of the student concept maps led the author to generate a list of propositions that were incorrect or inaccurate. This was carried out, as discussed, to allow the author to identify the areas where students were finding it difficult to understand and also where they find it difficult to represent their understanding. Table 7.4 represents the inaccurate propositions and the topics students did not expand on when constructing their second concept map on Electricity. The concept maps constructed by the 10 students who participated in the semi-structured interviews in Phase 3 are available in the appendix (See Appendix O). The remaining maps are not included due to the enormity of the task and limited time available to the researcher as each map is drawn using the CmapTools software. Hardcopies of the maps constructed by the students are available upon request.
Table 7.4: List of inaccurate propositions and topics with limited information found in the student second concept map on Electricity

<table>
<thead>
<tr>
<th>Propositions</th>
<th>Topics with limited information</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Electricity gives power</td>
<td>• Coulomb’s Law</td>
</tr>
<tr>
<td>• Electricity has an electric force</td>
<td>• Lightning – causes of lightning</td>
</tr>
<tr>
<td>• Flow of electrons through conductors</td>
<td>• Polarisation</td>
</tr>
<tr>
<td>• Electricity is transferred by current</td>
<td>• Movement of charge</td>
</tr>
<tr>
<td>• Lightning rod is a form of polarisation</td>
<td>• Electrons/Protons</td>
</tr>
<tr>
<td>• Electricity is measured in volts</td>
<td>• Location of Electrons</td>
</tr>
<tr>
<td>• Electricity is units amps</td>
<td>– Atoms</td>
</tr>
<tr>
<td>• Electricity can be calculated by coulomb’s law</td>
<td>• Charging by induction/friction</td>
</tr>
<tr>
<td>• Flow of charge is related to coulomb’s law</td>
<td>• Potential difference</td>
</tr>
<tr>
<td>• Electricity can have insulators or conductors</td>
<td></td>
</tr>
<tr>
<td>• Energy is absorbed by insulators</td>
<td></td>
</tr>
<tr>
<td>• Static Electricity is the repulsion/attraction between two forces</td>
<td></td>
</tr>
<tr>
<td>• Electricity has an equation Ohm’s Law</td>
<td></td>
</tr>
<tr>
<td>• Electric current consists of resistors</td>
<td></td>
</tr>
<tr>
<td>• Electricity transfers the current of conductor</td>
<td></td>
</tr>
<tr>
<td>• Electricity flows in current</td>
<td></td>
</tr>
<tr>
<td>• Electricity can be positive and negative</td>
<td></td>
</tr>
<tr>
<td>• Electricity is a build up of charge</td>
<td></td>
</tr>
<tr>
<td>• Electricity flows in a current</td>
<td></td>
</tr>
<tr>
<td>• Coulomb’s Law equation is ( F = \frac{Q_1 Q_2}{r^2} )</td>
<td></td>
</tr>
<tr>
<td>• Electricity creates electric charge</td>
<td></td>
</tr>
<tr>
<td>• Electric charges can be electrified by rubbing two charges together</td>
<td></td>
</tr>
<tr>
<td>• Current needs a steady force</td>
<td></td>
</tr>
<tr>
<td>• Energy is the flow of electrons</td>
<td></td>
</tr>
<tr>
<td>• Currents have voltage</td>
<td></td>
</tr>
<tr>
<td>• Voltage measured in amps/current measured in amps</td>
<td></td>
</tr>
<tr>
<td>• Electricity travels in currents</td>
<td></td>
</tr>
<tr>
<td>• Charge causes energy</td>
<td></td>
</tr>
</tbody>
</table>
Similar analysis was carried out on the third and final concept maps collected from the student cohort. When the students were asked to construct a concept map explaining their understanding of ‘Electric Circuits’ it was found that the main emphasis of their maps was on electrical equipment and circuit components; i.e. students included concepts such as resistors, ammeters, capacitors, diodes and voltmeters. These concepts were elaborated further in the maps as the students included information relating to each component. As this final map was constructed on week eleven of a 12-week semester the author hoped that the students would have included concepts and propositions relating to other topics including Kirchhoff’s laws and potential difference. The following table (Table 7.5) gives an indication of the topics that students found difficulty with and the incorrect propositions they included in their maps.

Table 7.5: List of inaccurate propositions and topics with limited information found in the student third and final concept map constructed in Phase 3

<table>
<thead>
<tr>
<th>Propositions</th>
<th>Topics with limited information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric circuits can travel in parallel</td>
<td>Kirchhoff’s Law</td>
</tr>
<tr>
<td>Current is measured in ohms</td>
<td>Resistance – in series and in parallel</td>
</tr>
<tr>
<td>Coulombs Equation – several different variations of the equation collected</td>
<td>Capacitance – in series and in parallel</td>
</tr>
<tr>
<td>Magnetic field is moved by a force</td>
<td>Electromagnetic force</td>
</tr>
<tr>
<td>Kirchhoff’s Rules</td>
<td>Diode – characteristic curve</td>
</tr>
<tr>
<td>Resistance in Series and in parallel – 1/(I_1) = 1/(I_1)+1/(I_2)</td>
<td></td>
</tr>
<tr>
<td>Equations for total resistance, capacitance on series and parallel</td>
<td></td>
</tr>
<tr>
<td>What does K stand for in Coulomb’s equations</td>
<td></td>
</tr>
<tr>
<td>AC and DC- association with circuits</td>
<td></td>
</tr>
</tbody>
</table>

The following pages will address the research questions set out in this section of Phase 3. Each will be discussed individually.


7.4.3 Categories of Scientific Technical Language

Research question addressed:

- Can solutions to theoretical qualitative physics problems be categorised into levels of scientific language? If so how many categories of language are used when solving physics word problems and what are the characteristics of each category?

The analysis of the interview transcripts (See Appendix P and Q) revealed a hierarchical set of categories that describes the interview participants’ use of scientific technical language when solving physics problems (Table 7.6). As mentioned earlier there were eight theoretical questions asked within the two interviews. These questions were further broken down into subsidiary questions to analyse the language, depending on the concept involved and in which context. Each category will be described in detail, with examples of the initial question, associated subsidiary questions and students’ responses illustrating the characteristics of each category.

Table 7.6: Categories of Scientific Technical Language and their characteristics

<table>
<thead>
<tr>
<th>Category</th>
<th>Key Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>Qualitatively explains the concepts as in the criterion books</td>
</tr>
<tr>
<td></td>
<td>Uses concise, accurate and clear language</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Qualitatively explains the concepts using language which is not the criterion language but which correctly explains the phenomenon</td>
</tr>
<tr>
<td></td>
<td>Language used is similar to that of transitional language; showing some level of understanding and influence of education</td>
</tr>
<tr>
<td></td>
<td>The student response is a step towards the correct response</td>
</tr>
<tr>
<td>Instinctive</td>
<td>Qualitatively explains the concepts correctly using non scientific Language</td>
</tr>
<tr>
<td></td>
<td>Descriptions students would use prior to instruction; use of intuitive natural, colloquial language</td>
</tr>
</tbody>
</table>
Scientific Level

Criterion referencing (Snowman and Biehler, 2000) was used to generate the highest level within the hierarchical categories of responses. Three university physics books which were on the recommended reading list for the *Electricity and Magnetism* module were used to determine the ‘criterion’ language. The books included:


The participants that use this level of language when answering theoretical problems use concise, accurate and clear language to represent their understanding, similar to that of the criterion reference books. These students identify the concepts involved in the problem and show a clear understanding when describing the theory associated with it.

Intermediate Language

The language that was categorised as intermediate was not the criterion language but language that correctly explains the concept or phenomenon. The language represents some level of understanding and signifies the influence of education. The interviewees are familiar with the concepts that relate to the problem and use language similar to transitional language to explain their understanding.

Instinctive Language

The key characteristic of instinctive language is that it resembles that of colloquial language. The interviewees whose language is so categorised are using language that one would expect prior to any formal instruction on the concept or topic.
The following examples will represent examples of each category. These examples have been chosen as they contain all three examples within the question.

**Example 1**

This example is related to Question 1, Interview 1 of the research study. In this question the interviewees were asked to answer the following question:

*An uncharged, Styrofoam ball is suspended in the region between two vertical plates. If the two plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates.*

When answering this question the interviewees mentioned several aspects relating to charge and its characteristics. The following abstracts include the ten students’ responses to this question. As can be seen in these extracts there are several dominant elements involved in answering this question. The author identified these elements and generated three key subsidiary questions that can be asked to encapsulate the student’s understanding when answering this question. These
subsidiary questions are used to represent the students’ responses and subsequently their level of understanding.

**Student 1**

**Student:** OK. An uncharged Styrofoam ball is suspended in the region between two vertical plates. If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates.

**Interviewer:** OK what are the first ideas that come into your head as soon as you read that?

**Student:** OK well I don’t know the charge of the ball so I’d say its neutral. If it was positive...oh it says its neutral in the question. So if it had been charged and if it was positive it would repel off the positive plate because like charges repel and unlike attract. So obviously if it was negatively charged it would have been attracted to the positive plate and likewise with the minus plate over here. Likes repel and unlike attract.

**Interviewer:** Perfect. So what’s the question asking you to do?

**Student:** If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates. It wants to know if the ball is moving of would it be stationary. So.....I’d say it would be stationary.

**Interviewer:** OK so it says to describe the motion of the ball after it’s brought into contact....

**Student:** Well if it’s uncharged and it hits off a charged one it may become charged.....no....yeah, it may become charged!

**Interviewer:** And what would happen?

**Student:** Well if it’s charged then it could be positive...no hang on, if it hits the positive it will become positively charged and likewise if it hits the negative it’ll become negatively charged. So then the motion would be different. It would either be repelling or attracting.

**Interviewer:** So you’re saying to me it’s going to hit the positive, what’ll happen then?

**Student:** It will become positively charged because it touches.

**Interviewer:** It becomes positive. What happens next?

**Student:** It’ll be attracted to the negative so the motion...the ball will move to the left and back to right.

**Interviewer:** Exactly so your final answer is.....

**Student:** The ball will move...oh no....if the ball becomes charged the motion will change, the ball will move.

**Interviewer:** Perfect. So when you see a question like this, how confident are you answering a question about charge?

**Student:** Them ones, fairly OK.

**Interviewer:** Out of 10 what would you give yourself?

**Student:** 7

**Interviewer:** 7. Have a bit of faith! So you’re saying we have charge...the two laws of physics that are coming into play here are....

**Student:** Coulomb’s and Ohm’s......no.

**Interviewer:** You said it first...what happens with the positives and negatives?
Student: They...what happens....
Interviewer: 2 positives come into contact?
Student: Oh they repel. And if 2 negatives come into contact they repel. And if it was a plus and minus they attract each other because opposite charges attract
Interviewer: Exactly. SO that’s 2 characteristics of charge. Can you tell me anything else you know about charge?
Student: Like conductors and stuff? Oh you know with the experiment....you know with the round ball, the charge off it, I can’t think of the name of it.
Interviewer: The Van de Graaff?
Student: Yeah, the Van de Graaff. We stood on the plastic because it’s an insulator because the charge is running through you and we touched it and someone got shocked. So...I don’t know what happened there but I was trying to think of it in my head but obviously it’s something to do with charge. Because she got a shock and wasn’t supposed to apparently. Oh no she caught on to someone else and got a shock. They weren’t on the.....there we go!

Student 2

Student: An uncharged Styrofoam ball is suspended in the region between two vertical plates. If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates
Interviewer: So you can just say what...like.....what’s come to your mind, what do you think the question wants you to do?
Student: It wants me to say what will happen to the ball, will it move to the left or will it move to the right or will it stay in the middle if both of the plates on either side are charged. And they both have different charges.....I think the ball would sty in the middle because it’s neutral. Well it doesn’t say if the ball is charged or not
Interviewer: Yeah, ok
Student: Question one. The ball is suspended between the metal plates. What does this problem involve? Just saying whether the ball is going to move or which side it’s going to move to. It wants me to describe how to go about answering this problem. I basically just say that.....describe the charges, the one on the left is positive; the one on the right is negative. And what this means.....it doesn’t say that this ball has any charge so...it’s going to be neutral
Interviewer: So what do you think would happen to the ball again?
Student: I don’t think it would move because if we were told it was positive it would move to the negative plate because opposites attract, and if it was negative it would move to the positive plate. But it doesn’t say that it’s either so I don’t think it would move.
Interviewer: Right, so is there anything you would be unsure about?
Student: Yeah, well I wouldn’t be 100% confident about that answer. That’s what I think from my understanding so far but there could be....it mightn’t be that simple, it mightn’t be that straight forward. There
could be polarisation; there might be charge on either side of the ball or something.

**Student 3**

**Student:** An uncharged Styrofoam ball is suspended in the region between two vertical plates. If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates.

**Interviewer:** OK so first in your own words, describe what you think the problem involves.

**Student:** Well if you’re bringing the Styrofoam ball near one of the plates, its going to pick up the charge of the plate it’s near. So when you remove it, it’s going to be attracted to the opposite plate and repelled from the plate it was touched against because it has the same charge.

**Interviewer:** When you look at the question first, what would be the first things that come into your head?

**Student:** The first things that come into my head?

**Interviewer:** Yeah, if you were going to solve it, how would you approach it? If you were going to write down the description for an exam or something.

**Student:** What I would do first is draw the ball, and obviously it has positive and negative spread evenly, so you’d have all you positives and your negatives just scattered round. When you bring it close, all your positives would lie on one side, and negatives would lie on the other so that when it comes close the to the positive, sorry, say I’m bringing it to the positive side, it gets a positive charge, so the positive and positive would repel each other. So therefore that now has a positive charge, it would be attracted to the negative charged plate. So what does that involve….it involves attraction and repulsion. So before I go about answering the problem, what exactly is the question?

**Interviewer:** Right, so would you know what characteristics, or like, expand more on the characteristics of charge, if you know anything about charge?

**Student:** I don’t really understand the question…..the overall….what does that question involve? Because it’s just, you know…..

**Interviewer:** So basically….if you bring the….well you’ve kind of answered it already. If you bring the ball over here what happens?

**Student:** OK so yeah, ok the characteristics of charge would be that positive attracts negative and negative attracts positive, positive repels positive and negative repels negative and neutral can be attracted to either of them. What am I unsure about….the question I suppose (laugh). Am I confident about the solution…..Yeah, I would have no problem answering that.

**Interviewer:** OK good stuff. So the next one then is about….so just read that one out again if you want…..
Student 4

Interviewer: So if you were going to answer it in an exam, what way would you approach it? What would be the first thing you would say?

Student: I would probably explain the principle of it, about the electron and the charge, the basic principle of it is that positive and negative attract and that 2 positives......like repel like. So if this became charged...positive, it would repel the positive. But if it was negative, it would repel the negative. But like right here this is just positive and this is just negative and it’s in the middle then it has no charge.

Interviewer: So what are you saying will happen the ball overall?

Student: Overall the ball will...if it’s brought like it says here, if it’s brought into contact with one of the plates it will pick up a charge.

Interviewer: Is there anything you would be doubtful about or unsure about if you were describing it?

Student: Well this one because it’s a Styrofoam ball

Interviewer: You don’t know what that means is it?

Student: The Styrofoam, would that pick up a charge? Is it only metal that would pick up a charge? I though Styrofoam was more of an insulator than a conductor.

Interviewer: OK that’s fine. So would you be confident in answering the question overall?

Student: I would be yeah; I’d probably want the actual technical terms, what law this could lead to, to get full marks. Or for me to think I should get full marks. But overall I would be alright.

Interviewer: OK so would you know any...is there any characteristics of charge or laws that you can think of?

Student: It’s probably leading up to Coulomb’s Law.

Interviewer: OK so it’s building up to Coulomb’s Law.

Student 5

Student: An uncharged Styrofoam ball is suspended in the region between two vertical plates. If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates. So the plates are charged and if the ball hits one of the plates then it will gain the charge so it will deflect off the one its opposite to...no, the one it’s the same as. So
it will be attracted to the other one and repel off the one it’s already hit because it’s charged the same.

**Student:** I’d draw out the diagram and make sure you know which is which. I’d go about explaining that it if hits the charge it’ll gain the charge then repel off whatever plate it’s the same as and be attracted to the other one. And characteristics of charge….positive and negative and like charges repel and unlike charges like positive and negative attract each other. If you were to ask that in an exam you have to be really sure about the terms like polarisation and which charges repel and which attract.

**Interviewer:** So would there be anything you’re unsure of?

**Student:** Yeah just making sure I knew what terms I was using, rather than just throwing them down because they sounded familiar in the question.

**Interviewer:** What terms would you find familiar, you would throw down for this one?

**Student:** Ammm….the characteristics of charge and which attracts which and polarisation.

**Interviewer:** OK so would you be confident in answering the question overall?

**Student:** Yeah I’d say I’d be fine at that question yeah.

**Student 6**

**Student:** Do I have to read it out loud?

**Interviewer:** Yeah you do. Just read out this part here.

**Student:** An uncharged Styrofoam ball is suspended in the region between the vertical plates. If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates. Question 1. The ball is suspended between the plates. What does this problem involve?

**Interviewer:** So what do you think it’s asking you to do?

**Student:** It’s asking me to describe what happens to the ball when it comes into contact with both of the charged metal plates.

**Interviewer:** So then how would you go about explaining it? What is happening?

**Student:** Well the ball has no charge. If you bring it into contact with the minus plate, the minus plate will attract the positive charges in the ball and the ball will become charged, I suppose. The same if the ball came near the positively charged plate, the plate will attract negatively charged particles in the ball, and it will become charged again. The ball might become polarised because of the charges attracting opposite charges in the ball.

**Interviewer:** So can you expand anything on charge?

**Student:** Charge…..am…, I suppose…..

**Interviewer:** Say what would come into your head when you think of charge?
Student: Charge, well I would think of electricity, I would think of static electricity as well. Electrical current, I think a charge goes from positive to negative. Of the battery, in a circuit.

Interviewer: OK that’s fine. If you had this problem in an exam and you were going to write it down, what would be the first thing you would say?

Student: I’d make the point that the ball has no charge. And that like charges repel each other, unlike charges attract each other. When you bring the ball to a charged plate, it polarises it. And makes it a charged, makes it a charged particle, say and attracts it to the plate. And same with the plus charged plate as well. That’s all I’d say about it.

Interviewer: Would you be confident about answering the question?

Student: Not really, no.

Interviewer: How come?

Student: I’m just not 100% sure of what would have to be said to cover the question.

Interviewer: Do you know the idea; you just don’t know the wording?

Student: Yeah, I suppose I’d need to study it as well, just to go back over it, refresh my memory over polarisation and stuff.

Student 7

Student: An uncharged Styrofoam ball is suspended in the region between two vertical plates. If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates.

Interviewer: OK so the first ideas that come into your head there straight away?

Student: Well if you being it onto contact with the positive plate, I think it would be to do with polarisation, and that if it’s positive, it would give the ball a negative charge. So then if you push it in contact, it’ll be repelled by the negative charge in the plate, and it will attract it then back to the positive.

Interviewer: OK so we’ve got charge. And you’re telling me that the 2 phenomenon so to speak taking place are…. Polarisation and attraction….repulsion

Student: Attraction and repulsion, perfect. If you were to describe anything else about charge, to tell me anything else about charge, is there anything else you’d like to put in there?

Interviewer: Any characteristics of charge you’d like to…?

Student: It’s negative and positive…and some have no charge

Interviewer: Exactly. So in relation to the whole description of charge, and where it comes from and what happens, how confident are you talking about it? Out of 10 maybe

Student: Out of 10 I’d say maybe 5 or 6

Interviewer: 5 or 6, ok. So that’s no problem. Just make sure I have these questions ordered. If you just look at this question here
Student 8

Student: OK, an uncharged Styrofoam ball is suspended in the region between two vertical plates. The 2 plates are charged, one positive and one negative. Describe the motion of the ball after it is brought into contact with one of the plates.

Interviewer: OK, so the first thing I want you to do is describe what the problem is, or what you think the problem means.

Student: There is two charges on the plates and a Styrofoam ball, and when you touch the ball off one of the plates its going to cancel...like, the positive on the plate will cancel the negative charges on the ball because the ball is neutral, it has positive and negative charges. O if it touches off the positive plate, it’ll cancel the negative charges in the ball. Then the ball will be attracted to the minus plate because it’s got a.....cancel the negative....so it’ll be plus, the ball will be plus so it will be attracted to the negative plate.

Interviewer: OK, am... so that’s kind of, you’ve described what’s going on. This one is short; you’ve also talked about working it out so what would eventually happen. Or...so you’re saying that....

Student: That it would hit the positive plate and it would cancel the negative, leaving the ball positive, and then it would be attracted to the minus plate. If it touches it then...it’ll cancel and the ball will just swing freely again.

Interviewer: OK, grand. So how confident are you about answering a question like this?

Student: Ah yeah, I’d be fairly confident about answering a question like this yeah.

Interviewer: OK that’s good, Am...., ok so let’s see. Do you know the characteristics of charge would be the last thing?

Student: They can be positive or negative charges....it can cause forces. Like charges repel and unlike charges attract each other.

Student 9

Student: An uncharged Styrofoam ball is suspended in the region between two vertical plates. If the 2 plates are charged, one positive and one negative, describe the motion of the ball after it is brought into contact with one of the plates.

Interviewer: OK? Am, so basically I want you to tell me what you think the question is asking you to do

Student: OK

Interviewer: So basically what comes in to your head first?

Student: Right, I would think it was ah, the motion of the ball with regard to each charged bit; or rather each charged plate, what direction it would go in, to the positive or negative charge within the Styrofoam ball, whether it is positive or negative.

Interviewer: OK grand. Then if you want to describe what you think would actually happen, then
Student: Am, depending on the charge within the Styrofoam ball would be, you know positive to negative, or negative to positive, that it would move to its defined area, you know. Does that make sense?

Interviewer: Yeah, so like if it went to one side, what would happen?

Student: Well, the electrons from the Styrofoam ball would, you know, “jump” I suppose is the best thing, to the plate and it would cause movement with the Styrofoam ball, it would move towards or would be repelled am by either of the two plates.

Interviewer: OK, grand. Am, OK so is there anything more you would like to say about it or?

Student: Am, No I’m pretty terrible at this, so you know,

Interviewer: You’re grand, so the next thing was to ask you what’s your, how confident do you feel about answering that type of question

Student: I wouldn’t be that confident, I would be, you know, I’d like to able to define it better rather than say, you know, it moves or something, you know, better terminology for it.

Interviewer: OK well if you want, you can use paper, if you want to just sketch down a few things, if you think it’ll help you any more, otherwise we can move on. It’s just up to yourself if you think though writing it down can help yourself then work away.

Student: No its grand, its just that I’d say with a bit more information, if I went and looked that up, I’d be able to explain it a bit better than just you know, kind of “off the cuff”, that way

Student 10

Student: An uncharged Styrofoam ball is suspended in the region between two vertical plates. The 2 plates are charged, one positive and one negative. Describe the motion of the ball after it is brought into contact with one of the plates. If the ball is suspended between 2 plates, what does this problem involve? And I would like you to describe how you would go about answering this problem.

Interviewer: Yeah so you can just answer the first bit if you want for now.

Student: Basically, metal plates and the ball and the plates are charged so if the ball is swung towards one, the plate is going to be polarised, so it’ll be positive charge. If it swings back then its going to have…like…if it swings towards the positive one way it started off, its going to have positive charge…like…polarised. When it swings back to the other, it’s going to be more attracted to it and more inclined to stick to the negative plate. That’s all it’s asking really, like.

Interviewer: Do you want to expand on charge and what you know about charge?

Student: Basically the charges are positive and negative like. The reason…..after the ball is positively…..polarised to put it one way, its more inclined to stick to the metal….negative metal plate due to the attraction of opposite charges. So if it was positive charge going to a positive plate, it would be repelled, going back and forward, stuff like that, so….that’s about it
In response to the students’ answers and comments the author developed three subsidiary questions that can be used to represent the students understanding and subsequently their use of language in answering the initial question.

1. What happens when an uncharged object comes in contact with a charged object?
2. How does charge travel from a charged object to an uncharged object?
3. Describe the motion of an object due to the presence of charge?

As mentioned above the recommended books from the reading lists formed the basis for the scientific language. The responses were then analysed to categorise the language into all three categories. This example will focus on the first subsidiary question (S1) to represent all three categories.

Q1 S1: What happens when an uncharged object comes in contact with a charged object?

The following table (Table 5.7) represents the student responses concerned with this question. All three levels of language are evident in the table. From the criterion books the scientifically correct proposition required to answer this question is “attracted to”, i.e. the uncharged object is attracted to the charged object.

<table>
<thead>
<tr>
<th>Student</th>
<th>Proposition used in answering the question</th>
<th>Category of Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>attract to</td>
<td>Scientific</td>
</tr>
<tr>
<td>2</td>
<td>attract</td>
<td>Scientific</td>
</tr>
<tr>
<td>3</td>
<td>attracted to</td>
<td>Scientific</td>
</tr>
<tr>
<td>4</td>
<td>move</td>
<td>Instinctive</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>No Response</td>
</tr>
<tr>
<td>6</td>
<td>attracted to</td>
<td>Scientific</td>
</tr>
<tr>
<td>7</td>
<td>attracted to</td>
<td>Scientific</td>
</tr>
<tr>
<td>8</td>
<td>attracted to</td>
<td>Scientific</td>
</tr>
<tr>
<td>9</td>
<td>attracted to</td>
<td>Scientific</td>
</tr>
<tr>
<td>10</td>
<td>move towards</td>
<td>Intermediate</td>
</tr>
</tbody>
</table>

Seven of the ten students used scientific language when defining their understanding of the concept. Their use of language was identical to that as the
criterion language. One student (student 10) believed that the “object moves towards” the charge. This response was categorised as intermediate language because the student showed a degree of understanding by including the direction of the object, stating that the object moved towards the charge. The response that did not give direction and merely stated that the object moved was recognised as instinctive language.

Example 2

To help further explain the methodology employed during the analysis and data collection in this Phase the author will include another example. This example relates to Question 2, Interview 2 of the research study. In this question the interviewee was asked to describe in their own words the demonstration carried out by the interviewer. The demonstration involved the interviewer rubbing a plastic pen against her jumper and then bringing the pen close to small pieces of paper on the table. The following transcripts indicate the responses given by the students to this question which subsequently framed the three subsidiary questions generated by the author.

Student 1

Student: OK the plastic pen and paper. The interviewer rubs the plastic off wool and tries to pick up small pieces of paper from the desk. One: What does the problem involve?
Interviewer: OK answer that part first
Student: Ah charges.
Interviewer: Is it working?
Student: It is yeah, the paper is being picked up on the pen. After rubbing it off your jumper. It involves charges. When you rub something, it picks up charges. So we had 3 rods in the experiment, one was....plastic. Was one polystyrene....I can’t remember
Interviewer: Perspex and
Student: Oh yeah, the Perspex one, and another one of plastic, I can’t remember the other one. I forget the name.
Interviewer: Polystyrene
Student: Oh yeah, I said that.
Interviewer: So in relation to this demonstration here, what do we have?
Student: We have a plastic pen
Interviewer: And what do we do to it?
Student: We rubbed it off a thing so it picked up a charge.
Interviewer: How do we charge this pen now? Through what?
Student: Static....Rubbing it off....friction like.
Interviewer: OK so we’re charging by friction here
Student: Ahh, can you explain that any further.
Interviewer: Tell me about the charge.
Student: The charge on the pen is positive….no hang on; you don’t know it….neutral. I don’t know.
Interviewer: The charge on the paper so first of all.
Student: I don’t know…..neutral I’d say. So the paper’s neutral, the pen would be neutral. So obviously if I…..friction causes….rubbing them off each other causes the friction so you pick up a charge from the material. Then the pen has a charge now so obviously what ever charge it is now, it picks up the paper. So that would indicate that they’re opposites. But I still can’t figure out which is which.
Interviewer: You’re after telling me the paper is…..
Student: Neutral. Hang on so…it has no charge. When I rub the pen off my jumper...
Interviewer: What…neutral doesn’t mean uncharged
Student: No, no, it has electrons and protons. So the pen probably picked up a positive charge, the friction caused a positive charge. So the paper was negative.
Interviewer: OK so how did the paper come from being neutral to negative?
Student: Ah when the pen picked up the charge and I brought it near the paper, the electrons moved around, well you can imagine in your head
Interviewer: Draw a diagram and tell me how it works
Student: There’s the paper,
Interviewer: It’s made up of?
Student: Protons and electrons. So you brought the pen towards it with positive charges…oh no, hang on yeah, sorry so if the electrons had been this side they would have moved around because you want opposites to attract.
Interviewer: And what’s that phenomenon known as, when electrons moves outside where they want to be?
Student: I don’t know, hang on….I should know it.
Interviewer: It’s separating, the charge is separating.
Student: I don’t know; hang on now…I’m going to get confused
Interviewer: No, you’re not going to get confused, take your time.
Student: Oh we did this with the 3 balloons….
Interviewer: It begins with “p”
Student: I can’t think of it Joanne.
Interviewer: Think of the opposite sides of the world
Student: Poles…..oh polarisation. Right, I’m writing this down to remember it. I get that because obviously it’s the same with the magnetic field, you know one is positive and one is negative. I understood that they separated I just couldn’t think of the name.
Interviewer: So you’re after explaining how it works, and other characteristics of charge? We have polarisation.
Student: What does the charge do?
Interviewer: Think back over the question we just answered
Student: The one with the Van de Graaff generator? Oh no hang on, the metal ball, what do you want to know, hang on….
Interviewer: Anything you want to say about charge

Student: OK so we don’t know the charge so there in polarisation we figured out….well everything has plus minus negative charges, you know like, because that’s due to the atom because you have protons neutrons and electrons. So if something was positively charged polarisation would cause them to go to one side like in chemistry with the dipoles, plus and a minus, and then in the last question with the metal plate, we knew one plate was plus the other was negative, we knew that was neutral. There were charges in the ball but it’s not charged up so obviously if it was charged up it would have been attracted to one of them.

Student 2

Student: The pen is picking up the paper due to static electricity. The paper has a particular charge and the pen has a particular charge. So they obviously have different, opposite charges and they’ll attract....the papers attracted to the pen.

Interviewer: So is there any characteristics of charge you can expand on or?

Student: Am..., well if the paper is positive and if the pen is neutral or negative it might attract to the pen.

Interviewer: That’s fine. So if you have this problem in the exam how would you go about describing it? What would be your thought?

Student: I’d probably just talk about the static electricity, what causes it to attract and pull up off the board and the pen....

Interviewer: Is there anything you’d be unsure about?

Student: Yeah, I probably wouldn’t......at the moment anyway I probably wouldn’t be able to put it into correct terms about exactly what’s happening. I know in my head kind of what’s happening but its hard to say exactly what I think is happening. I just think.....yeah static electricity.

Student 3

Student: Rubs a plastic pen off wool, and tries to pick up small pieces of paper off the desk. What does this problem involve? Well you’re charging the pen then by friction, so it’s showing then that the paper, being neutral, can be picked up. So the pen will be charged by friction, and the paper being neutral will be attracted to the pen. That’s how it works. The characteristics of charge are the same as earlier, how would I go about answering the problem? Am like that I suppose, the friction is exciting the electrons, causing charge to occur, and with the charge then, these are neutral I would imagine, they would be attracted to the charge, so its picks them up. I’d be relatively confident about that one

Interviewer: So you’d be happy enough with that one. OK grand.
Student 4

Student: By rubbing it off your jumper, you build up a charge in the pen and because the piece of paper has no charge it’s attracted to it. And depending on the charge, it will either attract it or hold it in the middle. It’ll just keep it in mid-air. But its basically static electricity, that’s what’s causing it to go to the pen.

Interviewer: So again if you were going to write it down, what would be the first kind of ideas...or....what would be your first thoughts?

Student: My first thoughts would be again, the overall heading, its all about static electricity. And I might define what electricity is, that it’s a form of energy and explain static electricity and then explain like I did there, the principle of the charges and how it sometimes goes to the pen and how it only stays in mid-air.

Student 5

Student: It’s that the pen is being charged off the wool and then it’s attracting whichever...it polarises the paper so it separates the charge out and then it picks up whichever is nearest to it. So the pen is positive and say the positive are all on one side and the electrons are on the other and picks it up. That’s why part of it hangs from the pen and the other half doesn’t.

Interviewer: OK. Any characteristics of charge that you would be talking about then or spring to mind?

Student: Well the same again. Whatever charge that was the same as the pen would stick to the pen and that’s why all the paper doesn’t stick to the face of it.

Interviewer: And would you be confident about answering it?

Student: Yeah I think that would be grand in an exam?

Interviewer: Would there be anything in particular that would turn you off answering the question?

Student: Again just knowing the technicalities. Say when the pen is rubbed off the jumper whether the pen becomes positive or negative. Just being unsure about which charges are which on the pen and paper.

Student 6

Interviewer: So can you describe what’s happening here and what’s involved?

Student: Static electricity....when you’re rubbing the pen in your jumper you’re positively charging it because of friction, causing the pen to become to become positively charged, that causes the paper to be attracted to it. What does this problem involve........it just works when positive charge is transferred to the pen from the wool. And it polarises the paper, causes the paper to become attracted, negatively. The negative of the paper becomes attracted to the positive of the pen. And the positive charge is caused by friction.

Interviewer: So now that you’ve had a think about it, if you were going to write it down in an exam, what way would you put it down?
Student: I suppose I’d describe how the pen becomes charged. I’d say that when you rub the pen it causes friction, the pen will become positively charged. And when you put it near paper, it induces negative charge on the paper to be attracted to the pen. And I’d say that’s static electricity from the pen.

Interviewer: And what can you tell me about the charge on the paper?
Student: It’ll be neutral, but it’ll still attract it. Like a balloon on a wall.

Interviewer: So how does the balloon, or how does the paper….for attraction to take place, what charge must the have?
Student: Opposite charges

Student 7

Student: You’re….charging the pen which is attracting the pieces of paper to stick to it. So it’s to do with static electricity. So because you’re causing friction with your jumper it’s giving the pen a charge. I think it’s that the material in your jumper is scraping electrons off the pen, so it’s giving it a charge, so it’ll attract the paper.

Student: That’s static electricity. When you rub the wool, whichever one had more of an affinity for the electrons took it leaving a charge on the wool and the biro. Then when you brought it to the paper, it picked it up because there was a difference in the charge

Interviewer: OK, am….so you have expanded…anything more you want to say?
Student: I’ll quit while I’m ahead I think.

Interviewer: So say if you were in an exam and you were asked to write it down, what would be kind of, the first things that would come into your head that you would want to get down on paper?
Student: Am…static electricity, the charge….just using buzz words, an attraction, difference in like and unlike charges, and then put words in between to link them all together, hopefully

Interviewer: Grand, that’s fine. Again, would you be confident in answering something like this?
Student: Yeah, I’d be confident of answering that, yeah.

Interviewer: OK that’s good. Next question, again I want you to read out once more what it says.
Student 9

Student: Am, it’s a form of static electricity ah, by rubbing it off your jumper, you’re charging a plastic pen and in doing that, am, parts of the page will you know, attach themselves to the pen. Am it’s got to do with movement of electrons between each. Am I don’t know if I can expand on it any further or go into detail about it

Interviewer: Uh-huh, well you kind of say, am what does the problem involve, you have kind of explained how it works. Am, do you know the characteristics of charge? Can you talk about charge any more?

Student: Am, it can be positive or negative, I mean, you wouldn’t have repelled the page, or any of the pages really because you know, by charging it, you know, there is I think it is free electrons or something passing between each, and that’s why it attaches. I think that’s the best way I could explain it.

Interviewer: OK am, ok, so what would you be unsure about

Student: I’d say the most thing I’d be unsure about is how the page, how the bits of paper you know attach to the plastic rod is that, you know, am, is that movement of electrons, or is it you know, because the page is, say, negatively charged, and you’re after charging it on your arm. Is it because it is negatively charged does it attach then. To explain it better I suppose is that what happens in between rather than just charging it and putting it to a piece of paper

Interviewer: OK, so if you go to answer, I probably should have asked you this at the start, when you actually initially see what I was doing there, and you went like say answer “explain what’s happening” what were the first things that would come into your mind, what would be the logical thought process?

Student: Well first it would be, you know, we’ve seen it all done before, its been done in a school or something like that, as a little demonstration, or as you’ve done it yourself, you know, you see the charging with a woollen jumper or something like that, that’s causing the pen to be, I think I don’t know whether, well its going to be positively charged and you know, then attraction occurs between the little bits of paper and that so you’re kind of, you’ve seen it before but to explain it in detail that involves, am, explain it in a physical aspect rather than just “the page attaches to a pen”, I suppose it would be better to do it that way, rather than you know, it kind of sounds like its coming from a lay man if I say you know, “the page attaches to the pen”. I would much prefer to be able to explain it in regards to the Physics.

Student 10

Interviewer: So you’re basically supposed to describe what’s supposed to be happening here

Student: All the pieces of paper are supposed to be picked up?

Interviewer: Yeah….so what does the problem involve again?

Student: Am the plastic pen and paper. The problem involves static electricity and just the attraction to a charged particle. When you rub the biro off your sleeve or your hair, a bit of cotton or
something like that, its going to charge and the negative ions in the paper or whatever it is you’re trying to pick up will be attracted to the biro and they kind of stick to it. Same with the balloon and a piece of paper as well. Explain how it works….am…it’s basically the attraction of opposite charges again.

**Interviewer:** Would there be anything you’re unsure about when you’re answering it?

**Student:** Like charges are fairly simple anyway, there’s nothing majorly difficult about them, just….positive and positive repel each other, and positive and negative attract. Like poles and all that.

Again this question was broken down into three subsidiary questions during the analysis in an attempt to include all concepts that were mentioned in the student interview transcripts. The three questions include:

1. What will happen the paper when you bring a charged object close to it?
2. How was the plastic pen charged?
3. What happens when you rub the plastic pen against the jumper?

This example will present the responses given for the third subsidiary question.

**Q2 S3: What happens when you rub the plastic pen against the jumper?**

Again all the levels of language in the hierarchy are present in the students responses (Table 7.8). The scientific response that was required for this question was that the electrons are transferred from the jumper to the pen.

<table>
<thead>
<tr>
<th>Student</th>
<th>Proposition</th>
<th>Category of Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>it picks up charge</td>
<td>Instinctive</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>No response</td>
</tr>
<tr>
<td>3</td>
<td>friction excites the electrons causing charge to occur</td>
<td>Instinctive</td>
</tr>
<tr>
<td>4</td>
<td>charge builds up on the pen</td>
<td>Instinctive</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>No Response</td>
</tr>
<tr>
<td>6</td>
<td>charge is transferred to the pen</td>
<td>Scientific</td>
</tr>
<tr>
<td>7</td>
<td>scraping electrons off the pen giving it charge</td>
<td>Instinctive</td>
</tr>
<tr>
<td>8</td>
<td>pen takes electrons off the wool</td>
<td>Intermediate</td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>No Response</td>
</tr>
<tr>
<td>10</td>
<td>it charges the pen</td>
<td>Instinctive</td>
</tr>
</tbody>
</table>

It is clear to see from Table 7.8 that the students had difficulty with this question. From the 10 students analysed, three did not mention any aspect of the movement
of charge from the jumper to the pen during their interview and a further five students used instinctive language to explaining their understanding of the concept. One student used intermediate language stating that the “pen takes electrons off the wool” and the final student used scientific language as it correctly used the relating word ‘transferred’ to explain their understanding of what happens when you rub a plastic pen off a wool jumper.

Summary of Findings

Overall, the findings from the first research question demonstrate that the language that students use when solving qualitative physics word problems can be categorised into three hierarchical levels: Scientific, Intermediate and Instinctive. The scientific level of language is similar to that used in textbooks and it is language that clearly explains concepts in a concise and accurate manner. Intermediate language on the other hand is language used that qualitatively explains the phenomenon correctly but it is not as accurate and succinct as the scientific language. The students that use instinctive language are using language that resembles that of colloquial language and as such does not represent the students’ level of understanding.
7.4.4 Expert and Student use of Language

Research question addressed:

- Is there a significant difference in the level of language used by experts and students when problem solving?

As discussed above the interview questions were analysed using subsidiary questions. In total there were 8 theory questions with each question containing at least two subsidiary questions. This resulted in a final total of 28 questions for analysis provided the interviewees attempted all questions. However this was only the case for two of the students and five of the experts.

In an attempt to answer this research question the author scored both the students and the experts responses as a percentage for each subsidiary question (Table 7.9). The subsidiary questions with an asterisk (*) signify the theory questions from the second interview which took place in week 12 of the semester.

From the table it is evident that both the students and experts use all three levels of language when problem solving, however the frequency of which students use scientific language differs slightly to that used by the experts. When answering four of the 28 subsidiary questions the students did not use any scientific language, whereas the experts used scientific language in answering every question. The students used instinctive language when answering 15 questions however the experts used instinctive language in only 7 cases out of the 28.
Table 7.9: Student and Expert use of Scientific Language when solving qualitative physics word problems

<table>
<thead>
<tr>
<th>Subsidiary Question</th>
<th>Student Responses</th>
<th>Expert Responses</th>
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<td>Intermediate (%)</td>
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<td>1B</td>
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<td>1C</td>
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<td>2C</td>
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<td>3A</td>
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<tr>
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<td>*1B</td>
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</tr>
<tr>
<td>*2C</td>
<td>50</td>
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</table>

Even though there was very little statistical difference in the use of language used by the experts and students some differences did occur. More than 60% of the language used by four of the six experts to answer the qualitative questions was scientific language (Figure 7.6). In contrast only two students used scientific language more than 60% of the time (Figure 7.7). Also every student used instinctive language when answering the qualitative questions. However, 83% of the experts used instinctive language during problem solving.
Figure 7.6: Experts’ use of language during problem solving

Figure 7.7: Students’ use of Language during problem solving
Summary of Findings

As discussed in the initial research question the language used by students to answer qualitative physics problems can be categorised into three hierarchical levels. Experts in the field of physics also use these three categories when explaining physical phenomenon. The results produced in this research study serve to imply clearly there are differences between the language used by that of the expert and the student (novice), however this difference is not significant ($p > 0.05$) in the majority of the cases.

It is also important to note that every student and expert used scientific language at some point to represent their understanding. From the six experts only one qualitatively answered the questions without the use of instinctive language. The data collected from the experts provides strong evidence to suggest that they use very little instinctive language when explaining their understanding of their physical concepts.
7.4.5 Relationship between use of Language and Problem Solving Ability

Research question addressed:

- Is performance in physics word problems affected by the level of scientific language proficiency?

Following the analysis of the students’ and experts’ use of language when solving physics word problems the author analysed the relationship, between scientific language proficiency and quantitative problem solving ability. To facilitate this, ten students were questioned on six mathematical problems during the two interviews. The work of Walsh et al., (2007) supported this analysis as they identified five categories to describe the problem solving state of a set of novice college students in quantitative physics problems. These categories were generated as part of a larger research study to explore the relationship between conceptual knowledge and problem-solving ability which took place in the Dublin Institute of Technology (DIT). The five categories that emerged from the study are described in the following table (Table 7.10).
Table 7.10: Categories of Problem Solving Approaches and their Key Characteristics

<table>
<thead>
<tr>
<th>Category</th>
<th>Key Characteristics</th>
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<tbody>
<tr>
<td>Scientific</td>
<td>• Qualitatively analyses the situation&lt;br&gt;• Plans and carries out solution in a systematic manner based on that analysis&lt;br&gt;• Discusses the way in which the concepts relate to the problem&lt;br&gt;• Refers to concepts to guide the solution&lt;br&gt;• Draws diagrams only when they believe it will help them visualise the problem&lt;br&gt;• Evaluates the solution</td>
</tr>
<tr>
<td>Plug and Chug - Structured</td>
<td>• Qualitatively analyses the situation based on required formulas for the problem&lt;br&gt;• Relates the concepts to variables involved and identify the target variable&lt;br&gt;• Plans the solution based on the variables and proceeds systematically&lt;br&gt;• Refers to concepts to guide the solution&lt;br&gt;• Focus throughout solution is how the concepts are related&lt;br&gt;• Evaluates the solution</td>
</tr>
<tr>
<td>Plug and Chug - Unstructured</td>
<td>• Analyses the situation based on required variable&lt;br&gt;• Proceeds by choosing formulas based on the variables in a trial and error manner.&lt;br&gt;• Refers to concepts as variables&lt;br&gt;• May identify the concepts and equations correctly but may carry out an incorrect methodology and answer the question incorrectly&lt;br&gt;• Conducts no evaluation</td>
</tr>
<tr>
<td>Memory – Based Approach</td>
<td>• Analyses the situation based on previous examples; perhaps done in the class&lt;br&gt;• Proceeds by trying to “fit” the given variables to those examples; recalling from situations encountered in the past&lt;br&gt;• Believe that the problem can be solved in the same way as the previously encountered question&lt;br&gt;• Refers to concepts as variables&lt;br&gt;• Conducts no evaluation</td>
</tr>
<tr>
<td>No Clear Approach</td>
<td>• Does not try and approach the problem with any sort of strategy&lt;br&gt;• Analyses the situation based on given variables&lt;br&gt;• Proceeds by trying to use the variables in a random way&lt;br&gt;• Refers to variables as unrelated terms or letters&lt;br&gt;• Conducts no evaluation</td>
</tr>
</tbody>
</table>

Adapted from Walsh et al., 2007, p. 4
These categories were identified and applied to the interview transcripts for each quantitative question asked in order to categorise the responses. As previously mentioned there were six quantitative physics problems; two from the first interview and four from the second. Tables 7.11 to 7.14 inclusive represent the results of the analysis in both the student and expert interviews. The tick mark (✔) in the tables signifies which category the solution of the question was allocated. The questions that were not answered in the interviews, perhaps due to time restrictions, are shaded in grey. An example of each problem solving approach is provided to display the characteristics associated with each. The author would like to point out that unlike the study carried out in DIT the students were not given access to an equation sheet to assist them in their problem solving.
### Table 7.11: Student Approaches to Problem Solving in Interview 1

<table>
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<tr>
<th>Student</th>
<th>Question</th>
<th>Scientific</th>
<th>Plug-and-chug structured</th>
<th>Plug-and-chug Unstructured</th>
<th>Memory Based</th>
<th>No Clear Approach</th>
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### Table 7.12: Expert Approaches to Problem Solving Interview Number 1

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### Table 7.14: Expert Approaches to Problem Solving Interview 2

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Scientific Approach

The following interview abstract is the solution given by a student (Student 7) to question seven in the first interview. This question asks the student to calculate the force between two charges.

**Interview 1 – Question 7**

*Tom and Jerry are sitting on the opposite ends of a bench at a distance of 600 cm apart. They both have an equal charge. What force is experienced between them?*

**Student 7**

**Student:** Tom and Jerry are sitting on the opposite ends of a bench at a distance of 600 cm apart. They both have an equal charge. What force is experienced between them?

**Interviewer:** Ok so what do you think is being asked here? Or what are the first ideas that come into your head?

**Student:** Coulomb’s Law.

**Interviewer:** Can you expand on that any bit more?

**Student:** I can’t define it, but I can tell you that it’s to do with the force between 2 charges. And the force that’s given out between the 2 charges and ….

**Interviewer:** And they’re telling us here that they are equal charges, so what type of force are we going to have?

**Student:** Am…, If they both have an equal charge

**Interviewer:** They’re the same and they’re equal. Give me a value for any 2 charges that are equal

**Student:** 2 and 2

**Interviewer:** 2 and 2, ok. So we have 2 equal charges, 2 and 2, and they are equal so its 2 positives

**Student:** Obviously they repel each other

**Interviewer:** They repel each other; there will be repulsion, ok? So you, do you know the formula for that?

**Student:** Am…, $k$ times $q_1$ $q_2$ over $r$ squared.

**Student writes:**

\[ F = \frac{k q_1 q_2}{r^2} \]

**Interviewer:** Perfect and that equals? Your force in newtons.

**Interviewer:** So if you just want to make up a value there, and see if you can calculate out the force.

**Student:** So $k$ is a constant, it’s 10 times

**Interviewer:** 9 by ten to the 9, I think
Student: OK 9 times 10 to the 9, sorry. So \( q_1 \) and \( q_2 \) represent the charges of the 2 objects. So if we say the charge is two. \( Q_1 \) is equal to 2 and \( q_2 \) is equal to 2 because they are equal charge. \( R \) is the distance between them, and it should be converted to metres, so 600 centimetres is 6 metres. So if I fill all that in I have 9 times ten to the 9 times 2 times 2, all over 6 squared.

\[
\frac{(9 \times 10^9)(2)(2)}{6^2}
\]

\[1 \times 10^9 \text{ N}\]

Interviewer: 1 by ten to the 9. So your force is?
Student: 1 by ten to the 9 Newton’s. And that’s the force experienced between Tom and Jerry.

The students initial thought of this problem was the idea of “Coulomb’s Law”. He continues to explain that Coulomb’s Law is “to do with the force between 2 charges”. In line with the characteristics of the scientific approach the student identifies the concepts involved in solving the problem and discusses the solution in a coherent manner. The student is familiar with the equation required to solve the problem and is aware of how the concepts are related, “Obviously they repel each other”. This again is a key characteristic to the scientific method (Table 7.9).

Plug-and-chug: Structured Manner

The following abstract is from question 6 in the second interview. This student (student 4) solves this mathematical question concerning Kirchhoff’s laws using the plug-and-chug structured approach.
Describe this circuit diagram? What does this it represent?
Discuss the flow of current in this diagram. How does this relate to Kirchhoff’s first Law?
What is Kirchhoff’s second law concerned with?
Calculate the current flowing through each branch.

**Student 4**

**Student:** This is Kirchhoff’s. I like this. So the circuit diagram is 2 loops, 3 resistors, 2 power supplies and there’s basically a big loop and a small loop when you’re trying to work out everything. So the current will flow…it will come out of the 15 volt go through the 3 ohm resistor and it will come down…well actually no it will go the other way because it flows from positive to negative. So it’ll come out the 15……

**Interviewer:** You can draw it there and label it there so Joanne can see. Take your time, you have loads of time.

**Student is drawing the diagram**

**Student:** OK so power will start the big loop is this one……ok say this is the small one

*(Student identifies the two loops on the diagram)*

So with this the current comes out and basically it will split so if \( i_1 + i_2 = i_3 \) and \( V = IR \). And this is \( i_1 \) and when I come down this here is \( i_3 \) and over across is \( i_2 \). *(Student marks in the flow of current)*

**Interviewer:** So which direction is \( i_2 \) going in?

**Student:** \( i_2 \) is going towards the 18 volt supply. So my \( V \) is 15 volts = …. 

**Interviewer:** Which loop are you going to take first? 

**Student:** I’ll start with the small loop.
Student writes:

\[ i_1 + i_2 = i_3 \]
\[ V = IR \]

So I come down across to \( i_2 \) and I meet the 18 volts power supply. But that's going positive to positive so its 15-18 = 9 times \( i_2 + \)......when it comes back up here \( i_1 \) and \( i_2 \) have met again so this is going to be \( i_1 \). So I have 9 times \( i_2 + 3 \times i_1 \). That's 15-18 = -3 = 3\( i_1 \) and 9\( i_2 \) and that is my first equation.

Student writes during explanation:

\[ 15 - 18 = 9i_2 + 3i_1 \]
\[ -3 = 3i_1 + 9i_2 \ldots \text{(1)} \]

Then my large loop......So I have 15 volts again and then I have 3 times \( i_3 \) and 3 times \( i_1 \). And you do simultaneous equations here but I have \( i_1 \) and \( i_2 \) in equation 1 and \( i_3 \) and \( i_1 \) in equation 2. So I'll substitute my \( i_3 \) here. So am \( i_3 = i_1 + i_2 \) and I'll put that in here. 15 is equal to three and three is 6\( i_1 + 3i_2 \) and this is my second equation.

Student writes during explanation:

\[ 15 = 3i_3 + 3i_1 \]
\[ 15 = 3i_1 + 3i_3 \]
\[ 15 = 3i_1 + 3(i_1 + i_2) \]
\[ 15 = 6i_1 + 3i_2 \ldots \text{(2)} \]

Now I use simultaneous equations. Multiply this by minus 2.

(Equation 1) So 6 = -6\( i_1 \) - 18\( i_2 \), \[ 15 = 6i_1 + 3i_2 \]. \( i_1 \) cancels......so \( i_2 \) is -1.4 and I can substitute this back into my first equation. \[-3 = 3i_1 + 9i_2 \]. So \( i_1 = -9.6/3, \ i_1 = -3.2 \). And I can put that into my other equation then. So we have \( i_1 + i_2 = i_3 \), -3.2-1.4 = -4.6 so \( i_3 = -3.2 \) amps, \( i_2 = -1.4 \) amps and \( i_3 = -4.6 \) amps. That's my final answer. The minus indicates the direction of flow so sometimes they're not minus, \( i_1 \) and \( i_2 \) can be plus and \( i_3 \) can be minus, just depends on the actual question

Calculations:

Simultaneous Equations:

\[ -3 = 3i_1 + 9i_2 \ldots \times -2 \]
\[ 15 = 6i_1 + 3i_2 \]
\[ 6 = -6i_1 - 18i_2 \]
\[ 15 = 6i_1 + 3i_2 \]
\[ 21 = -15i_2 \]
\[ 15i_2 = -21 \]
\[ i_2 = -1.4 \]
\[-3 = 3i_1 + 9i_2 \]
\[-3 = 3i_1 + 9(-1.4) \]
\[-3 = 3i_1 - 12.6 \]
\[3i_1 = 3 - 12.6 \]
\[3i_1 = -9.6 \]
\[i_1 = -9.6/3 \]
\[i_1 = -3.2 \]
\[i_1 + i_2 = i_3 \]
\[-3.2 - 1.4 = -4.6 \]

\[i_1 = -3.2 \text{ A} \]
\[i_2 = -1.4 \text{ A} \]
\[i_3 = -4.6 \text{ A} \]

In line with the key characteristics of the structured approach to problem solving (Table 7.9) the student identifies the concepts involved in this question and discusses in a coherent manner the steps involved in solving the question. When solving the question the student is also familiar with the equation required, \( V = IR \). The student then plans the solution based on the variables that are given in the problem; resistance and voltage. From the onset of the solution the student is aware of how the concepts are related, i.e. that there are two loops in the circuit and that both loops will result in a simultaneous equation allowing her to calculate the target variables: current flowing through each resistor.

**Plug-and-chug: Unstructured Manner**

The following example exemplifies the characteristics associated with solving a mathematical problem in a plug-and-chug unstructured manner. The initial part of this question asks the students (student 2) to discuss the flow of current in the diagram. To answer this, the students qualitatively explained the flow in the circuit. As this qualitative aspect of the question is not to focus of the analysis it will not be included in the transcript below. The abstract will concentrate on the students’ solution to the quantitative aspects of the question which focuses on the calculation of the equivalent resistance within the circuit and the current flowing in the circuit.
Describe the above diagram.
Describe the flow of current and the voltage in this diagram.
Calculate the equivalent resistance in this How can you calculate this?
Calculate the current flowing through each resistor and the voltage across each resistor?

Student 2

Student: The voltage is 60 V from the power supply. Calculate the equivalent resistance in this diagram. Is that just the total R? So $R_{\text{total}}$ for a circuit in series is just $R_1 + R_2 + R_3$ and for the part in parallel its $1/R_T = 1/R_1 + 1/R_2$. For this circuit because there’s a parallel and series, if you add $R_2$ and $R_3$ it’ll give you a resistance of 15 Ohms.

Student writes:

$$R_T = R_1 + R_2 + R_3$$
$$1/R_T = 1/R_1 + 1/R_2$$

Interviewer: So write out your formula for adding $R_2$ and $R_3$.
Student: Oh yeah sorry, no its $1/R_T = 1/R_2 + 1/R_3$ which is $1/8 + 1/8$. Do you have to put that into the calculator as it is?

Student writes:

$$1/R_T = 1/R_2 + 1/R_3$$
$$1/R_T = 1/8 + 1/8 = 1/4$$
$$R_T = 4$$

Interviewer: You can add it as a fraction either.
Student: So that's $1/4$ so $R_T$ is 4. Then that give you a circuit now which is in series so you can put that then into the equation $R_T = R_1 + R_2 + R_3 + R_4$ so 5+6+4 which is 15 Ohms altogether for $R_T$. 
**Student writes:**

\[ R_T = R_1 + (R_2 + R_3) + R_4 \]
\[ R_T = 5 \Omega + 4 \Omega + 6 \Omega = 15 \Omega \]

**Interviewer:** Perfect so that's the equivalent resistance, next part then

**Student:** Calculate the current flow through each resistor and the voltage across each resistor. The current flow...that's \( V_{\text{total}} \) isn't it? \( V_{\text{total}} \) has a similar formula to the resistance one.....in series its \( V_1 \)...no its not...

**Interviewer:** So you have your voltage....

**Student:** Well they all have to add up to 60 volts anyway.

**Student writes:**

\[ V_T = \text{add up to 60} \]
\[ I_T = \]

**Interviewer:** So you're asked first to find the current. What's the current?

**Student:** \( I_{\text{total}} \). I can't remember how to get the current. It's the same formula is it?

**Interviewer:** So you have the voltage here already and you have your equivalent how would you find you....you have a value for voltage and a value for resistance how do you get the current.

**Student:** Oh \( V = IR \). 60 = \( I \) by 15. So 60/15 = \( I \) which is 4.

**Student writes:**

\[ V = IR \]
\[ 60 = I (15) \]
\[ 60/15 = I \]
\[ I = 4 \]

**Interviewer:** So if you were to get the current then through each individual resistor, what is it?

**Student:** Ammm.....

**Interviewer:** So coming into \( R_1 \) what’s the current?

**Student:** 4.

**Interviewer:** Then when it comes down here what happens?

**Student:** It splits, so it’s going to be 2.

**Interviewer:** So how would you find what the current through each of those resistors is?

**Student:** One over....I don’t know.

**Interviewer:** You can go on to the next bit then

**Student:** Voltage across each resistor. Oh, do \( V = IR \) for each resistor. So for \( R_1 \) \( I \) is 4 and \( R \) is 5. So voltage is.....I can’t even concentrate!

20. Voltage in \( R_1 \) is 20. For \( R_2 \), do it in the individual again?

**Student writes:**

\[ V = IR \]
\[ V = (4) (5) = 20 \]

**Interviewer:** Do you know anything about voltages across resistors in parallel? Is there any rule for currents and voltages across resistors in parallel?
Student: Probably is, I don’t know it.
Interviewer: You’re grand. So you’re getting mixed up when you get to the parallel side, you don’t know what to do there. So would you be confident about answering that question?
Student: No
Interviewer: No, what part?
Student: I know the formulas the $R_i$ in series and the $\frac{1}{\text{over}}$ but when it gets to the parallel, getting the voltage across the. And the current flow, I wouldn’t be able to do that.

In this example the student immediately seeks to identify the variable required – total resistance. The student then proceeds, without delay, to relate the variable to the required formula which is the key characteristic of this problem solving approach (Table 5.9). The student was successful in calculating the total resistance however finds difficulty in determining the current flowing through each resistor in the circuit. The student confuses current and voltage “The current flow….that’s $V_{\text{total}}$ isn’t it? $V_{\text{total}}$ has a similar formula to the resistance one…..in series its $V_1$….no its not…” and struggles to calculate the current. The student attempts to remember a formula for current and again reverts back to the variables and states that the total voltage is 60 V. This again is a key characteristic of the unstructured plug-and-chug problem solving approach. It was only through the help of the interviewer and the use of probing questions that led the student to the correct answer.

Memory-Based Approach

The following example represents a student (Student 1) using the memory-based approach to solve question 3 in interview 2. This question also contained a qualitative and quantitative aspect. The students’ solution to the quantitative aspect is given below.
Interview 2 - Question 6

Describe this circuit diagram? What does this it represent?
Discuss the flow of current in this diagram. How does this relate to Kirchhoff’s first Law?
What is Kirchhoff’s second law concerned with?
Calculate the current flowing through each branch.

Student 1

Student: Oh these are the ones with simultaneous equations. We do them every week with Joanne! Describe the circuit diagram. What does this represent? Oh ok, my circuit diagram I have voltmeter, 3 ohms, it breaks up, hang on. I don’t know how to explain this; I know how to do......if you give me the maths of the question.

Interviewer: Ok so you can......like.....

Student: I know we do simultaneous equations to figure out......see we have 1 circuit flowing like that, one long big circuit and then one little

Interviewer: You can write out the equations for those if you want to go ahead, if you think it will help you.

Student: Which way is current flow in this diagram....the current flows all around then it breaks....no hang on......Kirchhoff’s Law. I should know Kirchhoff’s Law. That’s the total resistance is equal to the....no......I can’t remember anything. I’m not going to attempt it because I know I’m only going to mess it up.

Interviewer: No, so maybe if we take the top loop, write down.....or even the outside loop, what would you write down for that loop? How would you go about writing the equation?

Student: AM.....for the first loop. I know its...15 volts. Oh god, this is terrible because I’m probably not learning anything but I go back and look at the previous ones. Just to get the starter. I know its....hang on......to get \(i_1\) and \(i_2\) and \(i_3\). You want to get one of them on their own. So you can fill it back into the equation to figure out the current....no, \(i_1\) would be the current. The current in the first loop and the second loop and the 3rd loop so it’s basically......
Interviewer: If you drew that out now would you be able to find the currents $i_1$, $i_2$ and $i_3$?

Student: I’d put....hang on......$i_1$, no...$i_1$ there, no....I’m lost again.

Interviewer: Remember I told you start at your battery and go from there. If you took one of the batteries.

Student: So go from the positive and go all the way back around. Hang on... is that right? No, What am I going to say, the current flowing, $i_1$ and $i_2$ is equal to.......33 volts....no hang on., I’m trying to find the current, I’m confused now. I know I use $V = IR$...I don’t know, I’m lost.

The student’s solution to this question represents all the key characteristics of the memory-based approach. Once the student reads the question she immediately recalls the method she used in the past “I know we do simultaneous equations to figure out.....see we have one circuit flowing like that, one long big circuit and then one little”. The student is aware that in order to solve this question she must find simultaneous equations however she is not able to recall the method in which to do so. The student then relates the variables to laws that she believes will solve the problem but is unable to remember the associated formulas. Also in line with the characteristics of this problem solving approach (Table 5.9) the students focuses on the variables and the diagram without making any connection to the concepts involved.

No Clear Approach

The final approach identified by Walsh and her research team is labelled “no clear approach”. Students who use this approach do not solve “the problem with any sort of strategy” (Walsh et al., p. 2007). The following example presents a student (student 2) using this approach to answer question 6 in the second interview.

Interview 2 – Question 6

This again is the question on Kirchhoff’s laws.

Student 2

Student: To work it out you just have to label them $i_1$, $i_2$ and $i_3$ in the flow of, whichever way the current is flowing.

Interviewer: Do you want to do that, can you do that?
Student:  
*Student draws out the diagram, identifying the small and big loop*

A small loop and a big loop.....15 goes to a 3 ohm resistor. And then there’s 18 volts......there’s a small loop and a big loop. So if we start off with the small loop and label the first resistor $i_1$ then going into the smaller loop call this one $i_2$ and then the $2^{nd}$ 3 ohm resistor $i_3$. One of the formulas is $i_1 = i_2 + i_3$. So to work out $V = RI$ put it into the Ohms Law equation so the first voltage is 15 volts, and that runs through the first resistor which is 3 by $i_1$ by the current......and then I get stuck there!

*Student writes:*

\[
\begin{align*}
    i_1 & = i_2 + i_3 \\
    V & = RI \\
    15V & = 3 \, (i_1) \ldots
\end{align*}
\]

Interviewer:  So you don’t know what do when you get out of that loop is it?

Student:  Yeah.

In this example the student is aware that she has to “label them $i_1$, $i_2$ and $i_3$ in the flow of, whichever way the current is flowing” however once she has carried out this step she does not know how to proceed. She does not even attempt to try and work out the solution to the question and simply gives up.

Following the analysis of the students’ and experts’ solutions to the problems and the assigning of categories of problem solving, the author was able to generate figures representing the students’ (Figure 7.8) and the experts’ (Figure 7.9) percentage score for each category. Again the students’ and experts’ scores are represented as a percentage to facilitate statistical analysis.
Figure 7.8: Students’ problem solving approaches in solving quantitative mathematical questions

Figure 7.9: Experts’ problem solving approaches in solving quantitative mathematical questions

To answer the research question set out at the beginning of this section statistical analysis was carried out to determine if there was a correlation between the interviewees’ proficiency in scientific language and their ability in problem solving using the Pearson’s correlation coefficient. Two sets of tests were carried out to test the strength of the relationships. The first concerned both the experts and the students as the data was grouped (Table 7.15, 7.16 and 7.17). The second
set of tests for correlation investigated the relationship between performance on
the physics word problems and the proficiency in scientific language for the
students only (Table 7.17, 7.18, 7.19). The sign in front of the \( r \) value indicates
whether there is a positive or negative correlation. The size of the value provides
information on the strength of the relationship. “A perfect correlation of 1 or -1
indicates that the value of one variable can be determined exactly by knowing the
value of the other variable. On the other hand, a correlation of 0 indicates no
relationship between the two variables” (Pallant, 2007, p.g.120).

Table 7.15: Correlations between proficiency in scientific language and problem solving
ability for the students and experts

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Pearson’s Correlation</th>
<th>Significance</th>
<th>Description</th>
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<td>Problem Scientific</td>
<td>( r = 0.32 )</td>
<td>( p = 0.23 )</td>
<td>Moderate positive correlation; not significant</td>
</tr>
<tr>
<td>Problem Structured</td>
<td>( r = -0.20 )</td>
<td>( p = 0.46 )</td>
<td>Weak negative correlation; not significant</td>
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</tr>
<tr>
<td>Problem Unstructured</td>
<td>( r = 0.26 )</td>
<td>( p = 0.34 )</td>
<td>Weak positive correlation; not significant</td>
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<tr>
<td>Problem Memory-Based</td>
<td>( r = -0.03 )</td>
<td>( p = 0.92 )</td>
<td>No relationship; not significant</td>
<td></td>
</tr>
<tr>
<td>Problem No Clear Approach</td>
<td>( r = -0.50 )</td>
<td>( p = 0.04 )</td>
<td>Strong negative correlation; significant</td>
<td></td>
</tr>
</tbody>
</table>

The relationships between scientific language and the five categories of problem
solving for students and experts grouped are represented in Table 7.15. From the
five tests carried out there is only one strong negative relationship, \( r = -0.50 \), \( n =
16, \ p < 0.05 \). This is between the variables scientific language and the problem
solving approach ‘no clear approach’ [problem no clear approach]. This is
represented in the following scatterplot (Figure 7.10). This scatterplot
succinctly indicates that a high percentage scored in problem solving using the
‘no clear approach’ relates to a low percent scored in using scientific language.
The green plots indicate the results of the experts and the blue represent the
students. It is clear from the graph that the experts achieved higher in the use of
scientific language and all but one expert did not demonstrate the use of the ‘no clear approach’ when problem solving.

**Figure 7.10:** Scatterplot of scientific language against the problem solving approach ‘no clear approach’ used in solving quantitative problems

The remaining correlation tests carried out using scientific language as a variable resulted in moderate, weak and no relationships with no statistically significant correlations recorded. Similar tests were carried out using intermediate and instinctive language (Table 7.16 and Table 7.17 respectively).
Table 7.16: Correlations between proficiency in intermediate language and problem solving ability for the students and experts

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Pearson’s Correlation</th>
<th>Significance</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Intermediate Language</strong></td>
<td>Problem Scientific</td>
<td>$r = 0.41$</td>
<td>$p = 0.12$</td>
<td>Moderate positive correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Structured</td>
<td>$r = -0.34$</td>
<td>$p = 0.20$</td>
<td>Moderate negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Unstructured</td>
<td>$r = 0.09$</td>
<td>$p = 0.73$</td>
<td>No relationship; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Memory-Based</td>
<td>$r = 0.06$</td>
<td>$p = 0.89$</td>
<td>No relationship; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem No Clear Approach</td>
<td>$r = -0.33$</td>
<td>$p = 0.22$</td>
<td>Moderate negative correlation; not significant</td>
</tr>
</tbody>
</table>

Table 7.17: Correlations between proficiency in instinctive language and problem solving ability for the students and experts

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Pearson’s Correlation</th>
<th>Significance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instinctive Language</strong></td>
<td>Problem Scientific</td>
<td>$r = -0.47$</td>
<td>$p = 0.10$</td>
<td>Moderate negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Structured</td>
<td>$r = 0.47$</td>
<td>$p = 0.07$</td>
<td>Moderate positive correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Unstructured</td>
<td>$r = -0.14$</td>
<td>$p = 0.61$</td>
<td>Weak negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Memory-Based</td>
<td>$r = -0.23$</td>
<td>$p = 0.40$</td>
<td>Weak negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem No Clear Approach</td>
<td>$r = 0.31$</td>
<td>$p = 0.26$</td>
<td>Moderate positive correlation; not significant</td>
</tr>
</tbody>
</table>

Both sets of results show that there were no statistically significant correlations found between both the intermediate and instinctive language and the five categories of problem solving. However, moderate and weak relationships are evident between certain variables. It must be noted that these correlation tests are carried out using a sample group of 16 participants and this small sample size will influence the statistical significance of the relationship greatly.
Correlations tests were also carried out on the data collected from the ten students only (Table 7.18, 7.19 and 7.20). This reduced the sample size further and consequently influenced the statistical significance of the relationships. However, for the small sample sizes moderate and strong relationships are evident. There are strong correlations between scientific language and both plug-and-chug approaches, suggesting a strong relationship between the variables.

Table 7.18: Correlations between proficiency in scientific language and problem solving ability for the students only

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Pearson's Correlation</th>
<th>Significance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Language</td>
<td>Problem Scientific</td>
<td>r = 0.47</td>
<td>p = 0.17</td>
<td>Moderate correlation; no significance</td>
</tr>
<tr>
<td></td>
<td>Problem Structured</td>
<td>r = -0.56</td>
<td>p = 0.09</td>
<td>Strong correlation; no significance</td>
</tr>
<tr>
<td></td>
<td>Problem Unstructured</td>
<td>r = 0.61</td>
<td>p = 0.06</td>
<td>Strong correlation; no significance</td>
</tr>
<tr>
<td></td>
<td>Problem Memory-Based</td>
<td>r = 0.08</td>
<td>p = 0.85</td>
<td>No relationship; no significance</td>
</tr>
<tr>
<td></td>
<td>Problem No Clear Approach</td>
<td>r = -0.59</td>
<td>p = 0.07</td>
<td>Strong correlation; no significance</td>
</tr>
</tbody>
</table>

For example a correlation test carried out between scientific language and the problem solving approach plug-and-chug structured resulted in a strong negative correlation, r = -0.559, (n = 10). This is to say that students scoring high in scientific language score less in using the problem solving approach ‘plug-and-chug structured’ (Figure 7.11).
The only strong positive correlation that was recorded using scientific language as the dependent variable was found when it was assessed against plug and chug unstructured ($r = 0.611; p > 0.05; n = 10$). This indicates that as the percentage achieved in scientific language increases, so too does the percentage increase for the problem solving approach plug and chug unstructured (Figure 7.12)

Figure 7.11: Scatterplot of scientific language against the problem solving approach ‘plug-and-chug structured’ for the students only.

Figure 7.12: Scatterplot of scientific language against the problem solving approach ‘plug-and-chug unstructured’ for the students only.
Table 7.19: Correlations between proficiency in intermediate language and problem solving ability for the students only

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Pearson’s Correlation</th>
<th>Significance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermediate Language</td>
<td>Problem Scientific</td>
<td>r = 0.12</td>
<td>p = 0.73</td>
<td>Weak positive correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Structured</td>
<td>r = -0.53</td>
<td>p = 0.11</td>
<td>Strong negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Unstructured</td>
<td>r = 0.48</td>
<td>p = 0.16</td>
<td>Moderate positive correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Memory-Based</td>
<td>r = 0.26</td>
<td>p = 0.47</td>
<td>Weak positive correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem No Clear Approach</td>
<td>r = -0.36</td>
<td>p = 0.31</td>
<td>Moderate negative correlation; not significant</td>
</tr>
</tbody>
</table>

Table 7.20: Correlations between proficiency in instinctive language and problem solving ability for the students only

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>Pearson’s Correlation</th>
<th>Significance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instinctive Language</td>
<td>Problem Scientific</td>
<td>r = -0.32</td>
<td>p = 0.37</td>
<td>Moderate negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Structured</td>
<td>r = 0.55</td>
<td>p = 0.10</td>
<td>Strong positive correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Unstructured</td>
<td>r = -0.56</td>
<td>p = 0.09</td>
<td>Strong negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem Memory-Based</td>
<td>r = -0.48</td>
<td>p = 0.16</td>
<td>Strong negative correlation; not significant</td>
</tr>
<tr>
<td></td>
<td>Problem No Clear Approach</td>
<td>r = 0.29</td>
<td>p = 0.42</td>
<td>Weak positive correlation; not significant</td>
</tr>
</tbody>
</table>

Summary of Findings

In order to answer this research question the work of Walsh et al., (2007) was used to categorise the students and experts approach to problem solving. These categories comprise of the scientific, plug-and-chug structured, plug-and-chug
unstructured, memory based and finally the no clear approach. These categories, together with the three categories of scientific language identified in section 7.4.3., were used to classify the solutions to the interview problems. Statistical analysis was carried out on the data collected to determine if there was any relationship between the proficiency in scientific language and problem solving ability. As the sample number of students in the analysis was small, the author initially grouped the experts and students together. A statistical significant correlation was found \((p = 0.04)\) between the percentage of scientific language used and the lowest category of problem solving – no clear approach. Participants who approached problem solving of mathematical questions using the no clear approach were seen to have lower levels of proficiency in scientific language. Following this, the author examined the correlations for the students alone (Table 7.18, 7.19 and 7.20). Although no significance was reported, strong relationships \((r > 0.5)\) were found in several cases for the small sample size.

7.4.6 Impact of the Lecturers use of Scientific Language and Problem Solving Skills on the Students

Research question addressed:

- In what way, if any, did the lecturer’s use of language and problem solving ability impact of the students’ proficiency in scientific language and problem solving ability?

7.4.6.1 Impact of the lecturers language

Given the previous findings the author examined if there was any relationship between the level of language used by the expert, who was lecturing the module, and the students’ proficiency in scientific language. Table 7.21 highlights the depth of language used by both parties.
Table 7.21: Levels of scientific language used by the students and the lecturer

<table>
<thead>
<tr>
<th>Student/Expert</th>
<th>Scientific (%)</th>
<th>Intermediate (%)</th>
<th>Instinctive (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>7.4</td>
<td>7.7</td>
</tr>
<tr>
<td>2</td>
<td>15.5</td>
<td>15.4</td>
<td>11.5</td>
</tr>
<tr>
<td>3</td>
<td>53.6</td>
<td>17.85</td>
<td>14.2</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>7.7</td>
<td>15.4</td>
</tr>
<tr>
<td>5</td>
<td>52</td>
<td>26</td>
<td>4.5</td>
</tr>
<tr>
<td>6</td>
<td>47.8</td>
<td>17.4</td>
<td>8.7</td>
</tr>
<tr>
<td>7</td>
<td>69.2</td>
<td>11.5</td>
<td>7.7</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>10.5</td>
<td>21.4</td>
</tr>
<tr>
<td>9</td>
<td>38.5</td>
<td>11.53</td>
<td>7.7</td>
</tr>
<tr>
<td>10</td>
<td>61.5</td>
<td>15.4</td>
<td>7.7</td>
</tr>
<tr>
<td>Lecturer</td>
<td><strong>64.3</strong></td>
<td><strong>28.6</strong></td>
<td><strong>3.5</strong></td>
</tr>
</tbody>
</table>

This table represents the percentages that each individual student (1-10) and the lecturer scored in the three categories of scientific language. The values for each participant do not add to 100% as the student or expert may have given the correct response to the subsidiary question and these were not included in the analysis.

The lecturer scored a percentage of 64.3% in scientific language; 28.6% in intermediate language and 3.5% in instinctive language. These values differ from the student average collected for each category (Table 7.22). However it is important to note that the lecturer did use all three levels of language when providing solutions to the qualitative word problems.

Table 7.22: Average levels of scientific language used by the students and the lecturer

<table>
<thead>
<tr>
<th>Student/Expert</th>
<th>Scientific (%)</th>
<th>Intermediate (%)</th>
<th>Instinctive (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Averages</td>
<td>48.8</td>
<td>14.06</td>
<td>10.65</td>
</tr>
<tr>
<td>Expert/ Lecturer</td>
<td><strong>64.3</strong></td>
<td><strong>28.6</strong></td>
<td><strong>3.5</strong></td>
</tr>
</tbody>
</table>
7.4.6.2 Impact of the lecturer’s problem solving ability

The analysis of the lecturer’s language led the author to examine more carefully the lecturer’s problem solving ability. Again a table was produced (Table 7.23) to display the percentages achieved by the ten students and the lecturer in each problem solving approach.

Table 7.23: Problem solving approaches used by the students and the lecturer

<table>
<thead>
<tr>
<th>Student/Expert</th>
<th>Scientific (%)</th>
<th>Plug &amp; Chug – Structured (%)</th>
<th>Plug &amp; Chug – Unstructured (%)</th>
<th>Memory Based (%)</th>
<th>No Clear Approach (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>40</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>0</td>
<td>60</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>25</td>
<td>50</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>33</td>
<td>16</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>25</td>
<td>75</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Expert/Lecturer</td>
<td>16</td>
<td>50</td>
<td>16</td>
<td>0</td>
<td>16</td>
</tr>
</tbody>
</table>

When solving the problems, the lecturer demonstrated four of the five approaches of problem solving when answering the mathematical questions. The lecturer did not utilise the memory based approach when problem solving. However, the interview did reveal that the lecturer demonstrated the no clear approach when answering a small proportion of the questions (16%). The averages calculated for the students indicate that 9.2% of the solutions to the mathematical questions recorded from the student interviews approached the question in a scientific manner; 56.6% of the questions were answered using the plug-and-chug method; 4% were attempted using the memory based approach and further 29.8% of the solutions represented no clear approach (Table 7.24).
Table 7.24: Average percentages of the problem solving approach used by the students and the lecturer

<table>
<thead>
<tr>
<th>Student/Expert</th>
<th>Scientific (%)</th>
<th>Plug &amp; Chug – Structured (%)</th>
<th>Plug &amp; Chug – Unstructured (%)</th>
<th>Memory Based (%)</th>
<th>No Clear Approach (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Averages</td>
<td>9.2</td>
<td>24.9</td>
<td>31.7</td>
<td>4</td>
<td>29.8</td>
</tr>
<tr>
<td>Expert/Lecturer</td>
<td>16</td>
<td>50</td>
<td>16</td>
<td>0</td>
<td>16</td>
</tr>
</tbody>
</table>

Summary of Findings
When the data from the ten students and the lecturer are compared one might assume that the proficiency of the lecturer’s language and their problem solving ability will have an impact on the students’ progress in both areas. The lecturer did use all levels of language throughout their problem solving during the interviews. With this, it is fair to say that the lecturer perhaps uses scientific, intermediate and instinctive language during their teaching.
### 7.5 Section B – Data collected from Questionnaires (Qualitative and Quantitative Data)

The results reported in this chapter refer to two questionnaires administered at the end of Phase 3 of the research. Both will be reported individually. The students completed the first questionnaire (post Concept Mapping questionnaire) on the final week of the research study, which questioned them on the use of concept mapping in the classroom. The second questionnaire (Post Teaching Practice) was completed by the students upon their return from teaching practice five months after the completion of the research study. The qualitative and quantitative data collected from two questionnaires focuses on key issues concerning the implementation and impact of Concept Mapping in a physics classroom and their affect, if any, on student learning. The following table represents the research aims, questions and method associated with this section of Phase 3.

**Table 7.25:** Summary of Research Questions, Research Methods and Analysis undertaken in Phase 3, Section B

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Phase 3 – Section B</th>
</tr>
</thead>
</table>
| **Research Question** | • What issues in relation to students’ attitudes and beliefs concerning concept mapping and the use of the tool in a science classroom come to light following a year’s experience of the tool?  
• Does having experience in concept mapping encourage pre-service teachers to use the tool in their own teaching? If so, in what aspect of teaching do they incorporate it into and what are their conceptions concerning Concept Mapping following its usage? |
| **Research Method** | • Questionnaire – both questionnaires were administered to the entire cohort of students, N = 77 following the research study. The first questionnaire was completed at the final stage of the research, whereas the second questionnaire was completed upon the students return from teaching practice. |
| **Analysis** | Quantitative – SPSS (Version 15) |
7.5.1 Student Profiles

The demographic profile of the students that completed the questionnaires is identical to those in Phase 2. 68% of the sample was female, with the remaining 32% of the cohort male. It was found that almost three quarters (~75%) of the students had not completed Leaving Certificate Physics prior to commencing this science degree. Table 7.26 represents the students grades achieved in the Leaving Certificate exam. All students that completed Physics at senior cycle sat the higher paper. It is important to note that these students are enrolled in a science education degree and will, in the future, be teaching the subject at least to junior level.

Table 7.26: Student grades achieved in the Leaving Certificate Physics Exam*

<table>
<thead>
<tr>
<th>Leaving Certificate Grade</th>
<th>Number of Students</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>5.9</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>17.6</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>2.9</td>
</tr>
<tr>
<td>Not Applicable</td>
<td>25</td>
<td>73.5</td>
</tr>
</tbody>
</table>

*Note: This data was generated from the Post Electricity and Magnetism questionnaire which received a response rate of 44% (n = 34)

The author also looked at the students’ grade in their previous physics module, Light and Sound (PH4202). The Physics Department exam results indicate that 3% of the cohort received an A grade, almost 30% were awarded a B, 42% were awarded a C, with the remaining 10%, 10% and 2% getting a D, and F grade respectively. This signifies that a large proportion of the students (75%) were awarded a C grade or over in their first year physics module.
7.5.2 Questionnaire 1 – Post Concept Mapping (Post Electricity and Magnetism Module)

The first questionnaire administered in Phase 3 to the students was done so during the final tutorial of the module, prior to the students completing their end of term exams. This questionnaire was similar to the one that the students received at the end of Phase 2 however it contained three sections; Personal Information, Concept Mapping and the Impact of Concept Mapping. The consequence of giving this questionnaire on the last day of the semester resulted in a forty-four percent (n = 34) completion rate. This would have had an impact on the data collected as almost half of the group were missing.

As mentioned above the aim of this questionnaire was to generate data concerning the students’ attitudes and beliefs concerning the Concept Mapping tool and its use in the classroom. This is discussed in full as it is a key research question set out in Phase 3.

7.5.2.1 Students’ attitudes and beliefs concerning Concept Mapping and the use of the tool in the science classroom

Research question addressed:

- What issues in relation to students’ attitudes and beliefs concerning Concept Mapping and the use of the tool in a science classroom come to light following analysis of the quantitative data?

The second and third part of the questionnaire questioned the students on Concept Mapping and the impact it had, if any, on their learning of physics in the classroom following a year-long experience of the tool. This section of the chapter examines the results of each of the questions asked. The majority of the questions asked in the second part of the questionnaire were qualitative in nature and will be represented in this way.
Students Attitudes towards Physics

Similar to Phase 2 the students were asked how they ‘felt’ about physics after completing the module. The students were asked whether or not their attitude towards physics has improved, disimproved or remained unchanged as a result of the teaching and learning associated with the module. Following their experience of the tool twenty students (59%) stated that their attitude towards physics improved, with three (8%) stating it disimproved and eleven students (33%) identifying that their attitude remained unchanged. All the students who stated their attitude disimproved had not studied physics at Leaving Certificate level and from the students who believed their attitude remained unchanged, only one had studied physics at Leaving Certificate.

The student cohort was also asked to respond to an open ended question which asked them: After completing this Physics module, how do you feel about Physics in general? Both positive and negative results were recorded and are reported here. A recurring issue that emerged from the negative comments is that students did not enjoy or succeed well in physics due to the perception that it contains a lot of mathematics and those who are poor at maths with undoubtedly be poor at physics. From the thirty-four questionnaires collected; twenty students had positive comments to say about physics following their experience. A representative of each is listed below.

Positive

- “Better than last year, glad I kept it on” (Male, did not do Physics for the Leaving Certificate)
- “Fine, more confident towards teaching the subject” (Male, did do physics for the Leaving Certificate)
- “I feel that physics is manageable” (Male, did not do Physics for the Leaving Certificate)
- “Its getting easier to understand” (Male, did not do Physics for the Leaving Certificate)
- “Confident” (Female, did do Physics for the Leaving Certificate)
• “I feel I understand it compared to last year” (Female, did not do Physics for the Leaving Certificate)

Negative
• “I still find physics difficult to understand and work through” (Female, did not do Physics for the Leaving Certificate)
• “I still dislike physics but that’s coz I dislike maths” (Female, did not do Physics for the Leaving Certificate)
• “I don’t have a very positive attitude towards it, not very mathematical minded so find it hard to understand” (Female, did not do Physics for the Leaving Certificate)
• “I still dislike it and I think it is boring” (Female, did not do Physics for the Leaving Certificate)
• “Still hard, glad to be getting rid of it” (Female, did not do Physics for the Leaving Certificate)

Concept Mapping in the Physics Classroom
The author also examined the students’ perceptions of the Concept Mapping tool and its use in the classroom. Question 8 in the questionnaire asked “Do you feel that Concept Mapping is beneficial in the Physics classroom? This again was an open-ended question which resulted in very positive comments. From the 34 student questionnaires only one negative comment was recorded and this student felt “it has no real benefit”. A variety of the positive comments are listed below and it is visible that the majority of the students saw Concept Mapping as a beneficial tool. The student responses to this question are both from the point of view of a student and a pre-service science teacher.

Positive:
“Yeah it connects prior and new knowledge”
“Yes it reminds you of the formulas and relationships you know”
“Definitely – it provides a summary that’s easy to read”
“Yes – they are good visual aids”
“Yes as it lets you know how much you do know off hand and what sections you need to learn more about”

“Yes it helps piece all the concepts together and make sense of them”

“Yes – to gather your thoughts/ideas on the topic”

“Yes, it would help fond out what students don’t know”

Impact of Concept Mapping on Teaching and Learning

The third and final part of the first questionnaire questioned the students on the impact Concept Mapping had, if any, on their learning (Figure 7.13). This question consisted of nine statements assessing students’ beliefs about the tool and its affect in learning physics using a Likert scale. Respondents were asked to indicate their level of agreement with each item: SD = strongly disagree, D = disagree, U = unsure, SA = strongly agree, A= agree.

**Figure 7.13:** Student responses to the effect on Concept Mapping on their learning of Physics

Figure 7.13 clearly indicates that students believed that the construction of concept maps helped them in all situations in the classroom. Seventy-three percent (73%) of the students agreed that they understood the theory easier after constructing concept maps. 85.3% agreed that they were able to link prior and
new knowledge as a result of the concept mapping tool with 91.2% agreeing (strongly agree or agree) that the concept mapping tool allowed them to summarise material efficiently.

The author also compared the students’ end of semester grade in three modules, the module taken before experience of Concept Mapping (Mechanics, PH4101) and the two modules involved in the research study. This was carried out to determine if there was an increase in the students’ overall grade following experience of the tool. The following graph (Figure 7.14) shows the percentage of students awarded each grade in all three modules.

![Figure 7.14: Student end of term exam grades in a module preceding the use of Concept Mapping and two modules which incorporated Concept Mapping](image)

Statistical analysis was carried out on end of term exam results collected from sixty-nine students as these were present at all exams. This was carried out to determine if there was a significant difference between the student scores. Paired samples t-tests were used to test for significant differences on average between the two exams scores. A 5% level of significance was used for all tests. The t-test examined the difference in mean values of performance of students after no
exposure to Concept Mapping (Mechanics module) and after one semester (Light and Sound module) experience. There was no statistical difference on average between these two exam results \( (p > 0.05) \).

Following from this a second paired-sample t-test was conducted to evaluate the impact of a full year of experience of Concept Mapping on the students’ grades. There was a statistically significant difference on average in the students’ end of term grades from their first module (Mechanics with no Concept Mapping) \( (M = 54.95, SD = 13.15) \) to their final module (Electricity and Magnetism with a year experience of Concept Mapping) \( (M = 66.54, SD = 10.74) \), \( t (68) = -8.512, p <0.0005 \). As there were no control group used in this study one cannot assume that the concept maps alone caused the students to achieve better grades.

**Summary of Findings**

The research question posed in this section is very broad as it deals with the students attitudes towards Concept Mapping but also its use in the classroom. The results indicate that twenty students (59%) believed their attitude towards physics improved. The remaining believed that their attitudes remained the same (33%; \( n = 11 \)) or disimproved (8%; \( n = 3 \)). The students who felt their attitude disimproved all made reference to another physics module they were completing at the time, implying that it was that module that was affecting their attitude.

With regard to the students' opinions of the use of the tool in the classroom, the majority of student responses were very positive; signifying that they believe the tool is appropriate and useful in the physics classroom. Seventy-three per cent (73%) of the students agreed that they understood the theory easier after constructing concept maps with 85.3% agreeing that they were able to link prior and new knowledge as a result of the concept mapping tool. These are very significant as the tool aids the students in the underlying principles that are crucial in understanding physics.

Finally, to determine if the Concept Mapping tool had an impact on the student performance in exams paired sample t-tests were carried out on exam results from sixty-nine students. These were students that completed the end of term
exams for all three modules – Mechanics, Light and Sound, and Electricity and Magnetism. A statistically significant difference was found between the results from the module without Concept Mapping (Mechanics) and results of the final module which contained exposure to the Concept Mapping tool. As there were no control group used in this study one cannot assume that the concept maps alone caused the students to achieve better results, however the students mean results increased significantly following experience of the tool.

7.5.3 Questionnaire 2 – Post Teaching Practice

As mentioned previously the author administered a second and final questionnaire to the students in Phase 3 following their return from a six week teaching practice block. This was carried out in order to answer the final research question in the quantitative study.

Research question addressed:

- Does having experience in Concept Mapping encourage pre-service teachers to use the tool in their own teaching? If so, in what aspect of teaching do they incorporate it into and what are their conceptions concerning concept mapping following its usage?

The students were queried on their use of Concept Mapping during teaching practice and asked to comment further on the use of the tool in the classroom. Fifty-three students completed the questionnaire (68% response rate).

7.5.3.1 Students’ use of the Concept Mapping tool during their own Teaching

From the cohort of students who completed the post teaching practice questionnaire sixty-four per cent (64.2%) of the students used the tool during their 6-week teaching practice in some way. Those who used the tool incorporated it into the assessment and instruction elements of teaching and learning (Figure 7.15) with almost twenty per cent (18.9%) of the group using the tool in both aspects of their teaching.
7.5.3.2 Pre-service science teachers’ conception of Concept Mapping

As Concept Mapping is recognised as a teaching tool and the group of students involved in this research study are pre-service science teachers, the author felt it was appropriate and important to evaluate the tool from the point of view of a pre-service science teacher. Question 9 of the questionnaire asked those who used the concept mapping tool in their teaching if they believed that it was a “good teaching tool?” From the 64.2% of the students that used it, 58.5% of the students believed it was a viable tool for the science classroom.

The final question in this questionnaire focused heavily on the pre-service teacher’s conceptions of Concept Mapping and its use in the classroom. This question consisted of nine statements assessing their beliefs about the tool and its implementation in the classroom again using a Likert scale. Respondents were asked to indicate their level of agreement with each item: SD = strongly disagree, D = disagree, U = unsure, SA = strongly agree, A= agree.
The results presented in Figure 7.16 signify that the pre-service teachers valued Concept Mapping as a teaching tool. The responses to the use of tool in the science classroom and the benefits of the concept mapping were very positive. 83% of the sample *strongly agreed* or *agreed* that it is a ‘valuable tool in the teaching of science’, with 79.2% *strongly agreeing* or *agreeing* that it can be used at all levels of teaching.

81% of the sample *agreed* that this tool should be incorporated into the training of all student teachers. A small percentage (3.8%) *disagreed* that it should be taught with 15.1% unsure. In regard to the implementation of the tool, the student teachers expressed mixed opinions on the amount of time required to train students how to use the tool. 39.5% *disagreed* that concept mapping requires a large amount of training, 39.6% *agreed* and the remaining 20.8% were *unsure* of the amount of time it would take to train students how to construct and use concept maps.

The five remaining statements in this question were concerned with applications of the tool; highlight areas of difficulty, highlight what you know, represent what you know, revising content and its use in brainstorming new material. A significant percentage of the student teachers (>73%) *agreed* and *strongly agreed* with all these statements thus confirming the benefits of concept mapping in the science classroom.
Summary of Findings

As the cohort of students involved in this research study was enrolled in a teacher training course, it was fitting to evaluate the tool from a teacher’s perspective as well as that of a student. Having returned from a six week teaching practice block the pre-service science teachers were asked to comment of the use of the tool within the science classroom and report any findings they may have following usage of the tool. A total of 64% of the student cohort stated that they used the tool during their teaching practice. Those that did use the tool reported that they believed the tool to be very useful as both an instructional and assessment tool. The teachers also agreed that it is a valuable teaching tool and argued that it should be included into the teacher training course as a teaching methodology.

Figure 7.16: Pre-service science teachers opinion of Concept Mapping as a teaching tool
Chapter 8

Discussion and Conclusion

8.1 Introduction

In this chapter the author will first present a summary of the procedures involved in the research and an outline of the purpose of the study. This will then be followed by a detailed account of the main conclusions from the research which will be presented in reference to individual themes identified through the research questions set out for each Phase (Section 6.3, 7.4 and 7.5). The data generated from Phase 1 and Phase 2 (Chapter 6) and Phase 3 (Chapter 7) forms the basis of these conclusions. The contribution that this research has made both nationally and internationally in the field on physics education will then be discussed and evaluated. The thesis concludes by offering recommendations and possible directions which future research may take which are proposed on the basis of the outcomes of this study and the findings in the literature.

8.2 Summary of Procedures

As stated earlier, this research project examines the use of Concept Mapping in third level science education and also investigates its role in exploring the use of scientific language and problem solving ability of second year pre-service science teachers. Prior to data collection a comprehensive review of the literature on Irish students’ participation in the physical science was undertaken. This review indicated the low number of students opting to study physics in second level and subsequently third level education. An in-depth examination of the Concept Mapping literature was undertaken to establish an understanding of the tool and its use in education since its development in the early 1970’s. A critique of the literature highlighted the diverse uses of Concept Mapping within the classroom, both in their use as a tool involved in assessment and instruction. Following from the literature review, a pilot study was developed to examine the feasibility of using the tool within an Irish university. This Phase (Section 5.12.1) provided essential feedback concerning the potential use of the tool in third level classrooms in Ireland and as a result the research was developed further and
Phase 2 (Section 5.12.2) commenced the following spring (academic year 06/07). A subsequent review of the literature highlighted the lack of research into the use of scientific language and the relationship between students’ use of language and problem solving ability in the classroom. This area was identified as a significant area of research because the students involved in this study were enrolled in an education course and would be teaching science in second level classrooms in the future. The complex nature and characteristics associated with Concept Mapping permitted the author to further extend the research to evaluate this, leading to Phase 3 (Section 5.12.3). This extension study involved further analysis of the Concept Mapping tool as well as the students’ considerations of the benefits of the tool in their own teaching. Within both Phases a combination of qualitative and quantitative methods were used to examine the research questions.

The population in this research study was a cohort of physics undergraduate students at the University of Limerick in their first year of study in the year 2006. The participants in the study were enrolled in either a biological science or a physical science four year concurrent teaching degree. The sample consisted of 88 students in total at the commencement of Phase 2; however, due to non-completion this number reduced to 77 at the end of data collection in Phase 3.

At each Phase data was collected from the students using concept maps, questionnaires and semi-structured interviews. To facilitate appropriate analysis of the concept maps, a total of twenty students were chosen to be involved in the data analysis in Phase 2, with the entire cohort involved in the analysis of the use of the tool in the classroom. The data analysed and reported in Phase 3 of the result was that from 10 students and 6 experts who took part in the semi-structured interviews. This allowed for the analysis of students’ problem solving ability and use of scientific language. Similar to Phase 2 the data collected from the entire cohort was used in the evaluation of the tool and their use during their own teaching experience. The concept maps collected were analysed using a criterion map developed by the author specifically for the module in question. The data generated from the questionnaires (3 in total) was coded and inputted in SPSS for analysis.
8.3 Purpose of the Study

The aim of this research was initially to introduce Concept Mapping into a third level physics classroom and to identify its benefits, if any, to students’ attitudes towards the subject and also their learning of physics. Following from the analysis of this stage of the research (Phase 1 and Phase 2) the author developed the study further to utilise the tool to examine students’ use of scientific language. Specific research objectives and questions guided the research study, which are detailed in the methodology and results chapters.

8.4 Summary of Findings and Conclusions Related to each Phase and Research Question

An analysis of the research questions highlights overlapping themes that are present within all three Phases. The conclusions drawn from these research questions will be presented according to the following themes:

- Students’ Initial View of Concept Mapping
- Concept Mapping and the Learning of Physics
- The training of Concept Mapping
- Concept Mapping and affect it has on students’ attitudes towards Physics and their learning of Physics
- Concept Mapping as an assessment tool
- Levels of Scientific Language
- Language used by an expert and a novice
- Effect of proficiency in language on problem solving ability
- Effect of lecturers’ language on students’ use of language
- Use of Concept Mapping following the intervention period
8.5 Summary of Findings from Phase 1

8.5.1 Students’ Initial Conception of Concept Mapping

International studies (Moneira, 1985; Adamczyk and Willson, 1996; Santhanam et al., 1998; Quinn et al., 2004; Hay et al., 2008) indicate that Concept Mapping is a widely used tool for many purposes in many different contexts in universities and third level education, however to date no research has been carried out on the use of the tool in an Irish setting.

As mentioned above the objective of Phase 1 was to introduce Concept Mapping into physics classrooms in the University of Limerick and to test its feasibility while also determining how Irish students would respond to the tool and its related tasks. The students were asked to construct individual maps at two stages during term one. The maps collected indicated that this proved very difficult for them. The level of training the students received was not adequate to teach them the process of constructing concept maps. This was a key finding from the pilot study which informed the subsequent Phases of the results. Following the construction of the second map the author questioned the students briefly on the tool and asked whether or not they enjoyed constructing them. Irrespective of the students’ ability in constructing the maps they responded very positively toward the use of the concept maps and did not hesitate to construct them. The students did try their best when drawing the maps and this was evident during the construction as they spent the allocated time drawing and re-examining their maps.

The fact that the students did not receive a large amount of training on the tool was subsequently found to have a significant effect on the success of its implementation. Research carried out detailing suitable methods of introducing Concept Mapping have found that the training session and introduction is of vital importance and its significance cannot by ignored. Santhanam, Leach and Dawson (1998) believe that the introduction can affect both the students’ and teacher’s acceptance of the strategy and therefore consideration must be allocated to the correct introduction of the tool. This issue is discussed in detail later in the
chapter as it relates specifically to another research question that the author set out to examine in Phase 2 of the study (Section 8.6.2).

**8.6 Summary of Findings from Phase 2**

**8.6.1 Concept Mapping and Learning of Physics**

Phase 2 Q1: How do concept map scores correlate with progression though a specified module?

The student concept maps represented varying levels of sophistication, together with the number of concepts included, links involved and the linking phrases used to show the relationships between concepts. The low level of direction provided the students with more opportunities to reveal their understanding of the key term (Ruiz-Primo *et al.*, 2001). As the students constructed maps on the same topic throughout the course of the module, a comparison of them enabled the author to measure the student’s progress or quality of learning. Research on measures of student learning using Concept Mapping is very novel and hence limited. However, research carried out by Hay (2007) provided a framework to measure the quality of change that has taken place over time. Using the framework, the maps constructed by the twenty students in this research study represent meaningful learning. According to Hay this is defined by the introduction of new concepts together with prior understanding, meaningful linking of new to prior knowledge and an overall improvement of the maps, both in its organisation and inclusion of richer connections (Hay, 2007, p.43).

In order to examine the students’ maps and allocate a score to them the author incorporated a scoring system that she felt best suited the research questions set out at the onset of the research, which were, amongst others, to introduce the tool and examine if they represent the progression of students’ understanding throughout a teaching term. The use of the tool as an instrument for assessment is dealt with later in the chapter (Section 8.6.4).

To determine and measure the students’ change in understanding across the 12-week teaching block a method of identifying this change at different intervals
within the time span was put in place. This was similar to research carried out by Osmundson et al., (1999) in which they employed knowledge maps as “a repeated measure to capture the ongoing development of ideas” (p.1). Comparable work was carried out by Meagher in 2009 where concept maps were also collected three times during the semester to examine students’ progression of understanding. In keeping with the constructivist recommendations to determine the prior knowledge of a student and teach from there, the students constructed a map on the second week of teaching. At this stage the students had received very little instruction on the topic. The author used this open-ended form of assessment in an effort to give the students the freedom to include the concepts and propositions they are comfortable with and to allow the author to identify their understanding, prior to instruction. Such a method is consistent with the work carried out by Hoz et al., 1997 (Cited in Stoddart et al., 2000, p. 1222). To assess the depth of the students’ understanding and development of ideas at stages throughout instruction, a criterion map was developed by the author. This was used to “emphasise the use of accurate relationships in deriving scores” (Rye and Rubba, 2002, p.33). Ruiz-Primo and Shavelson (1996) reviewed and examined twenty-one research studies that used concept maps to assess learning and found that the majority employed an expert or criterion map to do so. This method was favoured as it focused more on the “adequacy of the propositions” than simply the number of map components (Ruiz-Primo and Shavelson, 1996, p.595). This is in conflict with the work carried out by Novak and Gowin (1984) that scored maps using a point system where points were given for specific elements in the map. The criterion map included fifty-three propositions in total, specific to the aims and objectives identified in the module outline. The student concept maps were then assessed by calculating the proportion of scientifically accurate propositions to the propositions that were present in the criterion map.

The student scores (Table 6.3) identify the improvement of their understanding and their inclusion of new propositions from map 1 (week 2 of instruction) to map 3 (week 11 of instruction). The module the students were enrolled in included material on Light and Sound, however, the concept maps the students constructed only dealt with Light. The average score for map 1, 2 and 3 are
9.88%, 16.01% and 34.85% respectively. The maps show an improvement in the broadening of the students’ knowledge base from map 1 to map 3.

Research studies in the past that examine the use of concept maps in improving students understanding have compared the participants understanding in both an experimental group (experience with concept maps) and a control (no experience with concept maps). Zieneddine and El-Khalick (2001), in their research, report that the students that “received pre- and post laboratory concept maps achieved higher scores on their conceptual understanding test than those who did not construct such maps” (pp. 504 – 505). Similar research was carried out by Heinze-Fry and Novak (1990) in which twenty students volunteered to participate in a new learning strategy, namely Concept Mapping. These students received training on the tool and constructed individual maps on biology concepts and also participated in clinical interviews. The results indicated that the students that participated in Concept Mapping “showed higher mean scores” (p.468) in their multiple choice and interview data.

The data collected from this research and results gathered from previous published studies indicate that experience of Concept Mapping can improve students understanding of scientific topics. The students in this study received an intensive training session and experienced continued use of the tool throughout the duration of the module. Students received instruction on areas including sound and light; however, only their understanding of light was measured using Concept Mapping.

8.6.2 The Training of Concept Mapping

Phase 2 Q2: What elements are essential for the training of undergraduate physics students in Concept Mapping, as seen by the students?

The aim of this phase of study (Phase 2) was to decipher second year students’ opinion of the tool and their conceptions of Physics following experience of it. With this in mind the training focused on developing the students’ understanding of Concept Mapping while also helping students construct the maps themselves, without assistance from the teacher. Within the research presented in this thesis
the author designed the training session to last one hour. The author felt that this time would be appropriate as the students were undergraduate level and previous research reports that college students can learn to construct a simple concept map in a single 50-minute class period (Wallace, Mintzes and Markham, 1992). Analysis of the student responses to the post-questionnaire confirms that one hour is sufficient time to train undergraduate students on the method of constructing concept maps. From the total number of students that were present at the training session and that completed the questionnaire almost 95% of them believed the time spent on training was sufficient. Research carried out by Hay, Kinchin and Lygo-Baker (2008) supports this as they reported that Concept Mapping can be taught in 10-20 minutes, with a further 20-30 minutes required to construct a map. Using this time frame, they suggest that Concept Mapping training will fit into a 50-minute teaching session. Stoddart et al., (2000) also recognised the importance of appropriate training time and advocated that “anything less than 45 minute training session is probably inadequate” (p.1227). Most research studies suggest similar timing however some studies allocated longer time to training (Santhanam, Leach and Dawson, 1998; Chiou, 2008).

The individual components of the training session were also assessed using a post questionnaire. Five individual techniques were included in the training session in Phase 2, including definitions of the individual components of the map; individual, group and class construction of a concept map; the use of non-related topics to introduce the mapping technique and finally a classroom discussion on the task and its requirements. These elements were analysed to determine if the students felt they were required and necessary to train undergraduate students in the construction of concept maps. The findings suggest that the students believed all five elements of the session to be important. Almost 69% of the student cohort believed the class construction of a map was important (important and very important). Similar data was collected for the remaining components; PowerPoint presentation (63.5%), Individual construction of maps (61.7%), group construction of the map (61.9%) and finally the use of non-physics topics when drawing initial maps (57.2%). This latter component received the lowest percentage of importance; however research findings suggest that as the technique of Concept Mapping is often novel to students and should
be introduced using familiar concepts (Edwards and Fraser, 1983; Taber, 1994; Novak and Cañas, 2006). It is also important to point out that, although the students believed the PowerPoint presentation was not as important as the class construction of a concept map, it was the only feature of the training session which received no percentage in the “not important” category. This suggests that it is an essential element of the training session as the students must receive information on the individual aspects of the maps. The presentation also included information regarding the advantages of the tool and step-by-step guides on how to develop maps.

The majority of training methods are grounded on and are consistent with the work of Novak and Gowin (1984) and White and Gunstone (1992). Both studies emphasise the importance of the specific elements of the map, namely the concept, linking line, linking phrase, proposition and cross-link. In order to fully explain these components and their importance to the Concept Mapping task, several approaches are utilised to help students grasp their meaning. These include initial definitions of terms, constructing maps in groups and individually, comparison of concept maps to a written paragraph and finally group discussions on the task. Many researchers (Edwards and Fraser, 1983; Heinze-Fry and Novak, 1990; Rice, Ryan and Samson, 1998; Romance and Vitale, 1999; Zieneddine and El-Khalick, 2001; Chiou, 2008) amongst others describe the distinguishing features included in their training session. Within each study significant and repeated elements were identified. With all new teaching approaches it is necessary for both the teachers and students to be familiar with its method prior to using it in the classroom. It was essential that the students were confident in constructing the maps prior to administering an assessment activity (Stoddart et al., 2000). This is very important as students that lack confidence in their ability to construct maps often do not use the tool appropriately (Briscoe and LaMaster, 1991). To ensure the students were comfortable in using the tool, the author developed an intensive training course which was consistent with the procedures of Novak and Gowin (1984). The training session can take many shapes as each research study sets out to answer different research questions, however good instruction on the tool will ensure
that students as young as six years of age could construct a concept map (Novak, Gowin and Johansen, 1983).

8.6.3 Concept Mapping and the effect it has on Student Attitudes towards Physics and their Learning of Physics

Phase 2 Q.3: Does experience of Concept Mapping improve students’ attitudes towards Physics and what issues concerning the use of the tool are identified after one semester’s experience?

Phase 3 Q.5: What issues in relation to students’ attitudes and beliefs concerning concept mapping and the use of the tool in a science classroom come to light following a year’s experience of it?

The author assessed the effect of Concept Mapping on the students’ attitudes of Physics at the end of both Phases of research. Therefore it is appropriate to discuss the findings together in the discussion. Both of these questions focus on the effect of Concept Mapping on the students’ attitudes towards physics and also the students’ attitudes towards the Concept Mapping tool. As students attitudes can have an impact on learning and uptake of a subject, science teachers are interested in developing and sustaining positive attitudes towards science. The students in this research study were asked to reveal their beliefs about the use of Concept Mapping and its benefits in the physics classroom through the use of a questionnaire. The results obtained are consistent with preceding studies which examined the use of concept maps, with a large majority of the students indicating that they found the technique useful and contributed positively to their learning of the subject (Table 8.1). This table, generated from results displayed in Section 7.5.2.1, represents the percentage at which the students agreed (agree and strongly agree) that Concept Mapping has being attributed to improving their learning of physics, at the end of Phases 2 and 3 of the research study.
Table 8.1: Science students’ perceptions of Concept Mapping following Phase 2 and Phase 3 of the research study

<table>
<thead>
<tr>
<th>Do you feel by constructing Concept Maps that you are able to:</th>
<th>‘agree’ and ‘strongly agree’ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 2 (N = 63)</td>
</tr>
<tr>
<td>Understand theory easier</td>
<td>77.8</td>
</tr>
<tr>
<td>Identify physics concepts</td>
<td>77.7</td>
</tr>
<tr>
<td>Link prior to new knowledge</td>
<td>85.8</td>
</tr>
<tr>
<td>Answer problems more easily</td>
<td>57.1</td>
</tr>
<tr>
<td>Summarise material efficiently</td>
<td>84.1</td>
</tr>
<tr>
<td>Represent knowledge clearly in good English</td>
<td>84.1</td>
</tr>
<tr>
<td>Organise your knowledge into general and specific domains</td>
<td>74.6</td>
</tr>
<tr>
<td>Identify misconceptions more easily</td>
<td>50.8</td>
</tr>
<tr>
<td>Make valid connections among concepts</td>
<td>85.8</td>
</tr>
</tbody>
</table>

It is clear from the table above that several elements concerning their benefits remained constant following the initial use of the tool (Phase 2). This suggests that the students developed a stable opinion of the tool from their initial experience. From the nine statements questioned two saw a reduction in the number of students who agreed with them following Phase 3, namely ‘understand theory easier’ and ‘identify physics concepts’. The author suggests that this may be due to the content the students were studying. In Phase 2 the students were enrolled in the Light and Sound module and in Phase 3 the students had progressed into the Electricity and Magnetism module. A large body of research reports that electricity is a topic that students struggle with and have difficulty in understanding (Engelhardt and Beichner, 2004). Also, due to the timing of the administering and collection of the questionnaires, a large proportion of the students were missing and unable to complete the task. This may have affected the results.

Research studies in the past have documented the advantages of Concept Mapping as perceived by the researchers (Bascones and Novak, 1985; Sizmur and Osborne, 1997); however there has been very little attention to the use of the tool as perceived by the students. A notable exception to this is the work of Santhanam et al., (1998) and Zieneddine and Abd-El-Khalick (2001) where the
students’ views of Concept Mapping were examined through the use of questionnaires.

The work of Zieneddine and Abd-El-Khalick (2001) assessed and examined physics students’ perceptions of the tool as a teaching approach in the laboratory. Four benefits of the tool were highlighted during interviews. Firstly, the students noted that the tool helped them to organise their knowledge into a hierarchical structure. Secondly, the students revealed that Concept Mapping helped them to identify concept relationships within their experiments. Thirdly, the students noted that the instructional tool helped them to prepare for the experiments as it helped them focus on the key concepts. Finally, the students declared that the technique helped them develop a better understanding of the physics concepts (pp. 507 – 508).

These results are echoed in the findings of Santhanam et al., (1998); however a more in-depth analysis of the students’ perceptions of the tool is undertaken. This research focused on the views of science and agricultural science students who were enrolled in a genetics module. Based on the findings, the students viewed Concept Mapping as a valuable tool with almost 33% agreeing that the technique ‘encouraged thinking more deeply’ and 50% agreeing that the tool ‘helped in understanding relationships between concepts’ (Santhanam et al., 1998, p.323) following two cycles during which they used concept maps.

Students’ attitudes towards physics were also examined through the use of the end of Phase questionnaire. Research literature suggests that attitudes are formed from three components including a “cluster of feelings, likes and dislikes, behavioural intentions, thoughts and ideas” (Hogg and Vaughan, 2008, p. 150) and attitudes, once formed, are difficult to change. Attitudes, however, are developed in response to an object (Eagly and Chaiken, 1993) and in order to measure one’s attitude towards an object or event, verbalisations of feelings and emotions are used (Reid and Skryania, 2002). Numerous reports confirm that positive attitudes towards science peak at early second level education and decline dramatically thereafter (Hadden and Johnstone, 1983; Breakwell and Breadsell, 1992). This suggests that students’ experience of second level
education has a detrimental effect on students’ attitudes towards science and science subjects. Following from this, one can assume that students in a first year undergraduate course will have a diminished positive attitude towards science.

Concept Mapping was introduced in this research study in an effort to improve students’ attitude and opinion of physics. Irish students perceive physics as a subject that is loaded with content and as a result is dull and boring. This perception perhaps is one of the reasons students are opting not to study the subject and as a result few third level students graduate with a specialism in Physics. Little research has been carried out in this area as the majority of the studies assess students’ attitudes towards Concept Mapping rather than assessing the students’ attitudes towards the subject as a result of the tool. Again the students were asked to reflect on their attitude towards physics at two distinct intervals during the research study, at the end of Phase 2 and at the end of Phase 3. Table 8.2 illustrates the students’ change in attitude towards physics at both stages. This table was again generated from results presented in section 7.5.2.1 however the focus here is their change in attitude over time.

Table 8.2: Students change in attitude following experience of Concept Mapping, at the end of Phase 2 and end of Phase 3

<table>
<thead>
<tr>
<th>Effect of Concept Mapping on students’ attitudes towards physics</th>
<th>‘agree’ and ‘strongly agree’ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 2 (N = 63)</td>
</tr>
<tr>
<td>Improved</td>
<td>61.9</td>
</tr>
<tr>
<td>Disimproved</td>
<td>7.9</td>
</tr>
<tr>
<td>Remained unchanged</td>
<td>30.2</td>
</tr>
</tbody>
</table>

These results correlate with findings from the studies that do assess the relationship between the use of Concept Mapping and improved attitudes towards the subject (Novak and Gowin, 1984; Mason, 1992). Almost 62% of the student cohort agreed that their attitude towards Physics improved following experience with the Concept Mapping tool. These research findings confirm the benefits of using concept maps. The approach, which is grounded in the
constructivist view, promotes positive attitudes towards the subjects in addition to improving students’ knowledge base (Karenauskaitė and Katiliūtė, 2007).

8.6.4 Concept Mapping as an Assessment Tool

Phase 2 Q.4: Are concept maps valid assessment tools in third level education?

In the study presented in this thesis the author utilised a criterion map together with a three-point coding system to score the students’ self-constructed concept maps. This method of assessment was developed to assess the knowledge and comprehension levels of the individual students and the scores were based on the correctness of the propositions. This scoring method is a distinct shift from the traditional methods of scoring that focus on characteristics including levels of hierarchy, presence of crosslink’s and number of propositions (Novak and Gowin, 1984). The assessment task that was provided by the author was one of low direction which allowed the students to include as many concepts as they wished, while also including linking words that they generated and perceived as appropriate to represent the relationship between the associated concepts. As different techniques used across the level of directness (Figure 3.2) provide different information about the students’ understanding, it was essential to provide an open-ended task to allow students to represent their understanding of the concepts without any constraints. Variations of this approach are evident in the literature. Barenholz and Tamir (1992) asked the students to select their own concepts and construct a map in microbiology. However, the scoring system was different to the one used in this study as they scored the maps on the number of map components. Stoddart, Abrams, Gasper and Canaday (2000) also provided the students with an open-ended task regarding the construction of a concept map on the topic of marine science. Their scoring system differed to the one in this research also as the reviewers analysed the students’ use of vocabulary and content using a rubric.

As indicated in the methodology chapter, in Phase 2 the maps from twenty students were chosen to provide data on the use of the tool as an assessment
instrument. The maps developed by each student were scored for proposition correctness and recorded (Table 6.3). Correlation tests on the students’ map scores and the end of term exams were carried out to determine if there was any relationship between the grade the students achieved at the end of term exam and their concept maps. This test was carried out to test the validity of the tool as an assessment instrument in third level education.

Research results from this study resemble the findings of Novak, Gowin and Johansen (1983). Pearson’s correlation coefficient was used to measure the strength of the association between map results and end of term results. No statistically significant correlations were found but the correlation between the final map (map 3) and the end of term results was a moderate, negative one ($r = -0.38$). This indicates that as the scores in map 3 increase, end of semester results tend to decrease. This perhaps indicates that the end of term exam assess something different to what is assessed in concept maps. Similar results are reported in a studied carried out in Turkey (Ingeç, 2008) where pre-service science teachers were asked to construct maps on the physics concepts momentum and impulse. These maps were analysed using five different scoring methods, namely the holistic scoring method, the relational scoring method, the structural scoring method, the Novak and Gowin scoring method and finally the Ünlü-Ingeç-Taşar scoring method (Ingeç, 2008). Correlation tests between the achievement test scores and the concept map scores from the five different scoring methods resulted in statistically significant but weak relations between them. Ingeç attributes this to fact that the “concept map assesses the students’ knowledge from a conceptual perspective while the achievement tests measure the level of the students’ knowledge on the topic and his/her ability to apply this knowledge on different occasions” (Ingeç, 2008, p.13). Previous research provides conflicting evidence on the validity and reliability of Concept Mapping as an assessment tool. Novak, Gowin and Johansen, (1983) reported relatively low correlations between concept map scores and other measures of achievement, including final course grades. Rice, Ryan and Samson (1998) on the other hand, recorded high correlations between concept map scores and unit multiple choice tests and standardised tests, both state and national.
8.7 Summary of Findings from Phase 3

The author also investigated the students’ proficiency in scientific language and problem solving ability. The following themes, and associated research question discussed, encompass these investigations where the author combines the findings from her study with previous research studies to provide a clear overview of pre-service science teachers’ proficiency in scientific language and problem solving ability. The author also examines if there is a relationship between the lecturer’s use of language and that of the students.

8.7.1 Levels of Scientific Language

Phase 3 Q. 1: Can solutions to theoretical qualitative physics problems be categorised into levels of scientific language? If so how many categories of language are used when solving physics problems and what are the characteristics of each category?

Following from the success of the Concept Mapping tool in the physics classroom at third level the author set out to utilise the maps to generate physics problems. This was carried out so as to facilitate the author in identifying the students’ use of language when problem solving. The author believes that the level of scientific language used by the pre-service science teachers is very important since it is these students who will progress into the science classrooms in second level schools.

An analysis of the students’ solutions to the qualitative problems allowed the author to categorise the students’ use of scientific language into three levels, namely scientific, intermediate and instinctive. Each category holds specific characteristics defined by the students’ ability to explain a physical phenomenon. The students that expressed the use of scientific language during problem solving used concise, accurate and clear language to represent their understanding, similar to that of the criterion reference books. These students identified the concepts involved in the problem and showed a clear understanding when describing the theory associated with the concept. Students that used
intermediate language when problem solving used language that was not scientific, however, their language correctly explains the concept or phenomenon involved in the question. This language represents some level of understanding and signifies influence of education. The final and third level of language that formed a category was that of instinctive language. This language resembles colloquial, everyday language. The interviewees whose language falls into this category used language that one would expect prior to any formal instruction on the concept or topic.

In total, the language used by ten students was analysed. The results indicated that all ten students used the three levels of scientific language when solving the qualitative problems. On average, 48.8% of the language used during problem solving was scientific, 14.1% was intermediate and 10.6% was instinctive. These values do not sum to 100% as the students may have not answered the subsidiary questions correctly or perhaps did not attempt the question.

In the past studies have focused on students’ understanding and use of non-technical words in the science classroom. These studies (Marshall and Gilmour, 1991; Pickersgill and Lock, 1991) resulted in very interesting findings which suggest that students are confused and struggle with the use of non-technical words in the classroom. However this is not the focus for this research. The aim of Phase 3 of the research study was to identify pre-service science teachers use of scientific language when problem solving. For the purposes of this research the author views the term ‘scientific language’ as the best collection of words that represents and explains scientific ideas and concepts. It is important to identify the students’ use of language because it is through the medium of language that humans communicate their understanding and it allows teachers “assess and promote students’ learning of science” (Fang, 2005, p.345).

A review of the literature provides little research of this nature. Past researchers (Wellington and Osborne, 2001) have categorised words in the scientific language into three groups namely scientific, semi-scientific and non-technical. These categories focus specifically on the words; however, the research presented in this thesis focuses on the students’ use of combined words (similar
to that of propositions in a concept map) to represent their understanding and hence looks at their use of scientific language when solving problems. The author set out to identify the pre-service science teachers’ use of language so as to appreciate their level of understanding of the science concepts. This is especially important as these pre-service science teachers will be entering into classrooms to teach second level school students science in a little over a year from the date the data was collected. As new ideas in science are presented through the use of new language (Brown and Ryoo, 2008), if pre-service science teachers are not using scientific language they run the risk of presenting information and science concepts using the incorrect words and terminology.

8.7.2 Language used by an Expert and an Novice

Phase 3 Q. 2: Is there a significant difference in the level of language used by experts and students when problem solving?

The results found in this research study indicate that there is no statistically significant difference between the language used by the students and experts when problem solving. All ten students and five of the six experts utilised the three levels of language when solving the qualitative problem. From the six experts only one did not use any instinctive language when solving the problems. Even though there was no statistical difference in the use of language used by the experts and students some differences did occur. More than 60% of the language used by four of the six ‘experts’ to answer the qualitative questions was scientific language. In contrast only two students used scientific language more than 60% of the time. Also every student used instinctive language when answering the qualitative questions. However, five of the experts used instinctive language during problem solving. The data collected from the experts provides strong evidence to suggest that they use very little instinctive language when explaining their understanding of their physical concepts.

Research studies detailing the differences between a novice and an expert are extensive. Many reoccurring issues arise from these studies which together report the main differences between the two groups in education and educational
settings. Key factors including the level of domain specific knowledge, problem solving approaches and organisation of the knowledge structure distinguish novices apart from experts (Priest and Lindsay, 1992; Sweller, 1988; Chi, Glaser and Rees, 1982; Chi, Feltovich and Glaser, 1981; Larkin et al., 1980). Within this research the pre-service teachers are identified as the novice as they are new to the scientific language and concepts under examination. On the other hand the experts are those who have experience with the concepts and scientific language as they are postgraduate students and lecturers in the field. Despite the large volume of research publications that report the differences in novice and expert problem solving approaches and knowledge structure very little research has examined the differences in the language used by experts and novices when solving qualitative problems.

As mentioned above there is a copious amount of literature available regarding the problem solving ability of the novice and expert. Both groups continue along a distinctive path when solving a problem, which in essence, indicates whether they are a novice or an expert in the area. A study carried out by Muir et al., (2008) reported that behaviours identified when problem solving can be categorised into three categories as the categories ‘expert’ and ‘novice’ were not adequate to describe the range of behaviours. To resolve this problem they identified three categories – naïve, routine and sophisticated. With this they developed a problem solving continuum which highlighted eight themes that were common to the individual approaches (Muir et al., 2008, p. 230). One of the eight themes related to communication. Differences between the three approaches to problem solving were recorded where students approaching the problems in a naïve manner did so with inadequate written communication. This improved where students utilised a routine approach, however, students who were categorised as using the sophisticated approach “scored highly for both written and verbal communication” (p.230).
8.7.3 Proficiency in Language and Problem Solving Ability

Phase 3 Q. 3: Is performance in physics word problems affected by the level of scientific language proficiency?

Findings from the student and expert problem solving interviews indicated that both groups used different strategies when problem solving. For the students one approach was dominant over the others – the plug and chug approach. This is consistent with previous research carried out by Walsh et al., (2007) in DIT. Two aspects of the plug-and-chug approach exist, that which is structured and unstructured. There are slight differences between the two. Students that represent the structured approach evaluate the problem initially by stating the formulae that are required to solve the problem, relate the concepts to the variables and then identify the target variable. In contrast, students demonstrating the unstructured approach concentrate solely on the unknown variable (Walsh et al., 2007). All ten students utilised the plug and chug structured approach when problem solving, however for the majority of the students this was only the case for one or two of the questions. The plug and chug unstructured approach was used more frequently during the second interview. The questions asked during this interview included questions concerning Kirchhoff’s Laws, capacitance and resistance. Disappointingly, students used the ‘no clear approach’ when answering a large portion of the questions in the second interview. The least used approach was the memory based approach, with only two students demonstrating it when solving a problem. On the other hand, the problem solving approaches used by the experts represented better planning and understanding of the concepts as they related the concepts to the problem. All experts exercised the scientific and the plug and chug structured approach when solving the six quantitative problems. One expert however did demonstrate the use of the no-clear approach when answering two of the mathematical questions asked in the second interview.

Analysis of the problem solving approaches and the participants’ use of scientific language allowed the author to determine if there was any relationship between their proficiency in scientific language and their problem solving ability. Two
sets of tests were carried out to test the strength of the relationships. The first concerned both the experts and the students as the data was grouped (Table 7.14, 7.15 and 7.16). The second set of tests for correlation investigated the relationship between performance on the physics word problems and the proficiency in scientific language for the students only (Table 7.17, 7.18, 7.19). The analysis of the data collected concerning both the experts and students indicate that there is a relationship between the proficiency in language and problem solving. A strong negative relationship was recorded between the variables scientific language and the ‘no clear approach’ \( (r = -.50, n = 16, p = 0.04) \). This suggests that a high percentage scored in the ‘no clear approach’ category, relates to a low percentage scored in using scientific language, therefore as the percentage in scientific language increased the percentage scored in the ‘no clear approach’ decreased. This suggests that problem solvers with high proficiency in scientific language do not use the ‘no clear approach’ when problem solving.

Conflicting results were found when the students’ results were analysed individually. Although the sample size was reduced \((n = 10)\) moderate and strong relationships are record. There are strong correlations between scientific language and both plug-and-chug approaches, suggesting a strong relationship between the variables. A strong negative correlation was found between the use of scientific language and the problem solving approach ‘plug and chug structured’. This finding indicates that as scientific language increases the percentage scored in the problem solving approach plug and chug structured decreases. A positive correlation was recorded for the third category of problem solving and scientific language \((r = 0.611; p > 0.05; n = 10)\). This implies that as the percentage achieved in scientific language increases, so too does the percentage increase for the problem solving approach plug and chug unstructured. An extensive review of the literature to examine if research was carried out on the effect of proficiency of language on problem solving ability proved unsuccessful. Surprisingly the use of language as a factor in the quality of students’ problem solving ability is a rare focus in science education research.
The analysis of the data collected demonstrates that pre-service science teachers’ performance on mathematical quantitative problems is related to their linguistic proficiency in science. This is the first investigation that examines the impact and effect proficiency in scientific language can have on problem solving approaches. Although work has been carried out in areas regarding knowledge domain and the types of questions asked, the author was unable to locate any research that examined the effect of language on problem solving.

8.7.4 Effect of the Lecturer Language on Students’ use of Language

Phase 3 Q. 4: In what way, if any, did the lecturer’s use of language and problem solving ability impact of the students’ proficiency in scientific language and problem solving ability?

An analysis of the findings of Phase 3 demonstrates that the language used by the teacher and the student varies. When the students’ average scores for the three levels of language were calculated, the students used scientific language 48.8%, intermediate language 14.06% and instinctive language 10.65% when conveying their solutions to the qualitative word problems. This compares to the lecturer’s use of language where she used scientific language 64.3% in her solutions, 28.6% of the problem solutions was conveyed through intermediate language and a further 3.5% of the solutions was expressed using instinctive language.

Similar findings were recorded when the lecturer’s and students’ problem solving approaches were compared. For the five problem solving approaches, scientific, plug and chug unstructured, plug and chug structured, memory based and no clear approach; the lecturer demonstrated the use of four of them. Sixteen percent (16%) of the lecturer’s solutions demonstrated the use of the scientific problem solving approach, 50% was that of the plug and chug structured approach, 16% of the unstructured approach and finally 16% represented the use of the ‘no clear approach’. The students however demonstrated the use of all five problem solving approaches with almost 30% of the solutions representing the ‘no clear approach’. 
These findings have significant implications for the classroom as the majority of talk in the classroom comprises of teacher talk. The prevalence and prominence of teachers’ classroom talk must, undoubtedly, impact on the students’ learning (Oyoo, 2005). Past research confirms that there is a relationship between teachers’ language and students’ conceptions (Zeidler and Lederman, 1989). Ziedler and Lederman (1989) reported that the “implicit conceptions of the nature of science”, revealed through the teachers’ language are conveyed to the students (p.775). The research continues to suggest that scientific phenomenon must be described using specific comments rather than “commonsensical everyday comments” as without precise language students may form misunderstandings of the physical laws, theories and phenomena (Zeidler and Lederman, p.777). The significance of these findings outlined above lies in the development of pre-service teacher training. Teacher training not only should emphasise the teaching of subject matter and teaching behaviours, but should also highlight how to convey the subject matter through precise scientific language.

8.7.5 Use of Concept Mapping Following the Intervention Period

Phase 3 Q. 6: Does having experience in concept mapping encourage pre-service teachers to use the tool in their own teaching? If so, in what aspect of teaching do they incorporate it and what are their conceptions concerning concept mapping following its usage?

The findings of Phase 3 of this research study clearly demonstrate that Concept Mapping is perceived by pre-service teachers as a functional tool in the classroom. The analysis of the final questionnaire administered to the pre-service teachers revealed that 64.2% (n = 33) of the student cohort used the Concept Mapping tool during their own teaching practice. The majority of the students (51%, n = 27) used the tool for instructional purposes, with 32% (n = 17) using it for assessment.

An analysis of the pre-service students’ perception of Concept Mapping from a teacher’s perspective proved insightful and encouraging. A myriad of positive
comments were documented, reinforcing the pre-service teachers’ approval of the tool and its use in the classroom. The value of the tool, as perceived by the pre-service teachers during their teaching practice was also very reassuring. There exists a strong belief among the pre-service teachers that Concept Mapping is a viable tool in the science classroom. In total 64.2% (n = 33) of the student cohort used the tool during teaching practice, and from this 58.5% (n = 31) believed it to be a ‘good’ tool in the classroom. The following table, generated from results displayed in Section 7.5.3, represents the percentages at which the students agreed (agree and strongly agree) on various uses of Concept Mapping in the science classroom.

**Table 8.3**: Pre-service teachers agreement with the elements of Concept Mapping as viewed following use of the tool in their own teaching

<table>
<thead>
<tr>
<th>Do you feel by constructing Concept Mapping:</th>
<th>‘agree’ and ‘strongly agree’ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requires a large amount of training</td>
<td>39.6</td>
</tr>
<tr>
<td>Is a valuable tool in teaching science</td>
<td>83</td>
</tr>
<tr>
<td>Can be used at all levels of teaching</td>
<td>79.2</td>
</tr>
<tr>
<td>Is a good method for revising content</td>
<td>88.7</td>
</tr>
<tr>
<td>Is a good method for brainstorming new material</td>
<td>82.7</td>
</tr>
<tr>
<td>Should be taught to science student teachers during the degree course as an extra teaching tool</td>
<td>81.2</td>
</tr>
<tr>
<td>Can be incorporated easily into science teaching</td>
<td>83.2</td>
</tr>
<tr>
<td>Is a good tool to represent what you know</td>
<td>94.4</td>
</tr>
<tr>
<td>Is a good tool to highlight the areas where you are having difficulty with in a subject</td>
<td>81.1</td>
</tr>
</tbody>
</table>

These results suggest that the pre-service science teachers view the tool as an extremely valuable (83%, n = 44) one, that is very fitting in the science classroom. These findings provide support for the use of the tool in third level, especially in education courses where the students can develop the tool within their own teaching following the completion of the course.

As discussed in chapter 3 of this thesis Concept Mapping has been incorporated into pre-service teacher training (Adamczyk and Willson, 1996; Colli *et al.*, 2004) however literature is sparse on the use of the tool after the intervention period. One such study that did evaluate the use of Concept Mapping following
an intervention period was carried out by Santhanam, Leach and Dawson (1998) in Australia. Although this study was not carried out with pre-service science teachers, the researchers did evaluate their science students’ retrospective views of the Concept Mapping tool two years after they first experienced it. During interviews the students were asked to comment on whether they incorporated Concept Mapping into their own study strategies. The main reason for not doing so was because the students admitted they had “already developed their (learning) strategies prior to university entry, and they found it difficult to adopt a new technique” (Santhanam, Leach and Dawson, 1998, p. 323). Nonetheless, approximately half the students did acknowledge that they changed their study habits since their introduction to Concept Mapping.

The research findings presented in this section confirm the value, usefulness and ease of use of Concept Mapping in the science classroom, as reported by practicing teachers. A little over 80% of the pre-service teachers felt that this tool should be included in their teacher training course due to its numerous benefits such as their use in brainstorming ideas, revising content, highlighting student difficulties and their misconceptions. This research is the first insight into the experience of Concept Mapping as seen by both pre-service students and practicing teachers.

8.8 Significant Overall Conclusions

The original intention of using a Concept Mapping teaching and learning strategy in the research project was to introduce an action research project to promote students’ interests and positive attitudes towards physics. Although the samples of students examined in detail in this project are relatively small from which to draw generalisable conclusions the author feels that they are reflective of the situation that currently exists in third level education in Ireland. Thus, the significant overall conclusions emerging from the research undertaken include:

- Student participation in the science subjects is declining. Ireland is struggling with the low number of students studying the physical science subjects in second level and subsequently third level
education. Factors affecting subject choice include poor attitudes towards the subjects and the subject teacher.

- Students reacted very positively to Concept Mapping. Irish third level students responded very positively to the introduction of the Concept Mapping tool in their physics lessons. The majority of the undergraduate students reported that the tool was very useful in their learning of physics and aided them in understanding physics concepts and linking prior and new knowledge. This study is the first to investigate the use of Concept Mapping in Irish third level education, however the results are consistent with those prevalent in the existing literature (e.g. Novak and Gowin, 1984; Santhanam et al., 1998).

- The training of Concept Mapping is of vital importance for the successful completion of student concept maps. Students need to be confident in constructing the maps before any data is collected for research purposes. There are several components essential for the training of Concept Mapping, as seen by the students, which include practicing constructing maps and time for questioning.

- The investigation provides a comprehensive insight into the effect the Concept Mapping tool has on students’ attitudes towards Physics. Following Phase 2 and Phase 3 research findings support the use of the tool in improving students’ positive attitudes towards Physics. Little research internationally has examined the use of the tool in improving the students’ attitudes towards the subject. Instead the existing literature focuses on the attitudes towards the tool.

- A key issue relating to Concept Mapping also emerged from Phase 2 which investigated the use of the tool for assessment. Research findings suggest that concept maps should be used carefully for assessment purposes. No correlations were measured between the students’ final exam grades and concept maps grades and this perhaps
indicates that they are both assessing something different. These findings are consistent with those of Novak and Gowin (1984) and many other researchers in the field of Concept Mapping.

• One of the key issues that emerged from the third phase of this research was the levels of scientific language that are found when students problem solve and the relationship between proficiency in scientific language and problem solving. When solving qualitative word problems three levels of language were identified; scientific, intermediate and instinctive. Pre-service science and physics teachers demonstrated the use of all three levels of language when solving quantitative problems. Further research findings indicated that proficiency in scientific language affects students’ problem solving ability.

• When solving mathematical problems the dominant problem solving approach used by pre-service science teachers is the plug-and-chug approach (Walsh et al., 2007). This has significant implications for the teaching and learning involved in teacher training courses.

• Experience of Concept Mapping in third level education can have an impact in secondary school teaching. Pre-service science teachers’ positive experience of the tool during their degree encouraged them to utilise the tool during their own teaching. Accordingly, the pre-service teachers reported that Concept Mapping has a place in teacher training courses as a result of its many benefits in the classroom.

8.9 Contribution to Research
The significance of this study arises from the design, implementation and evaluation of this action research study which utilised Concept Mapping in third level physics education. The contributions to research which resulted from this thesis are presented in a principal/subsidiary manner where the principal contributions are followed by the subsidiary contributions. The findings add to
the national and international knowledge base by confirming information consistent with the literature and in some cases providing new insights into the teaching and learning of physics and the use of concept maps in third level education.

- The first principal contribution of this thesis is a theoretical contribution which refers to the examination of students’ scientific language and its effect on problem solving ability. This research has determined empirically that proficiency in scientific language can effect students’ ability to problem solve physics quantitative problems. This is the first study of its kind that examines the use of language used by pre-service science teachers when engaged in problem solving. The research findings facilitate a better understanding of factors that effect students’ capacities to problem solve. Significant research questions have arisen from the research study which will need to be addressed in further research.

- The second principal contribution is the development of a unique mixed-methods action research study to develop the use of Concept Mapping in third level education. The author adapted research tools and frameworks from educational research to advance our knowledge and understanding of Concept Mapping and its use in third level education settings. These include Novak and Gowin’s Concept Mapping tool (1984), the Newman Research Method (1977) and Walsh et al., (2007) categories of problem solving approaches. The author’s research highlights the value of the tool for the purposes of pre-service science teachers. The research demonstrates that the presence and use of Concept Mapping throughout teacher training can have positive influences in second level science classrooms and teaching and thus contributes to the body of knowledge of Concept Mapping and teacher training.

- A key subsidiary contribution that developed from these research findings is the utilisation of Concept Mapping in improving students’ attitudes towards physics. From the students involved in the research 58.8% of the
cohort agreed that their attitude toward Physics improved. Thus, Concept Mapping can contribute to teaching and learning practices where it can be implemented both as a pedagogical and a promotional tool.

- A subsidiary research contribution relates to the development of Concept Mapping as an assessment tool. An adaptation of existing scoring systems was implemented in this research study to assess students’ concept maps. In combining different assessment procedures the author has developed a new evaluation approach for the evaluation and scoring of concept maps. The findings presented in this thesis indicate that there is little association between the students’ end of term exam scores and their concept map scores. These results, together with existing literature, signify that this issue promises to be a very fruitful area of further research.

### 8.10 Limitations of the Study

The limitations in this research study, which could not be controlled by the author, are in connection with the methodology chosen and design of the project. The use of action research, questionnaires and semi-structured interviews set parameters on the interpretation of the results and consequently affected the validity of this research study. This research study was descriptive in nature and did not employ the use of a control. This is a limitation often associated with action research. A further limitation of this study is that the research was restricted to one group of students (N = 88) within one university in Ireland. Small groups of students and experts were utilised for the interviews in Phase 3. The author is aware of this limitation but believes this to be compensated by the wealth of data provided by both groups.

Another limitation developed from the use of different interviewers when carrying out the semi-structured interviews. Although all interviewers were provided with detailed information on how to carry out the interviews in an appropriate manner, ensuring that the interviews were carried out using a consistent and standardised approach to increase validity (Fraenkel & Wallen,
2003), differences in questioning styles and approaches may have affected the students’ responses and subsequently the validity of the interviews.

The response rate to the questionnaire administered to the pre-service teachers following the Electricity and Magnetism questionnaire was low. A response rate of 44% was achieved and therefore it is difficult to generalise the results from these students. This may imply that the findings may not be representative of all the students studying the module, and that those present on the day the questionnaire was administered may have different opinions than their peers that did not attend.

8.11 Recommendations

A number of recommendations have emerged from the findings of this research study.

- Research results from Phase 2 and Phase 3 highlight the positive influence of Concept Mapping on students’ learning of Physics and their attitude towards the subject. At a time, where participation rates in the physical sciences is extremely low, the author believes that Concept Mapping should be brought to the attention of all science teachers, at all levels of education in order to improve students attitudes towards science subjects and aid meaningful learning. She recommends that this be achieved through teacher training, both pre-service and in-service.

- The author strongly recommends that efforts are made to alter the teaching of science subjects in education. Concept Mapping represents the relationships between scientific concepts and this is an area of difficulty for many students. Also the use of the tool as an advance organiser proved beneficial to the students within this research study, both in the role of a student of that of a practicing teacher. The advance organiser allowed them to identify the concepts under discussion in the classroom and the upcoming lessons.
• Problem solving ability is affected by proficiency in scientific language. Therefore it is important to identify students’ proficiency in scientific language, as to ensure that teaching practices and strategies used in the classroom are designed to cater for the students’ learning needs.

8.12 Future Research

Following analysis of the research questions set out in this research study, subsequent issues have been identified that require further investigation.

• The research presented in this thesis focuses on the use of Concept Mapping in the Physics classroom. The author however believes that the Concept Mapping approach is extremely flexible and lends itself to applications in other science subjects. Future research on the effect of the tool on Chemistry and Biology pre-service teachers’ attitudes and conceptions is possible.

• There are several issues related to the students use of scientific language when problems solving which were raised from this research study that require further research. A more in-depth analysis and understanding of pre-service science and physics teachers approach to problem solving is necessary as well as further investigations in the area of scientific language and the use of Concept Mapping in representing it. Further research is necessary to explore the levels of scientific language outlined in this thesis and to investigate if the list is exhaustive. Additional research is also required to examine fully the relationship between increased sophistication of scientific language and problem solving ability.

• This research study was carried out on a group of science education students, however a similar study using non-education students is warranted to examine the use of Concept Mapping and their affect on non – education students’ attitudes towards science subjects and their opinions of the tool.
• Research findings from Phase 3 of this study indicate that the use of scientific language is a key factor that affects students capabilities to problem solve. A more in-depth analysis of students’ problem solving solutions is required to determine other significant factors that may influence students’ problem solving approaches and success of completion.

• The findings presented in this thesis indicate that there is little association between the students’ end of term exam scores and their concept map scores. These results, together with existing literature, signify that this issue promises to be a very fruitful area of further research.
References


Bryman, A. (2006) 'Intergrating quantitative and qualitative research: how is it done?', *Qualitative Research, 6*(1), 97-113.


Good, T.L. and Brophy, J.E. (1990) *Educational Psychology, A Realistic Approach*, 4th ed...


Rice, D. and Corboy, M. (1995) 'Elementary Science Instruction: Are teachers prepared to teach what their students must master?', Annual Meeting of the


List of Publications and Presentations


