CHAPTER 1

AN INTRODUCTION TO THIS INVESTIGATION

1.1 INTRODUCTION

Science education researchers have long been exploring how students develop conceptual knowledge and scientific reasoning skills, and have recognised a gap, of varying dimension, between what students are taught, what they learn, and how they can demonstrate that learning. Van Heuvelen (1999:88) proposed a model of physics education with three components:

1. the characterisation of the learner's initial state of particularly defined conceptual understanding;
2. the characterisation of the desired final understanding (as agreed by identified experts); and
3. the development of effective curricula and teaching strategies to maximise the developmental change for all students.

This model informed the initial design of this project, which was: to explore pre-service teachers' understanding of fundamental concepts associated with electricity and magnetism; and to develop a differentiated learning sequence to enhance their knowledge and ability to teach the concepts. The modelling of the pedagogy associated with the learning sequence was evaluated from a traditional assessment-based perspective, and in terms of the enhancement of pre-service teachers' perceptions of their confidence to teach fundamental electricity and magnetism concepts.

Electricity, magnetism and their interactions underpin modern society in terms of the provision of energy for most household and industry applications. An implication of the prevalence of electricity in our daily lives unfortunately also contributes to the injury and death of many young people. In a study of childhood electrocution cases in Australia and the United States over a forty-year period, Byard and his colleagues identified that childhood deaths due to electrocution are:

> *…more likely to occur when children are playing around electrical wires or equipment, and often result from either faulty apparatus, or a lack of understanding of the potential dangers involved. The majority of deaths (69%) occur in the home environment.* (Byard *et al.* 2003:48)

In this introductory chapter of the dissertation, I present the issues pertinent to this research project. The next section describes my personal reasons for conducting this research. Then I outline and discuss the context of this study within the larger framework of K-6 pre-service teacher preparation with an emphasis on science. Subsequent sections present the reasons why I chose the topics of fundamental electricity and magnetism. The chapter concludes with the presentation and discussion of the research questions and the road map for the rest of the dissertation.

1.2 FACTORS THAT INITIATED THE PROJECT

A teaching career that spanned more than thirty years enabled me to observe and promote effective school science teaching strategies. During my teaching career, there has been a significant move away from traditional transmissive pedagogies to more student-centred, inquiry-based approaches. These latter approaches were espoused by authorities and supported by educational research.

I taught in a range of schools and progressed through the Australian secondary (Years 7 to 10) school education system positions from assistant teacher to head teacher, consultant, and principal. After retiring, perhaps as a consequence of my diverse experience, I accepted a position as a lecturer with the Science Education Team at the University of New England (UNE). In this role, I enjoyed sharing my ideas and experiences about science teaching with pre-service teachers. Informal discussions revealed that most felt reluctant to teach science because of their personal perception of a lack of science content knowledge. Common emergent themes stated as reasons for this lack of knowledge included: 'boring teaching', 'lack of relevance to their interest as students' and the common belief that science was 'too hard' for them. The pre-service teachers also cited a lack of knowledge about specific teaching strategies that they could draw upon to effectively teach science. Many stated they would probably simply resort to transmissive pedagogies with which they felt safe and familiar, having personally endured them for the most part of their school science learning experience.

These concerns about the teaching of science sparked my interest into commencing an investigation into how these perceptions, and the consequent trepidation to teach science, could be addressed. I discussed this with my professional colleagues in schools and with the science teaching team at UNE. These conversations, and a review of the literature, reinforced my personal observations that, in the early years of schooling, the teaching of science is 'poor' or largely avoided (Angus, Olney & Ainley 2007; Appleton 2002; Goodrum, Hackling & Rennie 2001; Thomson *et al.* 2008).

To clarify and discuss the situation further, I facilitated, as part of my science method classes (n = 115), peer group discussions with second-year pre-service K-6 (Kindergarten to Year 6) teachers who were undertaking a mandatory one semester unit that covered both content and pedagogy. These discussions revealed:

1. more than 80% did not have a strong background in science having not undertaken any post-compulsory (beyond Year 10 (approximately 14-16 years of age) science study;
2. a strong background in science was essential to teach science effectively; and
3. as a consequence of their perceived lack of the necessary background content knowledge, they lack confidence in their ability to teach science, even at the K-6 level.

While the students acknowledged the need to know some fundamental science concepts, they also suggested that their knowledge had not reached the desired level after at least eleven years of compulsory school education, so the 50 or so hours available to them in their science method study would not greatly add to their overall level of understanding.

In Australia, K-6 teachers are usually required to teach across on average six different Key Learning Areas (KLAs) within the context of specified outcome statements and suggested timeframes. For example, in New South Wales it is recommended that each KLA has a specific proportion class time allocated to achieving the syllabus aims (refer to Table 1.1).

Key Learning Area	**Proportion of Class Time**
English	25% - 35%
Mathematics	20%
Science and Technology	6% -10%
Human Society and its Environment	6% -10%
Personal Development, Health and Physical Education	6% -10%
Creative and Practical Arts	6% -10%
Additional Activities	Up to 20%

Table 1.1: NSW Guidelines for proportion of time attributed to each KLA (BoS NSW 2010:1)

The recent emphasis by the New South Wales Department of Education and Training (NSW DET 2010) to link science studies with other KLAs in what are known as 'Connected Outcomes Groups' affirms teacher perceptions that science is not an important school subject. This is confirmed by the findings of Laidlaw, Taylor and

Fletcher (2009), who in a survey of both pre-service and in-service K-6 teachers, found that they ranked science as fifth out of the six most important of the DET NSW KLAs.

Consideration of policy and the literature led me to further discussions with experienced primary and secondary science teachers that explored and supported the notion that limited opportunity to study fundamental science concepts at a K-6 level may translate to the observed limited interest in the study of science beyond the compulsory years of schooling. These discussions reinforced the concerns raised by students in my classes as it became apparent that practising K-6 teachers held similar views to the students, despite the opportunities to engage in professional development espousing modern pedagogies. Further, the disjoint between the concept of teaching science between K-6 (primary) and 7-12 (secondary) teachers has resulted in K-6 teachers absolving themselves of their responsibility to teach science, a notion based on lack of personal science knowledge, and resources.

1.3 SITUATING THIS STUDY IN THE AUSTRALIAN LITERATURE

Discussions with my professional colleagues guided me toward a number of recent Australian reports on the standing of science education (Ainley, Kos & Nicholas 2008; Goodrum & Rennie 2007; Kang 2007; Lyons & Quinn 2010; Masters 2009; MCEETYA 2005; National Research Council (NRC) 2005; NSW DET 2005; Tytler 2007). An emergent common theme was that the performance of students in science, particularly K-6 students, is not at a level that is desirable. Riess (2000:327) encapsulates the impact of this evolving situation by saying ‘future societies will depend on a population which is able to understand the scientific conditions and implications of technical projects and therefore is able to make democratic and responsible decisions’.

Goodrum, Hackling and Rennie (2001) and Mulholland, Dorman and Odgers (2004) support the notion that a lack of conceptual and pedagogical understanding of science by teachers themselves has led to a lack of confidence to teach science, negatively impacting on the standing and quality of science education. Masters (2009) agrees, and the Australian Department of Education, Science and Training (DEST) adds further emphasis by stating, ‘The relative inattention to science teaching and learning in primary schools is inconsistent with aspirations for a scientifically literate society and excellence in Australian scientific achievement’ (2003:21).

Dr. Jim Peacock, Australia's Chief Scientist 2006-2008, also stresses this as a significant issue for Australia's future status as a scientifically literate nation by stating that 'today's society is in increasing need of science and technology based professionals to carry us into a technologically driven future' (cited in Tytler 2007:1).

1.4 STATEMENT OF THE PROBLEM

> *Science education in Australia, as in other post-industrial countries, is in a state of crisis. Government, industry and educators use the language of crisis alike to describe the diminishing proportion of students in the post-compulsory years who are undertaking science-related studies, particularly in the physical sciences.* (Tytler 2007:1)

Science has been a compulsory school subject as a component of generalist education since early in the 20th Century. Until the 1980s, those who completed post-compulsory science education were usually preparing for tertiary level study. Since then, post-compulsory science study has developed a two-tiered approach to cater for a wider range of students' interests and vocational aspirations. Traditional academic based elective subjects of Biology, Chemistry, Earth Sciences and Physics have been complemented by a 'Science for All' (AAAS 1989; Fensham 1985) approach manifested in various forms including General Science, Science Technology and Society, and, most recently, Senior Science and Science for Life in an attempt to make the study of science in the post-compulsory years more relevant and accessible to students.

A recent development underpinning mandatory school science syllabi is an emphasis on scientific literacy and an inquiry focus (Goodrum, Hackling & Rennie 2001; Norris & Phillips 2003; Tytler 2007). Although curriculum reforms have endeavoured to incorporate such emphases, the desired changes in the nature of compulsory science education are not widely reflected in the way teachers teach science (Crouch & Mazur 2001; Hake 2007; Rutherford 2005; Masters 2005, 2009). Many researchers also attest that teacher education courses are not effectively preparing pre-service teachers to implement the changes (Appleton 2002; McDermott, Heron & Shaffer 2005; McDermott, Shaffer & Constantinou 2000; Newton, Newton & Blake 2002; Sherman & MacDonald 2007; Tiberghien, Josem & Barojas 1998). Lyons (2005), in his analysis of reasons why students are disenchanted with school science study, highlighted as a major contributor the transmissive pedagogy that continues to characterise the teaching of science in the years when it is a compulsory component of the school curriculum. In the TIMSS (Trends in International Mathematics and Science Study) Video Study on science teaching, Roth *et al.* (2006) identified that the predominating instructional scripts were informed by traditional transmissive views of teaching and learning. This view is also held by Rutherford (2005), reflecting that school science today appears much the same as he experienced it immediately preceding the start of World War II. He acknowledges, however, that it is not due to a lack of effort, nor research. He cited the failure of curricula to incorporate modern technology as content and poor preparation of teachers who did not 'rise to the task of mastery of the subject matter' (2005:372) as a consequence of their training. Anderson and Helms (2001) argue that a reason why teachers are reluctant to adopt research-verified approaches to teaching beyond the predominantly transmissive ways they were taught is that they are not well enough informed about research on teaching and learning, particularly in terms of the educational benefits derived from social constructivist approaches.

Tytler (2007:15) also identified that 'attracting talented students into science teaching is a serious challenge'. While several researchers and authorities provide recommendations for the professional development of practising teachers, there is little reference in the literature to how teacher education, particularly of K-6 teachers, needs to change in response to the recommendations of science education research and to the changing needs and expectations of today's technologically driven society.

1.4.1 Compulsory Science Education

> *…young students need to be motivated to pursue science. It is increasingly felt that the process must begin early if flight of talent from basic sciences is to be arrested.* (Jolly 2010:1)

During the compulsory years of schooling, regarded in most western civilisations as being from the ages of 5 to 16, or from Kindergarten to Year 10, fundamental science concepts are identified by general science syllabi. Specific aspects of this general science education content have been widely researched by academics and teachers, theorists and practitioners, but spasmodically over the last century. The emphases have often varied according to: the dictates of education authorities in response to political agendas; academics and teachers in response to perceived need; and both in an attempt to improve teaching practice and, consequently, skills, knowledge and attitudes reflective of societal expectation. The methods and practices of teaching, the content of syllabi, learning and teaching materials, and teacher education and professional development have been variously emphasised in response to these needs.

Most recently, international education reform efforts have called for a shift in emphasis in compulsory school general science education from memorisation of facts and procedures, to a deeper conceptual understanding of the subject matter (reports from Australia, Europe, Asia and North America as outlined by the National Research Council (NRC 2005)). A recurring theme in the recommendations has been the incorporation of scientific inquiry as a representation of the essence of science education around the world (Abd-El-Khalick *et al.* 2004; Keys & Bryan 2001). Influenced by aspects of the works of Piaget, Driver and Vygotsky, the teaching of science using inquiry-based pedagogies has been advocated for several decades by reform movements globally, such as espoused in the National Science Education Standards (NRC 1996, 2005) in North America, the Beyond 2000 – Science Education for the Future (Millar & Osborne 1998) in the UK, and the National Declaration for Education 2001 (Australian College of Education 2001) in Australia.

The move toward 'conceptual reconstruction' (Kattman 2008, cited in Treagust & Duit 2009:97) through inquiry learning as a way in which 'students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills' (NRC 1996:2) is complemented by the fundamental societal notion that 'scientific literacy' is a high priority for all citizens (Lyons & Quinn 2010; Rennie *et al.* 2001).

Australian research efforts to improve the quality of science education for all by identifying fundamental premises have been categorised by Rennie, Goodrum and Hackling (2001:455) who state:

1. 'the purpose of science education is to develop scientific literacy'; and
2. 'teachers are the key to change'.

The Science Education Research Group of Monash University highlight limiting factors to the achievement of the scientific literacy focus stating:

> *While the aim of many science curricula around the world have scientific literacy as their major aim, there appears to be little effort to take this seriously by curriculum developers, teachers, students and more importantly political decision-makers.* (Monash University Science Education – research group 2010: online)

1.4.2 Historical Perspective

Pre–1965

Until the mid-1960s, less than 50% of Australian students proceeded past the compulsory years of schooling[1]. Science studies during these years were general in nature and included 'Nature Studies' in the K-6 curriculum.

1966–1995

Following a significant injection of funds by the Australian Federal Government into the provision of science opportunities for secondary school students and beyond the compulsory years, a series of successful, research-based initiatives were implemented in Australian schools. The stated purpose of these reforms was to improve the effectiveness of the teaching of science at the compulsory primary and secondary levels and included the Australian Science Education Project [ASEP], Web of Life and Primary Investigations. The success of these was attributed to the amalgamation of curriculum resources with professional learning. The reform agendas were often promoted through professional learning programmes for in-service teachers (for example Queensland's Spotlight on Science, Victoria's Science in Schools and Western Australia's Primary Science Project), acknowledging that the experienced teachers in schools have the most influence over school curriculum and culture (Anderson & Mitchener 1994). In support of this premise, Loughran (2007) argues that new teachers need to be supported in gaining professional skills (professionalisation) rather than being socialised into traditional pedagogical practices through a lack of advice and guidance.

The current *Science and Technology K-6 Syllabus* was first released by the NSW Board of Studies (BoS NSW) in 1991, and was amended in 1993 (BoS NSW 1993). A review of the syllabus by Professor Ken Eltis in 1995 highlighted that teachers were disillusioned with the large number of outcomes required to be taught and assessed for each student across all KLAs in the curriculum. Rather than being seen as a diagnostic teaching and learning aid, teachers came to view outcomes as an assessment and reporting tool.

1996–2005

In 2002, in response to a request from the NSW State Government, Professor Eltis conducted an evaluation of outcomes-based assessment and reporting, leading to reforms that have received favourable support in many western education systems. Eltis's final

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[1] 14 years and 9 months of age and/or the Intermediate Certificate completed at the end of 3rd Form (known today as Year 9 which was, up until 1967, the final year of compulsory schooling in NSW).

report (Eltis & Crump 2003) acknowledges a crowded curriculum in NSW primary schools.

In 2005, classroom planning and programming was supported by the introduction of Connected Outcome Groups (COGs) to assist teachers manage the perceived crowded curriculum by providing an opportunity to consider the total curriculum and making links between KLAs. However the overall observed effect, was to further dilute the emphasis on teaching Science in the K-6 curriculum.

2006–2011

Currently in Australia, science is taught to all students in the compulsory years of schooling. The BoS NSW K-6 Science and Technology syllabus states 'Science education assists students to understand themselves and the environment and provides opportunities for them to develop independent rational thought and responsible action' (BoS NSW 1993:1). In K-6 Australian classrooms in 2006, less than one hour of the recommended two to three hours in an average week of 25 hours is spent providing students with science education experience (Angus *et al.* 2007). This small proportion of the average primary school week effectively limits the opportunity to meet the overall aim of the syllabus confirming the concerns that have been widely expressed (Appleton 2003; Goodrum *et al.* 2001; Hackling & Prain 2005), about the quality of compulsory science education available to students. Further, Angus *et al.* (2007) found that more than 25% of teachers said they had insufficient time to teach science. Further, discussions with K-6 teaching colleagues revealed that they tend to place more emphasis on the KLAs of English and mathematics due to the perceived importance of external examinations that assessed literacy and numeracy.[2]

Current Environment and Initiatives

For the most part, evidence suggests that research-based and innovative practices are not widely reflected in the school classroom where the traditional transmissive exposition of science concepts continues to impact negatively on student learning (Schwartz *et al.* 2008). Analysis of Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) (Thomson & De Bortoli 2007) data

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[2] The English Language and Learning Assessment (**ELLA**) and Basic Skills Test (**BST**) were administered to students in years 3, 5 and 7 from 1996 until it was replaced by the National Assessment Program – Literacy and Numeracy (**NAPLAN**) in 2008. In all Australian schools the students in Years 3, 5, 7 and 9 are assessed using national tests in reading, writing, language conventions (spelling, grammar and punctuation) and numeracy. The data from the NAPLAN test results gives schools and systems the ability to compare their students' achievements against national standards and with student achievement in other states and territories over time.

infer that Australian 15-year old students perform well (on average) in the application of mathematical and scientific understandings to everyday problems. Interestingly, however, international benchmarking of the performance of Australian students has remained at an approximately static level since these scientific literacy tests began in 1999 despite a 37% increase in spending on education (Ainley *et al*. 2008). Fensham (2007) has also been critical of conclusions derived from analyses of TIMSS and PISA data.

> *It seems that the Context approach they adopted has achieved very little in providing insights to educational authorities, schools, and teachers about the factors and conditions that foster better quality science learning (TIMSS) or scientific literacy (PISA).* (Fensham 2007:169)

To address the perceived lack of improvement in science learning and literacy in Australian schools, the Federal Government embarked on a program to develop a new national science syllabus as part of a national curriculum initiative. In parallel a federally funded project entitled *Primary Connections – Linking Science and Literacy* (Australian Academy of Science 2007) began in 2006 and has recognised the importance of both science and literacy to the future of Australia's workforce and society.

> *High quality teaching of both science and literacy in Australian primary schools is a national priority in order to develop scientifically literate citizens who can contribute to the social and economic well-being of Australia and achieve their own potential. A community with an understanding of the nature of science and scientific inquiry will be better equipped to participate in and contribute to an increasingly scientific and technological world.* (Peers 2006:1)

The project has produced a suite of K-6 teaching resources covering a range of topics and it utilises the 5Es approach (Engage, Explore, Explain, Elaborate and Evaluate) (Bybee 2006) as its constructivist foundation.

Primary Connections is a conceptual change approach to the teaching of science that explores and challenges students' prior knowledge, establishes fundamental science ideas, and extends these ideas to incorporate a range of phenomena. The *Primary Connections* project combines in-service and pre-service teacher education. An ideal *Primary Connections* based scenario would see new teachers developing innovative and effective science teaching practices in their pre-service education, going into schools and being mentored by experienced teachers who share the same beliefs and practices and teaching using the same curriculum resource. The challenge for pre-service teacher education is to provide appropriate experiences that empower beginning teachers to confidently utilise these resources, and this will require a combination of pedagogical and content knowledge.

Affirming the success of this conceptual change approach, in 2009, the Australian Curriculum, Assessment and Reporting Authority released a framing paper drawing on recent science education research, in particular the Australian School Science Education National Action Plan 2008–2012 (Goodrum & Rennie 2007) and Re-imagining Science Education: Engaging students in science for Australia's future (Tytler 2007). The paper presents an inquiry-based approach to science education to 'provide students with a solid foundation in science knowledge, understanding, skills and values on which further learning and adult life can be built' (ACARA 2010: 5). The document explicitly states that 'the national science curriculum to be developed from this research will be useful and useable by experienced and less experienced teachers of K-12 science by incorporating flexibility that should engage every student'. This approach is also providing professional learning for science educators who teach science education units to pre-service primary school teachers in all Australian universities that have a teacher education program. However, specific reference to teacher education and professional development to enhance the implementation of the national curriculum are yet to be addressed and developed.

1.4.3 Post-compulsory Science Education

Mirroring the divergence from traditionally rigorous science study to a more generalist approach, coupled with the availability of what were perceived as 'easier' courses (Lyons & Quinn 2010), enrolments in post-compulsory science courses have demonstrated a steady decline since the beginning of the 1980s. In his ACER publication, *Re-imagining Science Education*, Russell Tytler attests that:

> *...throughout these changes the basic shape of school science has been kept in place, maintaining its emphasis on distinctive knowledge structures of science, in its treatment of context as applications of the central ideas, and in its emphasis in practical work on illustrating concepts and techniques. This basic shape has been supported by assessment regimes that have remained remarkably stable over all this time.* (Tytler 2007:5)

Tytler's perception, supported by Lyons (2005), is reflected by most Organisation for Economic Cooperation and Development (OECD) economies who, for the past two decades, have identified an increased level of participation in post-compulsory and tertiary education, but have witnessed significant declines in the proportions of students choosing science courses for post-compulsory and tertiary study (OECD 2006).

1.4.4 Pre-service Teacher Education

In Australia, the downward trend in post-compulsory science enrolments has been well documented (Ainley *et al.* 2008; Dekkers & de Laeter 1997; 2001). Figure 1.1 exemplifies recent national statistics on Year 12 enrolments in science subjects (Ainley *et al.* 2008).

The trend toward decreased enrolments in post-compulsory science education was identified as an international problem by Tiberghien *et al.* (1998) who suggested that it could only be reversed if a major emphasis is placed on effective teacher education, which is reflective of modern research into science learning and teaching.

Declining enrolments and decreasing availability of appropriately science educated teachers, are inextricably linked and form a vicious spiral. Recent reports published in Australia and internationally are stressing the need to address the shortage of teachers in particular areas, science and mathematics being highest on the list (MCEETYA 2003:1).

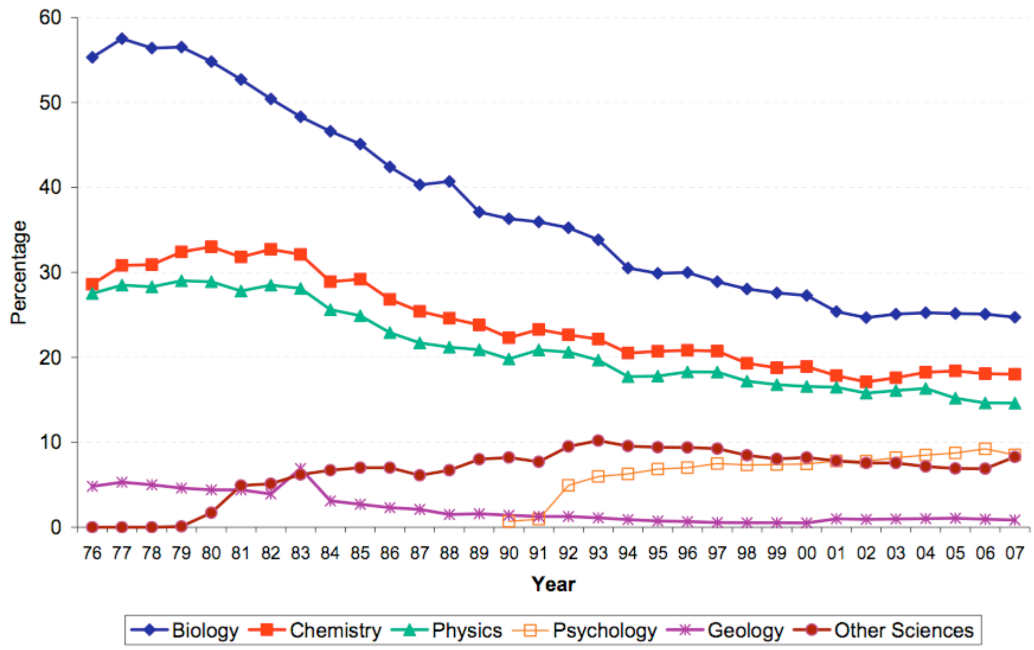

Figure 1.1: Year 12 science participation as a percentage of the total Year 12 cohort in Australian schools, 1976 to 2007 (Ainley, Kos & Nicholas 2008:18)

McDermott *et al.* (2000) advocates a specific special science course for pre-service elementary (primary, K-6) and high school (secondary, 7-12) teachers. She surmises that a major reason for the perceived crisis in science education is the failure of teacher education institutions to provide the type of preparation that pre-service teachers need to teach science effectively.

> *In physics, neither courses for majors nor for non-majors provide the kind of preparation required for teaching physics or physical science by inquiry. Science methods courses cannot help teachers develop the depth of understanding needed for this type of teaching.* (McDermott, et al. 2000:1)

Australian and international researchers such as Appleton (2002), Bybee (2006), Hackling (2002) and Rennie (2006), support this notion suggesting that in order to improve the image of the study of science, it may be necessary to reconsider fundamental aspects of the way that teachers are being prepared to teach science.

> *When teachers lack confidence to teach science, they tend to use familiar teaching strategies which allow them to maintain control of the classroom knowledge flow, but, in terms of contemporary science curricula, these strategies are not appropriate ways of engaging students in science.* (Appleton 2003:2)

In considering the future of teacher education, Hake (2002) has emphasized a need for research-based strategies that enhance student learning of science. He surmises that this should be done through a relevant and meaningful approach where:

1. university and K–12 teachers are educated to effectively implement those strategies; and
2. universities start to think of education in terms of student learning rather than the delivery of instruction.

After a thorough review of the available literature (see Chapter 2), I took the findings back to my students and sought their comments on the issues identified, posing the general discussion as: 'how do we address these issues of lack of confidence and preparedness to teach science as part of our class-work?'. An opinion was expressed, and strongly supported by 85% of students in the sample (n = 98 of 115), that there was little point in trying to teach the pre-service K-6 generalist teachers all of the science content needed in the relatively short time available to them (see Section 3.2.3 – Primary Science Education Units). The collective opinion was expressed that if they knew how to teach one thing well, they could apply a similar model and set of processes to the teaching of other concepts and that this would be most useful.

One of the challenges for future research and development described by Treagust and Duit (2009:96) is to bring successful conceptual change teaching approaches to normal classrooms. They go on to state that: 'conceptual change strategies may only be efficient if they are embedded in a conceptual change supporting learning environment that includes many additional features such as specially organised instruction based on models of teaching' (Treagust & Duit 2009:100).

1.5 WHY FOCUS ON TEACHING OF ELECTRICITY AND MAGNETISM

This project focused on the learning and teaching of electricity, magnetism and their interactions as a sub-discipline of science with fundamental importance to modern society and lifestyle. In a broader context, the study of electricity and magnetism would lead to insights and understanding of the technologies applied to maintain and enhance that lifestyle through health, entertainment, communication, travel and economic prosperity. Similarly, improvements in the economic viability of industry through efficiencies in data storage, speed of access to and analysis of data, transferability of data, robotics, communication, entertainment, domestic appliances developed to supply society with its 'needs' has contributed significantly to improved standards of living.

Researchers have clearly shown that students' pre-instructional conceptions deeply influence or even determine learning (Pellegrino 2003). Driver *et al.* (1989) and Duit, Goldberg and Niedderer (1991) were among the earliest researchers to suggest that teachers should reconsider the way they are teaching the concepts regarded as desirable in school science courses. However, Duit *et al.* conclude that most student conceptions about electrical and magnetic phenomena prove to be impediments to learning, as they are based upon incomplete observation and anecdotal explanation, and often are in stark contrast to, or directly contradict the concepts to be understood.

Despite the significant advances in understanding how students conceptualise other areas of physics, education researchers have not yet strongly reported in the literature mechanisms to explore and address the problems associated with the understanding of fundamental electric and magnetic phenomena in primary school students. There is an extensive body of literature about secondary and tertiary student ideas and beliefs (often referred to as 'alternative conceptions', or 'misconceptions') about electricity and magnetism[3]. However, investigations that have involved young children (e.g. Borges 1999; Cosgrove *et al*. 1985, Cosgrove 1995; Driver 1994; Shipstone 1985; Tiberghien 1998) are relatively scarce and limited to models of electricity and activities to do with simple circuits. Similarly, many studies offering diagnostic and developmental strategies to support the learning of electricity and magnetism have been published (Ferguson-Hessler & de Jong 1987; McDermott and Schaffer 1999), but few have identified the need to teach teachers how best to teach the associated fundamental concepts (Hake

[3] Duit *et al.* (1985) provide an overview of the research conducted until 1985.

2002; Tairab 2010; Waters & Ginn 2000). If, as many education researchers and authorities espouse, fundamental learning of important science concepts should begin in the elementary (K-6) years of schooling, there is a solid link between developing a reliable and verifiable mechanism for establishing these fundamentals in students. This can only happen, however, if the teachers are confident in their ability to support the learning process.

I discussed issues concerning the teaching of electricity and magnetism with several teaching colleagues and university academics and they suggested the difficulties encountered by students arise from a number of quarters:

- students lack a physical intuition for the knowledge;
- the concepts are often counterintuitive; and
- many elements of the study of electricity and magnetism are shrouded in mathematical formalism.

I have therefore chosen to concentrate on fundamental concepts associated with the study of electricity and magnetism based on the following observations:

- students find it interesting;
- it relates to everyday experience;
- it is a study that may be built upon once fundamental conceptual understanding is established;
- resources are readily available to support conceptual growth;
- the student perception that "learning one thing well" would lead to them being equipped to "teach other things well"; and
- there has been very little research into the learning and teaching of fundamental concepts of magnetism.

Acknowledging the plethora of resources and activities to support the learning of particular aspects of these topics, this project attempts to bring some of them together in a format that will not only teach the pre-service K-6 teachers, but provide them with a model of effective ways to teach the topics to their students from the very beginning of their career.

1.6 DEFINING THE PROJECT

The project has been designed to develop pedagogical materials to be included in a pre-service program for K-6 teachers that will:

- enhance content knowledge;
- lead to a growth in confidence to teach science;
- model teaching strategies that mimic what they could do in their classrooms;
- provide means of assessing the progress of concept building in learners;

with the same tools being used to collect information about their learning being equally applicable by them to their own students.

Except for gravity, our entire subjective physical world is made up of various electromagnetic effects. Light, the structure of atoms, friction, chemical bonds and temperature are all now understood as governed by the laws of electromagnetism. Society depends on electrical and magnetic phenomena in many ways, making them central to our existence. The challenge for educators and curriculum developers is to develop teaching strategies and support materials that facilitate modern students' learning about what they see as relevant to them and their everyday experiences.

1.7 RESEARCH QUESTIONS

This research proposes to investigate the effectiveness of inquiry-based teaching sequences in enhancing the learning of fundamental electricity and magnetism concepts in pre-service K-6 teachers, and how this is reflected in their confidence to teach science in the K-6 classroom.

The following research questions have evolved from this thesis statement, through discussions with colleagues, teachers and pre-service teachers.

1. *From a broad community context, what are the fundamental key concepts in the study of electricity and magnetism that should be explored by K-6 school students?*
2. *What are the perceived barriers that may limit successful teaching and learning about fundamental electric and magnetic phenomena?*
3. *Within the context of pre-service K-6 teachers, what are the variations in the understanding of the identified fundamental concepts?*
4. *How is the variation in understanding in the identified fundamental concepts of electricity and magnetism reflected in the confidence level of pre-service K-6 teachers to teach them?*
5. *Does the integration of Predict-Observe-Explain-Share strategies into the 5Es pedagogical model provide an effective means to support and enhance K-6 pre-service teachers' learning of fundamental concepts?*
6. *Can a peer-learning inquiry-based pedagogy be adopted and used as a framework in pre-service science teacher education for learning and as a model for teaching?*

The research questions have defined the phases of the investigation and provided a natural scaffold upon which to apply a multi-methodological approach to the collection and analysis of the data throughout each phase. These are detailed in Chapter 3.

1.8 THESIS LAYOUT

An overview of the research is presented below in three parts - the first concerns itself with the research setting; the second reports the results of the expert interviews, fact-finding and teaching interviews research phases; and the third part combines the results and reports the overall research findings.

Part 1: Research Setting

- Chapter 2: Literature Review - Provides a comprehensive review of research covering constructivist perspectives of learning and teaching, conceptual change, as well as elementary, secondary, and teacher education about electricity and magnetism.
- Chapter 3: Methodology - Describes the research framework and the theoretical viewpoint from which the research was conducted and the research methodologies and analysis techniques used to address and explore the research questions are discussed.

Part 2: Results of the Research Phases

- Chapter 4: Phase I – Expert Interviews – Details the conduct of semi-structured interviews with a group of experts about their perceptions of what they consider to be fundamental concepts of electricity and magnetism that informed the development of the initial instrument.
- Chapter 5: Phase II – Assessing and Enhancing Understanding and Confidence Initial Instrument – Outlines the relationship between the variation in student understanding and the intervention activities designed and trialled to improve their concept knowledge and confidence. It also reports on improvements suggested to increase the effectiveness of the instrument.
- Chapter 6: Phase III – Refined Instrument – Presents a qualitative and quantitative analysis of the effectiveness final sequence that incorporates the improvements identified in Phase II as presented to a different cohort of pre-service K-6 teachers.
- Chapter 7: Phase IV – Peer Teaching – Reports on the development and conduct of peer-teaching episodes during which final year pre-service teachers presented hands-on, open-ended, problem-solving activities to small groups of second year students.

Part 3: Reporting the Findings.

- Chapter 8: Implications for pre-Service Teaching and Learning of Science – Presents the key findings of the project in relation to the research questions and discusses recommendations for consideration for future research.

1.9 CHAPTER ONE SUMMARY

This introductory chapter of the thesis has described the issues that led to me to undertake this research. I have described my personal reasons for conducting this project and discussed the context of this study within the larger framework of teacher preparation to teach science to K-6 students. I also present a justification for my selection of fundamental electricity and magnetism as a foundation around which to design teaching sequences and formative assessment strategies.

The final section of the chapter presented the research questions the project seeks to address and the road map for the rest of the dissertation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a brief overview of the key literature that influenced the conduct of the project concerning:

- The development of scientific literacy; and
- The learning and teaching of fundamental electricity and magnetism concepts.

Please note that specific literature concerning learning theories has been incorporated as part of Chapter 3 – Developing the Research Plan.

2.2 DEVELOPING SCIENTIFIC LITERACY

Western governments and education authorities are trumpeting the need for society in general to increase its level of technological knowledge and scientific literacy (Appleton 2003; Bybee 1997; Evans & Rennie 2009; Goodrum, Hackling & Rennie 2001; Hackling 2002; Jenkins 2002; NSW Department of Education and Training 2009; Rennie 2006). The Organisation for Economic Co-Operation and Development's (OECD) Program for International Student Assessment (PISA) define Scientific literacy as:

> *the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.* (cited in Evans & Rennie 2009:26)

The NSW Department of Education and Training (2009) identifies students as scientifically literate when they:

- know and understand the scientific concepts and processes required for participation in society;
- ask, find, or determine answers to questions derived from curiosity about their world;
- describe, explain, and predict natural phenomena;
- read with understanding science articles in the popular press and engage in social conversation about the validity of the conclusions;
- identify scientific issues underlying national and local decisions;
- express positions that are scientifically and technologically informed;

- evaluate the quality of scientific information on the basis of its source and the methods used to generate it; and
- pose and evaluate arguments based on evidence and apply conclusions from such arguments appropriately.

To facilitate the development of scientific literacy skills in the early years of schooling, Australian and international researchers have recommended that K-6 teachers be given the opportunity to deepen their knowledge of the science content of the curriculum they teach (Akerson 2005, 2010; Akerson & Volrich 2006; Duschl, Schweingruber & Shouse 2007; Palmer 2008). Tytler (2007) supports this as a most desirable situation for aspiring primary school teachers: 'They need to have included, as part of their initial training, a mixture of science content knowledge and pedagogical content knowledge (PCK) in order to confidently teach science in primary school' (p. 67). His opinion is a reinforcement of the recommendations made by the Australian Government Department of Education, Science and Training (2003) who state that 'Teacher preparation must give new teachers a rich knowledge of how students learn, as well as an understanding of both the content they will teach, and of ways to teach well to a range of students' (p. 45). Geoff Masters, in his 2009 report on ways to improve literacy, numeracy and science learning in Queensland primary schools, has recommended:

> *That all aspiring primary teachers be required to demonstrate through test performances, as a condition of registration, that they meet threshold levels of knowledge about the teaching of literacy, numeracy and science and have sound levels of content knowledge in these areas*. (Masters 2009:x)

2.2.1 From Behaviourism to Constructivism

In the 1950s and 60s, the dominant psychological viewpoint in education was that of *behaviourism,* a school of thought that emphasised passivity of the mind with information from the surrounding environment being accumulated by the learner (Gilbert & Watts 1983). The approach focused on the formulation of educational objectives and aims — distinguishing between attitudes, knowledge and skills — and was organised in learning hierarchies and taxonomies (Anderson & Krathwohl 2001; Bloom 1956; Dave 1975). This resulted in the 'cultural transmissive' approach (Pope & Gilbert 1983) or 'conduit model' (Tobin, Briscoe & Holman 1990), that became dominant in Western education at that time, with programmed instruction, teaching machines and kit-based approaches developed into individually-paced study systems and mastery learning techniques (Young & Lee 2005).

In contrast to the behaviourist model of learning, the constructivist learning theory proposed by Bruner (1961, 1966) and others, including Papert (1980) and Steffe and Gale (1995), presupposes that students build on existing knowledge and construct their knowledge as a consequence of external experiences and interactions with their environment. The core commitment of a constructivist position is that knowledge is not transmitted from one to another but is actively built up by the learner (Driver *et al.* 1994:5). Constructivist pedagogy, therefore, puts the focus of control of the learning with the learner, with the teacher a facilitator of the learning.

As the researcher, I acknowledge that constructivist-learning theory has broader application than science education alone (Littledyke & Huxford 1998). Being something of a divergent movement, certainly in terms of its philosophical underpinnings as an explanation of how knowledge is acquired, constructivism incorporates ideas from a range of perspectives and is a large and multi-faceted subject (Gil-Perz *et al.* 2002; Phillips 1995; Solomon 1994; Sutching 1992; Taber 2006). Constructivism as an approach to teaching and learning is based on the epistemology of *constructionism*, in which people engage and construct meaning through interactions with each other and the world they are interpreting (Crotty 1998).

However, there are many prominent researchers who reject the basic premise associated with constructivism (for example, Cobb 1996; Fox 2001; Jenkins 2000; Liu & Matthews 2005; Matthews 1998; Robbins 2001; Tobin 1993).

> *…the term constructivism is currently used very widely in educational literature, in academic papers as well as in books used for teacher training, curriculum development and assessment. The level of precision is often rather low, and the term is seldom clearly defined. This has led some critics (e.g. Matthews 1994) to consider the term to be empty of meaning, and that its use is purely ideological. It seems to be used to distinguish the good guys (constructivists) from the bad guys (traditionalists).* (Sjoberg 2007:1)

There are many viewpoints to a constructivist perspective — for example, Dougiamas (1998) has described 'Trivial', 'Radical', 'Social', 'Cultural', 'Critical' and 'Constructionist' perspectives of constructivism. These may be distilled into two major schools of thought. Dewey is often cited as the philosophical founder of the first, the *cognitive* (also known as radical or traditional) constructivist approach to learning theory. It emphasises learner-centred and discovery-oriented learning. Bruner (1990) and Vygotsky's translated works (1978) have influenced the notion that social interaction is a significant contributor to the constructive learning process, leading to the second school of thought known as *social constructivism*.

Cognitive Constructivism – Piaget and Driver

'Piagetianism' is a psychological position that influenced the proposition of constructivism as a learning theory particularly associated with science education. Piaget's description of concrete and formal operational thinking (Piaget 1954; von Glasersfeld 1989) has influenced many curriculum projects (some of which adopted an explicitly Piagetian perspective; for example, the Harvard Physics Project of the US, the UK Nuffield Physics Project of the mid-1960s and Australian Science Education Project of the mid 1970s) where school science offered the student the opportunity 'to be a scientist for a day'. The application of Piagetian principles often prescribed the identification of stages of achievement of defined objectives. Achievement of desired behaviours was used as a diagnostic tool to identify benchmarks set by many newly-developed, nationally-supported curricula, as well as a means to match them to assumed age-dependent capabilities of pupils.

> *These 'physicist-for-the-day' curricula were often criticised as being inclined to overestimate the capabilities of 'all' pupils. 'Piagetianism' made the important shift from taking only the curriculum-to-be-taught as the sole starting point for curriculum development, to including also, the cognitive development of pupils.* (Lijnse 1997:4)

In 1978, Jack Easley and his PhD student at that time, Rosalind Driver, wrote about the learner's active role in constructing personal knowledge and the term 'constructivism' came into common use in science education (Driver & Easley 1978). In the early 1980s, in her book *Pupils as Scientists?* Driver (1983) criticised the curriculum of the day by questioning its heuristic induction[1] approach. She argued that children come to the classroom with already-formed ideas about the world and natural phenomena, some of which are 'correct' and others which are 'not'. Driver also attested that each 'student held belief' is reflective of the individual's experience and the construction of each is an attempt, by the student, to explain their surroundings in a way — and in a language — that makes sense to them. Over a period of a few years, the study of learners' ideas about science concepts became a significant international research focus. This produced a major body of literature that explored and debated the development of learners' understanding of fundamental science concepts (Carmichael *et al.*, 1990; Driver *et al.* 1994; Gilbert 1994) and the process of conceptual change ('theory change'). Proponents have been engaging in lively debate about particular perspectives since the 1980s (Carey 1985, 1999; Chi 1992; Posner *et al.* 1982; Smith, diSessa & Roschelle 1993).

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[1] The notion that students acquire knowledge by personally conducting investigations. It is also referred to as 'discovery learning' (Bruner 1967).

Based on Piagetian reasoning, curriculum materials of the late–1980s were often developed to be intervention lessons. The aim was not so much the improvement of science learning in a narrow sense, but more the advancement of the student's cognitive development itself. When first formulated, this approach gave a psychological foundation to the appeal of *discovery learning* and resulted in the projection of several modes of *learning cycles* (Adey, Shayer & Yates 1989), many of which are still in use as aids to lesson preparation and delivery. For example, embedded in all NSW DET syllabus documents is an understanding that explicit and systematic teaching and learning will best occur when teachers follow the process articulated by the teaching and learning cycle. The cycle is described as comprising four stages (see Figure 2.1) that facilitate the design and delivery of classroom tasks to incorporate an outcomes-based approach. The cycle has no start or end point, with each step informing the next. It is the process of gathering data and reflection that dictates where in the cycle you need to be operating.

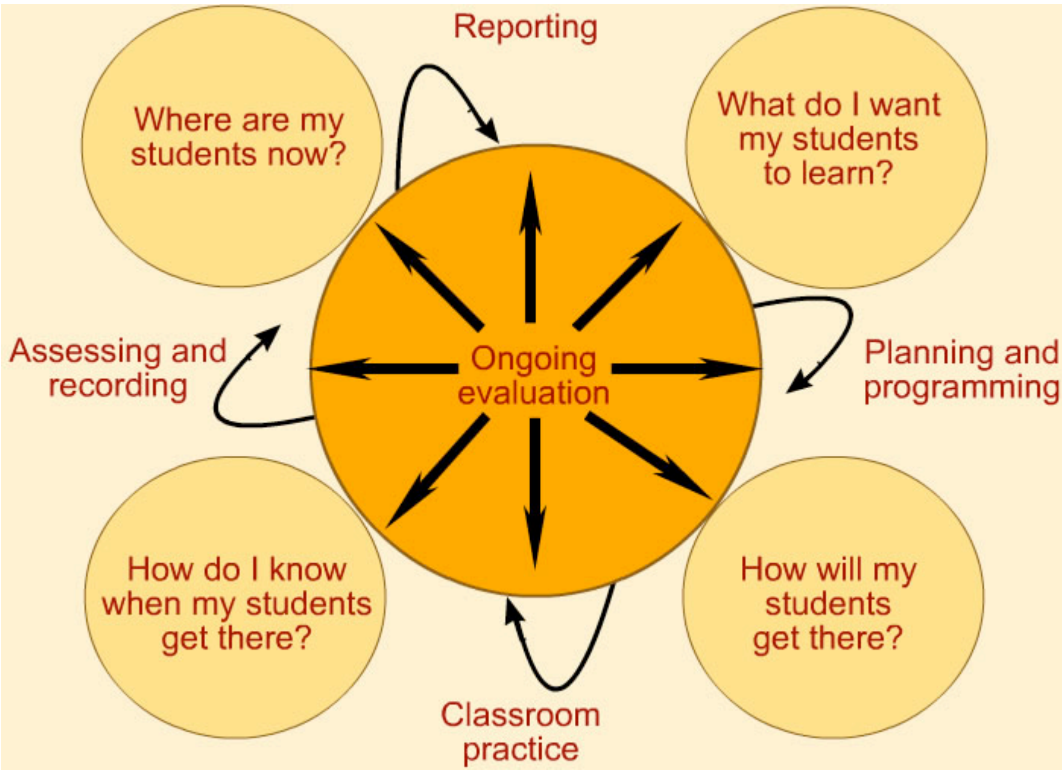

Figure 2.1: A representation of the teaching and learning cycle embedded in all NSW DET syllabus documents (NSW DET online).

Other popular variants of learning cycles that are often included in pre-service teacher pedagogy courses include those models developed and refined by Kolb (1984), based on his experiential learning model, and the 'metacognitive learning cycle' detailed by Blank (2000).

In 1994, Scott and Osoko joined with Driver to support a constructivist approach to the learning of science (Scott, Asoko & Driver 1994). They contend that, where the student's conception is not identified as correct for the level of understanding required, the teacher needs to facilitate *conceptual change* and may need to intervene by stating the 'accepted view' alongside the student's ideas. This process involves the student being challenged, through language, to compare the accepted, correct scientific view or explanation of a phenomenon with their own — and often that of their peers — explanation of the same phenomenon. This contrasts with the discovery learning notion that suggests that the learner constructs desired, predetermined conceptual understanding by themselves by being exposed to particular experiences that pose specific questions that lead the individual to the desired understanding.

The constructivist nature of science learning was further described in the introduction of the book *Making Sense of Secondary Science*, where Driver *et al.* (1994) proposed that student knowledge is not static, but is based on the modification of existing, or prior knowledge. Their investigations indicated that students have ways of constructing explanations for events and phenomena that are coherent to them, and that these fit with their domains of experience. Yet their constructions might differ substantially from the 'accepted' scientific view. Therefore, Driver and her contemporaries support the notion that effective science teaching should take account of students' pre-instructional ideas and provide activities that enable students to make the journey from their current understandings toward a more scientific view.

Driver *et al.* (1994) insisted that science learning was a process of enculturation rather than discovery, arguing that empirical study of the natural world would not reveal scientific knowledge because scientific knowledge is discursive, exploratory and prone to different interpretation in nature.

> *If teaching is to lead students toward conventional science ideas, then the teacher's intervention is essential, both to provide appropriate experiential evidence and to make the cultural tools and conventions of the science community available to students.* (Driver et al. 1994:7)

Essentially, cognitive constructivism proposes that, for learning to be effective, modification has to be owned by the student in terms of the personal adoption of the new knowledge or model. Consequently, successful application of this new knowledge is confirmed when it provides a better explanation of a phenomenon presented by a new or unfamiliar experience. By the mid-1990s, constructivism had become embodied in the aspirations of many educational reforms[2]. Hence, constructivism became an acknowledged 'frame' for conceptualising science education (Solomon, 1993) and an explicit referent for science teaching (Tobin 1993), so much so that major texts on teaching and learning science were marketed as taking a 'constructivist approach'.

Social Constructivism – Lev Vygotsky

The second school, the social or realist constructivist approach has, as its main contributor, a contemporary of Jean Piaget, the Russian Lev Vygotsky (1896-1934) and his students, mainly Alexander Luria and Aleksai Leont'ev. Vygotsky's work remained virtually unknown in the west until its 'rediscovery' in the 1960s, when the translation of *Thought and Language* (1934) was published in English (1962; revised edition 1986). It was not until the end of the 1970s, however, that Vygotsky's works began to get attention outside of Russia and his collected works were not widely available in English until the late-1990s.

The social constructivist approach to learning emphasises the central role of social interaction as its foundation (Liu & Matthews 2005). In this paradigm, learners are part of a *learning community* and their knowledge and understanding are reflective of their interaction with the learning environment, including their peers or others with opinions about the concept being discussed.

Vygotsky's Zone of Proximal Development

One of the means by which Vygotsky (1978) explained how individuals realise their potential was his construct of the *zone of proximal development*. This relates to Vygotsky's aim of empowering people through interacting with teaching (van der Veer & Valsiner 1991). It also draws on the Marxist notion that individuals can shape their worlds and develop their higher mental faculties through cooperating and interacting with others. Referring mainly to children, Vygotsky (1978) defined this zone as the area between what a person can achieve on their own ('discovery learning') and what they can achieve with the help of a more capable person. Vygotsky's often-quoted definition of zone of proximal development presents it as:

> *...the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers.* (Vygotsky, 1978:86)

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[2] Exemplified by the American curriculum of the time, where it was explicitly stated that students at all grade levels 'should have the opportunity to use scientific inquiry and develop the ability to think and act in the ways associated with [scientific] inquiry' (National Academy of Science, 1995:105).

A useful mental visualization of the *zone of proximal development* is shown in Figure 3.1. This emphasizes the learner's potential to develop with strategic intervention. Bruner (1966) referred to such structured and systematic assistance as *scaffolding*. Bonk and Cunningham (1998) attest that a learner's *zone of proximal development* can be extended with scaffoldings from instructors, peers and learning materials. The prompts, guidelines and questions that teachers provide students may also serve as scaffolds.

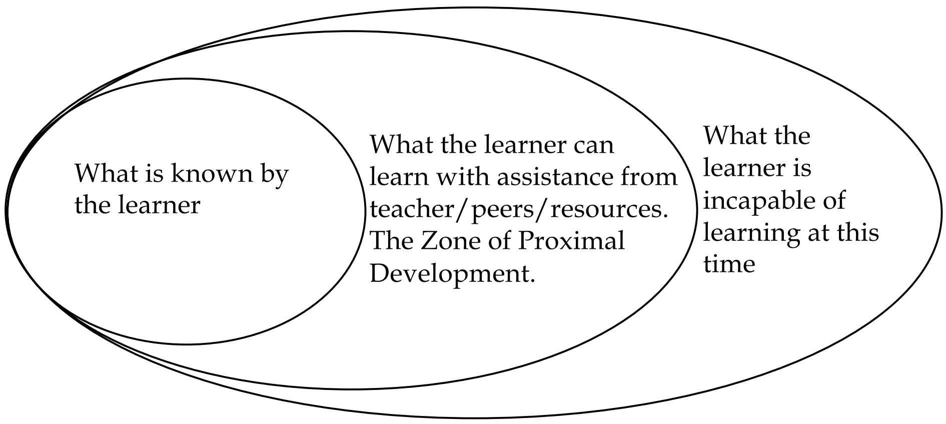

Figure 2.2: A representation of the Zone of Proximal Development and what can be achieved by the facilitation (by the teacher) of appropriate intervention(s).

Gallimore & Tharp (1990) describe progress through the zone of proximal development in a model of four stages as shown in Figure 3.2. Discussion of the model is necessarily abbreviated here; an extended description of the model and four stages is presented in Tharp and Gallimore (1988:Ch. 2). The model focuses particularly on the various relationships between self-control and social-control. In the first stage, more capable persons (for example, a 'more capable other' such as parents, teachers, experts and knowledgeable peers) guide the learner through the learning process, aiming to increase the proportion of the learner's responsibility for — and participation in — the task. In the second stage, a handover of the process from the 'more capable other' to the learner occurs. The learner can now perform the task unassisted, although they are not expected, yet, to have mastered the task. Mastery only occurs in the third stage, when the learner internalizes what has been learned and undertakes to practise the task to achieve automation. The fourth stage involves the de-automation of the learner's performance that leads to a return (recursive loop) through the zone of proximal development to where the student may no longer be able to perform previously achievable tasks. Quality teachers can address this commonly-occurring classroom situation by revisiting previous lessons and providing active opportunities for reflection of the defined stages in the learning process to the learner.

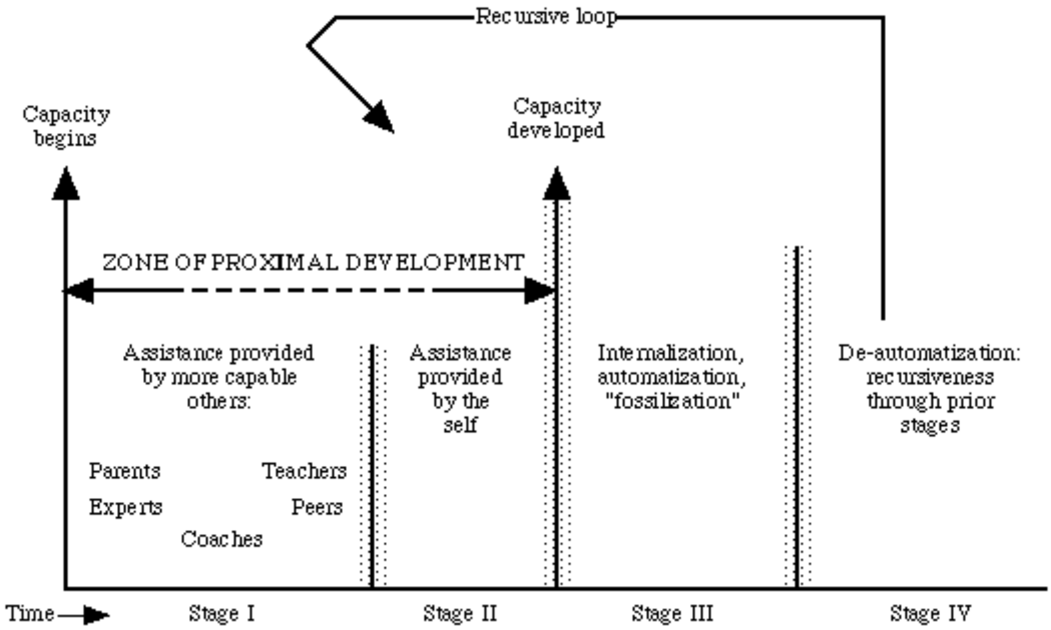

Figure 2.3: The genesis of a performance capacity: Progression through the Zone of Proximal Development and beyond (Gallimore & Tharp 1990).

In this study, the social constructivist view was adopted to inform the research process and Vygotsky's zone of proximal development was applied to assess progression and to provide a framework in which to build a report on aspects of the developed teaching sequences. The design of the teaching experiments to be conducted in the third phase of this research project is anchored in Vygotsky's idea of learning within the zone of proximal development via scaffolding activities. Several scaffoldings (activities, prompts, guidelines, and questions promoting individual and collaborative responses) were provided to students in order to move their identified previous knowledge about electric and magnetic phenomena toward that which is accepted as more scientifically correct. The scaffolded activities, and how these influenced students' knowledge construction and reconstruction are described and discussed in Chapter 6.

2.2.2 Discussion

Each of the two theoretical perspectives discussed above bring a set of underlying assumptions about learning. Both, however, highlight the importance of active, student-centred, teacher-facilitated learning. While the Vygotskian (social constructivist) perspective focuses on activity in a socio-cultural context, the Piagetian (cognitive) perspective focuses on the learning of individual students through 'hands-on' and 'minds-on' activities. So, while cognitive constructivists often refer to learning in terms of knowledge building processes within an individual learner's mind, social constructivists consider an individual's interaction with others, as the unit of analysis.

The philosophical approach adopted for this research supports a model that is a convergence of both schools of thought. The model advances the idea that science teaching is able to invoke a personal construction of science knowledge in the student by utilising the social interaction prompted as a consequence of working in small group investigative situations. I believe that the Piagetian and Vygotskian perspectives are mutually reinforcing since they lie very close to each other in each of the three learning dimensions as described by Phillips (1995:5-12):

1. The first dimension has at one extreme the idea of learning being the construction of meaning by an individual from interaction and experiences with their environment. The other extreme describes learning as a socio-political construction; it is a shared or collaborative experience that cannot be separated from the environment. The individual does not exist. Phillips (1995:7) labels this dimension as 'individual psychology versus public discipline'.
2. The second dimension concerns the construction of knowledge. At one extreme is the view that knowledge structures merely organise the learner's experienced world and define no link with the real or natural world. At the other extreme is a non-constructivist view: that knowledge structures correspond with, or match, external structures in the environment. Phillips (1995:7) describes this dimension as 'human the creator versus nature the instructor.'
3. The third dimension refers to the nature of the learning process. At one end of this scale is a non-constructivist view of learning as an automatic, 'prewired' response. This leads to an approach to learning where the learner is passive, receiving information about a topic or situation without participating in, or affecting it, in any way. The other end of the scale sees learning as an active, dynamic process that takes place by participation in, and negotiation of, the topic, situation and process.

Both the cognitive and social constructivist perspectives of constructivism are adequately described within the parameters of these dimensions, as both approaches view learning as a dynamic process; where students construct new ideas and skills, and reconstruct previous knowledge themselves and through interactions with their environment including their social environment. Cobb (1994, 1996) has coined the term "Eclectic Constructivism" to link the two perspectives, the basic elements of which are:

- Learners learn by linking new knowledge or information to their existing understanding;
- Learners often learn best when they are part of a group of people learning at the same time in a process called "enculturation";
- Learners and the teacher(s)[3] make up the learning culture;
- Learner's understanding improves if they share their constructed understanding as part of the group learning culture; and
- Learners will construct their own concepts and understanding of observed phenomena, but these may not resemble the accepted scientific model.

However, research has clearly shown that many teachers may present serious resistance to adopting 'constructivist' positions. As pointed out by Duit (1996), and Lyons and Quinn (2010), this resistance manifests itself in a reticence to organise science learning as the (re)construction of scientific knowledge through personal experience and social interaction (the busy, socially interactive, inquiry based classroom versus the quiet, teacher centred, 'write this down', transmissive classroom). This draws attention to a fundamental theoretical point about the process of construction of scientific conceptions; helping students to construct their own scientifically correct conceptions involves a process of induction and the teacher has an important role to play in facilitating the process, rather than directing the learning or transmitting the knowledge. Constructivist teachers, therefore, create classroom conditions that invite students to build on their personal and hence meaningful (to them) understanding by determining their prior knowledge and enhancing it. They are facilitators who mediate between the learner's current and emerging understandings. They also draw from a range of teaching practices; for example: exploratory study that links a student's emerging knowledge to the real

[3] Where the learning occurs in a group work environment, the "teacher(s)" may be identified as a 'more knowledgeable person' (Vygotsky 1978).

world around them; cooperative or peer learning; and experiential learning based on student interaction with primary data and manipulative opportunities.

2.2.3 Pedagogical Considerations of Teaching Science — a Constructivist Approach

> *Your mission is not to teach them everything you know but to prepare them to go on-ward without you.* (Swartz 2006:69)

When reporting on the way that science should be taught in K-6 classrooms, the research literature tends to focus on addressing misconceptions, often by recommending remedial approaches centred on cognitive dissonance (for example, Johnson & Johnson 1979, 2009; Lee *et al.* 2003), or the use of analogies to guide the change in conceptual understanding. The term 'misconception' is a poor choice of word to describe the commonly espoused notion of a personal incorrect or incomplete belief about the nature of a particular concept. Hancock (1940) defined a misconception as a belief arising from faulty reasoning. More recently, science educators have used a variety of terms such as 'preconceptions', 'naïve conceptions', 'naïve theories', 'alternative conceptions' and 'alternative frameworks' to describe perceptions or student ideas that differ from those that are 'scientifically correct' (Blosser 1987). An understanding of a concept is a personal belief and is therefore a 'conception'. That the personal conception does not necessarily agree with a more universally accepted norm does not make it incorrect in the understanding of the holder of that conception — their perception is their reality. It is through the learning process that an individual's personal understanding is challenged if it does not fit or explain an observation (actually experienced, imagined or metaphorical), and is subsequently modified, changed or even rebuilt to enable an explanation of the new phenomenon in question. Nussbaum and Novick (1983) propose a three-phase approach to science concept learning that involves:

1. exposing alternative frameworks (as limited or lacking in application);
2. creating conceptual conflict by confronting students with the inconsistencies entailed by their own beliefs (between the learner's explanation and an observation that cannot be explained by the learner's conceptual model); and
3. encouraging cognitive accommodation (the adoption of an amended model that more adequately explains the phenomenon in question).

This interpretation of constructivist theory draws on the work of Piaget and Vygotsky, both of who emphasized that cognitive change only takes place when previous understanding undergoes disequilibrium with the newly presented or observed information (Slavin, 1994). Hence, like most constructionist theories of cognitive development (Nussbaum & Novick 1983) constructivist teaching approaches emphasize the active role of learners in building their own understanding of reality.

2.2.4 Models and Analogies

Strategies adopted by teachers of science to instil in their students knowledge of the concepts to be learned have commonly identified the use of well-researched models and analogies (Clement 2000; Coll, France & Taylor 2005; Duit 1991; Glynn 2008; Heywood 2002; Treagust 1993). This sometimes story-telling or descriptive process is designed to create an imaginary scenario in the mind of the learner that explains observed phenomena, encourages them to reconsider their personal explanations from a different perspective, or, in more complex situations, explains what is being imagined. Analogies are, however, double-edged swords: they can foster understanding, but they can also lead to a further promulgation of misconceptions. As Duit *et al.* (2001:283) explain:

> *A growing body of research shows that analogies may be powerful tools for guiding students from their pre-instructional conceptions towards science concepts. But it has also become apparent that analogies may deeply mislead students' learning processes. Conceptual change, to put it into other words, may be both supported and hampered by the same analogy.*

Most recently, models and analogies have developed a sophisticated visual and graphically-enhanced manner to provide different representations of phenomena using computer simulations. Many software tools including the CUPLE (Comprehensive Unified Physics Learning Environment) Physics Studio (Redish, Wilson & McDaniel 1992; Wilson 1994), SToMP (Software Teaching of Modular Physics) (Bacon 1994), Physics Academic Software and others (Finkelstein *et al.* 2004) claim to emulate those situations that are either unobservable in a normal classroom environment (abstract, microscopic, 3-dimensional), too expensive to recreate, or too dangerous to observe or experience directly. Of these, many applets are reproducing experimental scenarios that enable the user to control the conditions and variables to create an inquiry situation (for example, Gizmos, National Aeronautics and Space Administration (NASA) simulations, Science, Technology, Engineering and Mathematics (STEM) Software, Sydney University Physics Education Research (SUPER) and Technology Enabled Active Learning (TEAL)). Most recently, education authorities (such as the National Research Council (NRC) 2010) are reporting evaluations of simulation software and computer games most favourably. It is critical, therefore, for teacher education institutions to endeavour to remain *aux fait* with these new developments, as they are not only reflective of research into effective learning strategies, but are most commonly accepted as modern and relevant by the students using them. Hence, this project, while not directly using simulation software, provided analogous classroom situations where direct observation of student created and manipulated scenarios are employed as elements of an evolving teaching sequence.

2.2.5 Conceptual Change

Since the 1980s, several theoretical models have been developed to explain conceptual change in the context of school learning (for example, Carmichael *et al*. 1990; Chi 1992; Chi & Roscoe 2002; diSessa 1993; Posner *et al.* 1982) and many of these have purported the notion of cognitive conflict to resolve dissonance as a constructive intellectual activity with desirable educational outcomes (Duit, *et al.* 2001). The most commonly adopted process involves the provision of anomalous data or suggestions of consideration of alternate components of observed phenomena inconsistent with student observations. Several researchers including Chan, Burtis and Bereiter (1997) reported positive results from application of this strategy. Others, including Champagne, Gunstone and Klopfer (1985), Dreyfus, Jungwirth and Eliovitch (1990), and Limon and Carretero (1997) reported negative results when adopting this type of strategy because 'even when students are confronted with contradictory information, they are often unable to achieve meaningful conflict or to become dissatisfied with their prior conceptions' (Chan, Burtis & Bereiter 1997:2). Limón (2001) reported that, despite any positive effects on learning, the lack of efficacy for students to achieve a strong restructure of their understanding limits the effectiveness of the process in contexts where a variety of student perceptions are present. Hence, specific approaches using this strategy to a classroom of students are limited, particularly as, up until recently, there has been no reliable method by which to assess the cognitive conflict students experience in their learning (Lee *et al.* 2003). It is apparent, however that this approach fails to consider the interaction of peers and the sharing of explanations for specific observations when building, developing or amending conceptual models that may be acknowledged as understanding.

> *A fundamental tenet in adopting a constructivist approach to the development of teaching strategies is that higher mental functioning as a component of learning is derived from social interaction both in terms of explaining one's model for an observation to someone more capable such as a teacher, or justifying and defending one's model with peers.* (Vygotsky, 1978:128)

One aspect of the cognitive conflict approach gaining increasing levels of support in the teaching of science is the recognition and incorporation of peer, or small group, or collaborative learning strategies (for example, Crouch & Mazur 2001; Johnson, Johnson & Smith 1991; Kagan 1990; Mazur 1997; Nelson 1994, 2005). In these situations students are encouraged to share their observations, and their explanations of those observations, with their peers in the first instance, using words that are commonly used and appropriate to them. It is postulated that discussion of the differences between explanations leads to the creation of a personal model of the concept or phenomenon under observation that is more closely akin to a realistic model. This new conceptual understanding is built in the sense that it is constructed from the student's previous knowledge by the incorporation of new ideas from personal or co-operative observations and explanations of peers. This model also closely matches the Predict-Observe-Explain (Palmer 1995)[4] learning strategy that is incorporated into the 5Es model (Australian Academy of Science 2007).

2.2.6 Sequence Design

In designing the sequences and considering the pedagogical approaches to their exploration, the five characteristics of constructivist teaching outlined by Appleton and Asoko *et al.* (1996), and the six identified by So (2002) to infer the use of constructivist views of learning by teachers to inform teaching, were incorporated into the classroom and lecture experience for the participants. The combined elements of these two diagnostic approaches lead to fundamental indicators described in Table 2.1 below. These indicators were adopted to guide the constructivist, socially interactive, inquiry driven teaching process modelled during phases II and III of the project.

[4] The Palmer (1995) strategy has been modified for the purposes of this project to incorporate the Share component reflective of the peer-learning situation espoused by Cobb (1996) as part of 'Eclectic Constructivism'– hence the model is presented here as Predict-Observe-Explain-Share.

Teacher Consideration	Indicators
A prior awareness of the ideas which learners bring to the learning situation, and/or attempts to elicit such ideas.	• each learner's ideas elicited before presenting the teacher's own (note individual diagnosis to reflect emphasis on the needs of the each learner) • challenge each learner's initial ideas by providing experiences that challenge existing explanatory models.
Clearly defined conceptual goals for the learners and an understanding of how learners might progress toward these.	• learners predict their observations • learners observe phenomena • learners describe phenomena • learners generate explanations and interpretations • learners explain to each other their explanations • teacher probes learner responses for clarification and justifications of identified contradictions and misconceptions
Use of teaching strategies that involve challenge to, or development of, the initial ideas of the learner and ways of making new ideas accessible to them.	• encouraged and active participation in a question-rich learning environment • learners generate their own questions to each other first, and then to the teacher, based on their observations • the teacher facilitates the investigation of the student question by the learner • learners expand on their questions and justify their responses
Provision of opportunities for the learners to utilize new ideas in a range of contexts.	• learners work with familiar materials (readily available and suitable for use in K-6 classrooms) and engage in inquiry activities that require psychomotor skills appropriate for the learner • with minimal help from the teacher, learners are encouraged to explore 'student questions' from a variety of approaches and not just seek an answer to a predetermined question
Provision of a classroom atmosphere that encourages children to put forward and discuss ideas.	• pupils put forward and discuss ideas with peers • pupils put forward and discuss ideas with the teacher • demonstrate connections that relate current, new observations and ideas to previous knowledge • pupils apply knowledge to new situations or real-life problem

Table 2.1: The combined elements of teacher awareness indicators of constructivist teaching strategies (modified from Appleton and Asoko (1996), and So (2002)).

2.2.7 Assessment

While much research over the last twenty years has focused on assessing the conceptual understanding of students using concept inventories, the vast majority of that research concentrated on undergraduates studying introductory physics courses (Evans *et al.* 2003; Halloun & Hestenes 1985; Pellegrino, Chudowsky & Glasser 2001; Richardson 2004). Pellegrino defines an assessment as 'a tool designed to observe students' behaviour and produce data that can be used to draw reasonable inferences about what students know' (2003:e7). What the teacher does with this data is only recently being considered as an important aspect of effective teaching in terms of its ability to guide future teaching strategies that address the limitations of the knowledge levels identified by the assessment processes.

Facilitating opportunities for participants to act as teachers (the cohorts of EDSE213 and EDSE412 as pre-service teachers learning about fundamental science concepts) encourages the consideration of formative assessment as a means of identifying change in conceptual understanding. This also emphasises the value of learner-designed assessment, enhancing the *Evaluate* component of the 5Es learning cycle as a celebration of learning identified by the learner (Australian Academy of Science (2007)).

As an integral component of K-6 science education, the Board of Studies NSW K-6 Science and Technology Syllabus and Support Document (1993) states that assessment:

- *provides advice on the means of gathering evidence of, and making judgements about, students' needs, strengths, abilities and achievements.*
- *provides advice on the means of collecting data and making judgements about the effectiveness of teaching programs, procedures and policies.* (28)

Specifically, the syllabus lists strategies for the assessment of students and the evaluation of teaching programs utilised for the learning process. Formative assessments available for the teacher to provide feedback to students are not considered in either the syllabus nor support document, yet many educationists extol the benefits of such strategies in the classroom as of equal value to both the learner and the teacher. The National Research Council (1999, 2006) suggests that diagnostic, formative assessments should be embedded into teaching sequences, used to gauge the students' developing understanding and to promote their self-reflection on their thinking processes. Such practices also promote reflection by the teacher in terms of the effectiveness of the teaching strategies they employed. Experience with the design of such data collection and pedagogical guidance mechanisms should therefore be of significant importance in teacher education programs. Formative assessment, considered as a fundamental tool for evaluating how well teaching is working, is examined in detail during this project in terms of the feedback provided to:

- the teacher about the level of desired development and conceptual growth and understanding; and

- the student as a reflective mechanism empowering them to take a degree of ownership of their own learning. (Australian Academy of Science 2007)

Participants in this project were encouraged to reflect on their personal learning journey and hence evaluate the strategies used to impart to them the fundamental conceptual understanding identified at the beginning of the teaching sequence(s). This entailed the identification of formative assessment techniques that provided information to the participant about the learning process in terms of:

- Being a learner, how is achievement recognised?
- Being a teacher, how is achievement recognised? And, if it is lacking,
    - What was it about the employed teaching strategies that were ineffective?
    - What teaching strategies may be employed to address the shortcoming?

2.3 TEACHING ABOUT FUNDAMENTAL ELECTRICITY AND MAGNETISM CONCEPTS

The following literature summary covers a broad selection of articles that were intended by their authors to be used specifically in the teaching of fundamental concepts of electricity and magnetism, and their interactions. The emphasis is on teaching the concepts to K-6 students. Research into the identification of commonly held misconceptions by K-6 students[5] is also discussed. Articles dealing with electricity and magnetism have been treated separately to reflect the differences in the types and styles of articles.

It is widely acknowledged that applications of electrical and magnetic phenomena are increasingly playing integral roles in the daily lives of people throughout the world. However, a search of the available educational literature reveals that there has been very little research devoted to the teaching and learning of fundamental electrical and magnetic phenomena in the K-6 years of schooling. Recognising that students have existing ideas about electric and magnetic phenomena (Cosgrove 1995; Demirci & Çirkinoglu 2004; Epni & Keles 2006; Maloney *et al.* 2001; Raduta 2005; Tsai 2003) and that it is very difficult to change pre-existing conceptual understanding (Carey 1991; Chi & Roscoe 2002; Duit *et al.* 2001; Strike & Posner 1982; and others), it becomes pertinent to consider how best to construct correct fundamental conceptual understanding in those

[5] Keith Skamp, in his book Teaching Primary Science Constructively (2008), provides examples of commonly held misconceptions for many of the elements of K-6 primary science syllabi.

early years of schooling for later development by more specialised secondary and tertiary learning opportunities.

2.3.1 Teaching about Electricity

While students' understanding of electricity has been studied extensively over the past 30 years, covering a wide range of age groups from primary to university level, the majority of pedagogical research into the learning and teaching about electricity in school contexts tends to be limited to: conceptual understanding associated with models of flow of charge in an electric circuit (Asoko *et al.* 1996; Cosgrove 1995; Osborne 1981; Shipstone 1984); pupils' views about the properties and uses of electricity (Duit, Jung & von Rhöneck 1985; Sefton 2002; Solomonidou & Kakana 2000); and connections in circuits (Asoko *et al.* 1996; Osborne 1981). Limited research in these areas has been carried out with the youngest children in primary school (Azaiza, Bar & Galili 2006; Blosser 1987; Cosgrove & Osborne 1985; Cosgrove 1995; Driver, Guesne & Tiberghien 1983; Winters & Hammer 2009). By far the majority of the literature refers to learning about electricity in high school, and in colleges and universities (for example, Borges 1999; Bradamante, Michelini & Stefanel 2006; Chabay & Sherwood 1999; Chabay & Sherwood 2005; Duit & von Rhöneck 1997; Raduta 2005; Sefton 2002; Taber, de Trafford & Quali 2006). It appears that the subject is too specialised to have significant presence in mainstream education literature.

2.3.2 K-6 Electricity 'Misconceptions'

Things should be made as simple as possible, but not any simpler. (Albert Einstein[6])

In order to identify 'misconceptions' in learners as a starting point to changing that understanding, many different forms of concept inventory have been developed, most of which are applicable to university courses (TUG-K, BEMA, CLASS, CSEM, DEEM, ECCE, FCI and FCME[7] to name a few). Attempts to identify the sources of such misconceptions often place the blame on textbooks where the wording of specific phenomenon explanation has been ambiguous, or presents with possible multiple meanings (Raduta

[6] A quote attributed to Einstein, but probably paraphrased from: 'It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience'. From 'On the Method of Theoretical Physics', The Herbert Spencer Lecture, delivered at Oxford (10 June 1933); also published in *Philosophy of Science*, Vol. 1, No. 2 (April 1934), pp. 163-169, p. 165.

[7] **TUG-K** - Test of Understanding Graphs in Kinematics (Beichner 1994); **BEMA** – Brief Electricity and Magnetism Assessment (Ding, Chabay, Sherwood & Beichner 2006); **CLASS** - Colorado Learning Attitudes about Science Survey (Adams, Perkins, Podolefsky, Dubson, Finkelstein and Wieman 2006); **CSEM** – Conceptual Survey of Electricity and Magnetism (Maloney, O'Kuma, Hieggelke and Heuvelen 2001); **DEEM** - Diagnostic Exam Electricity and Magnetism (Marx 1999); **ECCE** - Electric Circuits Concept Evaluation (Thornton and Sokoloff 1998); **FCI** – Focre Concept Inventory (Hestenes, Halloun and Wells 1998); **FMCE** - Force and Motion Conceptual Evaluation (Thornton and Sokoloff 1998).

2005). However, increasingly, the learner's own experience and intuitive attempts to explain phenomena are being recognised as major contributors (Appleton 2003; Bitner 1992; Blosser 1987; Harlen & Holroyd 1997; Posner *et al.* 1982).

Several authors have identified what may be regarded as 'incorrect' understandings of electric phenomena. These include the speed of electron flow in a circuit, the 'creation' of electricity, ideas that 'batteries store electrons', 'electric current is a flow of energy', 'water is a good conductor of electricity' and 'electricity comes out of the power point'. Beaty (2001, 2005) attempts to explain many of the misconceptions identified by other researchers and concurs with Raduta (2005) and Simanek (2008) by claiming that many of the misconceptions derive from poorly worded descriptions in textbooks.

Taber, de Trafford and Quali (2006) have discussed ways of solving the problems associated with misconceptions in electricity held by students through the use of models, analogies and personal imagination. For example, there is evidence that many students may recognise the logical implications of specific pieces of evidence in relation to different models of electricity flow but resolve inconsistencies in the application of one model by constructing or selecting new or different models to explain the behaviour of different circuits in different applications (Leach 1999; Leach & Scott 2002).

2.3.3 What K-6 Students Know about Electricity

The constructivist approach to learning suggests that learners have ideas about phenomena including electricity. Azaiza, Bar and Galili (2006) provide a detailed description of previous research on elementary (K-6) students' concepts of electricity, describing mental images held by students (Borges & Gilbert, 1999; Osborne, 1981; Stocklmayer & Treagust 1996) and descriptive models held by students about the nature of direct current (Driver, Guesne & Tiberghein 1983; Osborne 1981; Shipstone 1984). They surmised that these ideas or explanations, are constructed from learner's personal experience, and are justified and modified according to new experience or after being convinced that a better explanation exists. The source of this better explanation may be:

- an experience that is not concomitant with their personal model or conception;
- an observation, such as that gained through the media (what used to be written in books and magazines, is now more audiovisual — television and computers in particular); and/or,

- a more knowledgeable person, such as a teacher, or parent (Vygotsky 1978), or their peers.

During the course of everyday social interaction, learners, particularly those in their formative K-12 years of schooling, tend to listen more to their peers than to more knowledgeable experts. Sampayo (2006) points out that differences between the everyday language of the learner and language to which they are exposed during the formal schooling process, leads to confusion and may cause learners to lack confidence in their own knowledge or to question their own understanding. Leach (1999) points out that the everyday social language of the learner often does not agree with the scientific explanations of phenomena. For example, they know that 'volts' has something to do with electricity but believe that 'watts' is to do with how loud an amplifier can make their favourite music. Amps and ohms have little (amps = fuses) or no application (ohms = ?), in their everyday existence.

Other sources of explanatory models used by students were described by Solomon *et al.* as 'a store of life-world knowledge, with associated folklore and emotional overtones' (1985:289). In describing the nature of electricity as a possible thing of danger, Borges and Gilbert (1999) point out that younger learners tend to reflect and enunciate what they were told in terms of electricity causing pain, fire and maybe even death. Considering the possible dangers associated with the abuse of electricity, either by accident, ignorance or design, it is significant to note that there are very few references in the literature to students' knowledge of the issues of safety with electricity.

The inconsistencies with respect to learner language and scientific language are a reflection of the didactic and transmissive manner in which many of the concepts associated with electricity are often taught in schools. Syllabus documents require that the learner knows the definition of such terms as volts and watts without the provision of a relevant framework to make it meaningful for the learner to learn them.

The application of the teaching strategies trialled in this project avoids such barriers to conceptual understanding by, as the Australian Academy of Science (2007) 5Es model espouses, encouraging learners to initially use their own words and language to describe observed phenomena (*Explore* phase). It is not until the third (*Explain*) phase that the teacher begins to introduce scientific language and, as Sampayo (2006) has found, often this is after the students have done so themselves, of their own volition.

The literature points out that K-6 students have a very limited knowledge of electrical concepts, and that their personal explanatory models often differ from the more accepted scientific norm. This lack of knowledge often translates to a negative attitude toward science and may be maintained through later school studies if the learner's explanations do not match their observations. This can also be maintained beyond school and, in the case of the participants involved in this study, has been translated to a dislike of science as a subject, even though they will be required to teach 'it' in their classrooms. Considering the limited science learning experience of most pre-service teachers participating in this study, it is clear that if a fundamental knowledge science concepts is to be drawn upon for use in the K-6 classroom, a different learning approach will need to be applied, other than the one that created the air of malcontent among the learners in their school experience.

2.3.4 Ideas for Teaching K-6 about Electricity

The Board of Studies NSW K-6 Science and Technology Syllabus and Support Document (1993) states that 'The aim, objectives, learning experiences and learning outcomes of the Science and Technology syllabus are drawn from science education and technology education' (1). It also 'specifies that students will engage in learning experiences which will involve both scientific and technological content and processes' (5).

The question of what should be taught to K-6 students about electricity is, therefore, usually directed by education authorities through the syllabus document, or by textbook writers or teaching resource providers without any apparent justification. As Taber, de Trafford and Quail (2006) point out:

> *…curriculum models that are presented as 'target knowledge' for different levels/stages of school physics need to be simplifications of the scientific models used by professional physicists. Ideally, we aim for the 'optimum level of simplification' (Taber 2000), where we simplify enough for students to be able to understand and learn the target knowledge, but where the curriculum models themselves are authentic enough to support progression towards more sophisticated learning later.* (157)

These curriculum models do not, however, tend to consider the notion espoused by constructivist learning theory that learners are not 'blank slates', that they have deeply rooted ideas about the world, which are, to them, seemingly logical consequences of their perceptions and often reinforced with personal experience. Using the *Board of Studies NSW K-6 Science and Technology Syllabus and Support Document* (1993) as an example, the references to the concepts of electricity and magnetism are limited to a unit entitled 'Stuck on you' (96) in Stage 2 (Years 3 and 4) where the attractive/repulsive properties of static electricity and magnets are investigated. Ways of generating static electricity are also explored. In Stage 3 (Years 5 and 6), a unit entitled ‘Switched On’ (120) focuses on electrical circuits and their uses, requiring that students demonstrate a device that uses a simple electric circuit. The unit also recommends a link to the ‘Personal Development, Health and Physical Education Key Learning Area’ by referring to the safe use of electricity in the home. Tasks suggested for the students to complete include:

- Design and make a device that uses a simple electric circuit.
- Using a simple circuit design, make a device to test which materials will/will not conduct electricity.
- Design and make a presentation demonstrating how energy may be supplied to a community without using fossil fuels.
- Investigate the use of electrical circuits in our environment.
- Investigate the conditions that need to be fulfilled to make an electric circuit.
- Investigate the generation of electricity for everyday use.

The descriptions of the activities that may be incorporated into lessons to achieve these suggested tasks demonstrate a significant source of possible confusion with respect to the construction of conceptual understanding of electrical phenomena. For example: ‘observe items that are **powered** by simple electrical circuits’; ’classify (items) according to their electricity source, that is, mains or battery’; ‘discuss the **function** of batteries’; ’explore where the electricity we use **comes from**, for example, the power point, wires in the wall, circuit board, power lines, power station, fuel source‘; and ’research how electricity is **produced**‘ (96) are statements that require a deeper conceptual understanding by the teacher, particularly in terms of their confusing and contradictory nature. The necessary process of establishing links between the concepts explored in each of the suggested activities is not suggested nor implied. Hence the teacher is often presenting these activities in isolation because they themselves do not have an in-depth understanding of the relationships that exist between each of the phenomena under investigation.

The teaching strategies (referred to as Activities) associated with the assigned ‘Tasks’ may be loosely divided into instructional and experiential. The instructional mechanisms relate to suggested materials that may be presented to the student in a transmissive manner by either the teacher, a text or by audiovisual means including a video or television program or the use of computer software. The experiential investigations refer to activities that are designed to:

> *... capitalise on the fact that students learn best when they are actively engaged in the learning process. The provision of cooperative, hands-on, problem solving activities will assist students to develop strategies for dealing with new and unexpected circumstances and issues.* (Board of Studies NSW K-6 Science and Technology Syllabus and Support Document 1993:6)

In supporting the mandated content and experiences of various syllabi for K-6 science, many authors have developed a vast array of texts, activity books, lesson plans, sequences, models, analogies, simulations (including audiovisual, interactive software and online materials), equipment and assessment materials to assist students to achieve the outcomes defined by the various syllabi. Unfortunately, the plethora of available resources has led to confusion and reluctance to present more than the simplest of activities suggested by these materials. There is a dearth, however, of reviews or evaluations that are readily available to teachers to assist them to make informed decisions about the materials available. Hence the need for additional professional development to encourage sharing of experiences and/or enabling teachers to 'play' with the resources becomes apparent.

A number of tertiary institutions have designed courses that attempt to meet the needs of K-6 teachers for professional support to understand the fundamentals of electricity phenomena. One such course, 'Teaching Electricity and Circuits in the Elementary Classroom', offered by the University of North Carolina, is a six-week course and is designed to:

> *Boost your understanding of electricity and currents -- and impart that understanding to elementary students -- using inquiry-based instruction.*
>
> *In this workshop you'll learn about the science behind electricity and circuits, including conducting and insulating materials, open and closed circuits, and series and parallel circuits.*
>
> *You will acquire numerous inquiry-based teaching strategies throughout the course that will enhance your questioning techniques and teach you to better assess students' understanding of the content.* (Learn NC: Online).

Other online and printed materials similarly detail mechanisms to support K-6 teacher education and student learning in this area, or provide teaching and assessment strategies[8]. Anecdotal evidence comprising discussions pre-service teachers, beginning teachers and experienced teachers (see Section 4.5.2) reveals a perception that K-6 teachers do not generally take with them, from their pre-service teacher training experience, enough knowledge to effectively teach syllabus-required concepts in the realm of fundamental electricity.

2.3.5 Teaching about Magnetism

Student understanding of magnetism in the K-6 classroom context has been largely limited to magnetic interactions and magnetic materials. However, they have also experienced such things as magnetic refrigerator door closers, refrigerator magnets, the earth's magnetic field, magnetic toys and compasses. Most learners of school graduation age would have played with magnets and, increasingly, toys that use the magnetic properties of certain materials are being released on the market (a simple internet search yielded in excess of 314,000 results to search for 'magnetic toys'). The *Board of Studies NSW K-6 Science and Technology Syllabus and Support Document* (1993) is specific with respect to what K-6 students should undertake, stating that students should 'explore magnetic phenomena'. The Stage 2 Scope and Sequence element 'Stuck on You' (Years 3 and 4) identifies the property: 'magnets attract some materials but not others' (94); and in the Physical Phenomena context: 'magnetism and some of its properties'. In the assessment of the unit, suggestions include:

- Challenge students to make a device that is able to compare the strength of two magnets.
- Ask students to compare the strength of several magnets and to place these magnets in order of magnetic strength.
- Discuss with students their understanding of how a magnet can be used to make a motor.

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[8] In terms of K-6 teacher education, examples of two well-received physics education research based curricula in the United States are:

- Physics and Everyday Thinking (formerly Physics for Elementary Teachers) (PET), is 'a one-semester curriculum designed in part for prospective or practicing elementary teachers' (http://petproject.sdsu.edu/); and
- Physics by Inquiry, 'a set of laboratory-based modules that provide a step-by-step introduction to physics and the physical sciences.' '*Physics by Inquiry* is particularly appropriate for preparing preservice and inservice K-12 teachers to teach science as a process of inquiry' (http://www.phys.washington.edu/groups/peg/pbi.html).

The document goes on to suggest some resources for teaching about the content to achieve the outcomes but does not acknowledge the probable limiting factor of teacher knowledge with respect to these poorly defined phenomena — that have been in the realm of human experience for thousands of years, but that only recently are being explained conceptually. The syllabus does not prescribe investigations into the nature of polarity exhibited by magnets, nor the concept of fields that surround magnets, nor how magnets may be made. These omissions contribute to several misconceptions that are often overlooked or not addressed by secondary teachers, particularly if the dislike for science investigations has been entrenched in the learner.

2.3.6 K-6 Magnetism 'Misconceptions'

Research into the understanding of learners, with respect to fundamental aspects of magnetism, has been generally limited to high school students and undergraduates. Concentrating on the identification of misconceptions, the vast majority of this research does not consider the way that learners have constructed their existing mental models for magnetic phenomena and how these models relate to the learner's personal experience (Borges & Gilbert 1998; Brown & Jackson 2007; Johnson 1999; Narjaikaew *et al.* 2010; Ravanis, Pantidos & Vitoratos 2009). The misconceptions have generally been identified using instruments including concept inventories (see footnote 4) and other diagnostic tests. Most of the research states that the identified misconceptions tend to reflect on the teaching experiences of the learners and do not consider learners' previous learning experiences as a key factor in understanding the magnetic phenomena (Tanel & Erol 2008).

As is the case with student misconceptions about electricity, the research literature highlights the fact that K-6 students' knowledge of fundamental magnetism concepts is limited to observation and personal experience as a school-based inquiry, and that its mystery remains with considerable confusion and without reasonable explanation at the conceptual model level (Erickson 1994; Raduta 2005; Ravanis, Pantidos & Vitoratos 2009).

2.3.7 Ideas for Teaching K-6 about Magnetism

As detailed by the Board of Studies *NSW K-6 Science and Technology Syllabus and Support Document* (1993), the teaching of fundamental conceptual understanding of magnetic phenomena is limited to investigations about magnets, magnetic materials, their interactions and possible applications including the electric motor. The combination of magnetic materials explorations with investigations of static electricity can only lead to a confusion of models for the explanation of the interaction of magnetic poles and that associated with electrical charges. Several elementary texts and online resources continue to promulgate this cloudy link (for example *Gordon Speer on Electricity and Magnetism*: online). For example, questions are being of online resources such as 'I was wondering if **static** electricity produces **magnetism**?' (*Argonne National Laboratory – Ask a Scientist*: online) and answered in a manner that incorporates a number of abstract concepts including electric fields and picoamps), without context or relevance to the learner's experience.

Other textual and online resources[9] provide a content-based discourse on the properties of magnetic materials, their applications to everyday society and some even endeavour to provide analogies designed to create mental models for a conceptual explanation of the phenomena being described (for example *Nondestructive Testing Resource Centre – Magnetism* (online); *Thomasnet – More about Magnets* (online); *Magnet Man – experiments with magnets* (online); and *Explainthatstuff – magnetism* (online)).

Considering the confusion created by the abstract nature of magnetism, the teaching strategies developed during this project have not introduced the concept of permanent magnetism until late in the sequence, with the properties of magnetism induced by electric currents in coils chosen as a means to build a model to explain the existence of magnetic fields. This also promotes the establishment of a link between electricity and magnetism that can be observed and experienced rather than constructed in the abstract consciousness of the learner.

2.4 CHAPTER TWO SUMMARY

The research literature reveals that the determination of what should be learned by K-6 students in terms of electricity and magnetism has been a constant since the study of science became a mandatory field of investigation in most schools. The prescribed learning has been based on an accumulation of facts and apparently (to the learner) unrelated and abstract concepts. This is in spite of recent calls for a shift away from the traditional, didactic and transmissive approach to learning science as a body of knowledge toward a process of knowledge acquisition by inquiry reflective of learner perceptions of relevance. I acknowledge that many resources, models, analogies, learning sequences and lesson plans have been developed to support the learning of fundamental electric and magnetic phenomena, and to induce appropriate conceptual change. The adoption of these by K-6 teachers is superficial and acts as a crutch used to compensate

[9] An internet search (11 November 2010) revealed at least 33,100,000 links that make reference to magnets.

for their own lack of knowledge and understanding of the basic concepts. For example, many kits are available to build simple electric motors but invariably, these kits do not facilitate additional investigations of higher-level concepts such as factors that affect the efficiency of electric motors including the strength of the magnetic field and other variables. Thus, inexperienced and experienced teachers alike, without the necessary background conceptual understanding, tend to be restricted by the supporting material directed by, or aligned with the apparatus/resource/textual materials.

Similarly, many studies have endeavoured to assess student knowledge and identify misconceptions in the fields of electricity and magnetism. These, however, have mainly concentrated on senior high school and undergraduate students in an effort to diagnose areas of learning in need of remediation. Few attempts have referred to the fact that pre-existing understanding based on student experience often overshadows new information presented in the traditional formats of exposition and transmission of knowledge.

> *The challenge for school science teaching is so to structure the learning environment for the students that there is sufficient opportunity for play and practice in the areas of experience required by all students while at the same time to provide ample opportunity for every student to explore for themselves and to face their own challenges in investigations, such a structure clearly needs flexibility and space if it is to allow for individual needs, as in our thesis it must.* Woolnough (1989:131)

The results of this literature review, coupled with collegial and student discussions, informed the design and construction of the initial teaching and learning activities as part of this research. The sequence was undertaken by a cohort of second-year pre-service K-6 teachers, to identify and develop their knowledge and understanding, and to highlight the need to provide experiences to learners, that build upon existing personal understanding.

CHAPTER 3

DEVELOPMENT OF THE RESEARCH PLAN

3.1 INTRODUCTION

This chapter describes the educational environment and the philosophical and methodological framework of the project. The primary research setting and the pre-service teacher programs are also outlined. A detailed description of the research tools employed in the study, as well as the fully developed research plan, complete the chapter.

3.2 RESEARCH SETTING

The University of New England, an Australian public university, was established in 1938 as the New England University College, a College of the University of Sydney. As the first Australian university established outside a capital city, it became fully independent in 1954, and was named the University of New England (UNE). Its original and main campus is located in the city of Armidale in New South Wales, Australia. As at the 1st of July 2010, there were approximately 19,700 higher education students enrolled at the UNE (15,300 external and 4,400 internal. More than 20% of students were enrolled in pre-service teacher education programs).

Armidale has a long history of teacher education, with the establishment in 1928 of the Armidale Teachers' College, which became the Armidale College of Advanced Education in 1971 before being amalgamated with the UNE in 1989.

3.2.1 The School of Education

The UNE School of Education provides undergraduate and postgraduate teacher education programs for students in early childhood, primary (K-6) and secondary (7-12) schooling. Teacher preparation programs are available for school leavers and university graduates. Ongoing professional learning opportunities are also available for teachers in Graduate Certificate, Masters Degree, Professional Doctorate and short non-award programs. Students have the choice to enrol on campus, or may use a blended mode that includes distance education components. All units in the programs are supported by online learning management systems. These provide an integrated and common platform for students to facilitate direct engagement with their lecturers and peers, whether on campus or using distance education opportunities. These opportunities are available for both Australian and international students.

The School of Education has a strong research arm specialising in rural and regional education within Australian and international contexts. The flagship research group, the National Centre of Science, Information and Communication Technology, and Mathematics Education for Rural and Regional Australia (SiMERR Australia) was established within the School of Education at UNE in 1996. SiMERR Australia works with rural and regional communities to achieve improved educational outcomes for all students in the areas of science, information and communications technology (ICT) and mathematics education. The School of Education also hosts the Centre for Research in English and Multiliteracies Education (CREME) whose research activities and expertise in all aspects of literacy education in English and other curriculum areas provide support for researchers, teachers, students and others involved in primary (K-6) and secondary (7-12) school education.

3.2.2 Teacher Education Programs

Pre-service teacher training pathways available at UNE include:

Primary and Early Childhood Teachers:

- *Undergraduate*: Bachelor of Education or subject-specific double degree with Bachelor of Teaching;
- *Postgraduate*: Bachelor of Education, Bachelor of Teaching, Graduate Certificate in specific aspects of education, Graduate Diploma of Education, Master of Teaching and Master of Education, Master of Educational Administration and Doctor of Education.

Secondary, subject-specific Teachers:

- *Undergraduate*: subject-specific double degrees with Bachelor of Teaching;
- *Postgraduate*: Bachelor of Education, Bachelor of Teaching, Graduate Certificate in specific aspects of school education, Graduate Diploma of Education, Master of Teaching and Master of Education, Master of Educational Administration and Doctor of Education.

The Bachelor of Education (Primary) program is designed to train generalist primary school teachers. Upon graduation, they are usually required to teach each of seven Key Learning Areas comprising English, Mathematics, Creative Arts, Human Society in its Environment, Languages, Personal Development, Health and Physical Education, and Science and Technology as directed by education authority defined syllabi.

Students may enter the program directly from graduating high school. Mature age entry into the program is also available. Admission to the program does not require the study of science beyond the compulsory School Certificate (Year 10) or equivalent.

The School of Education graduates approximately 300 on campus mode and 600 off campus mode students per year. In relation to this study, approximately 120 on campus full-time and approximately 150 off campus part-time undergraduate students enrolled in the four-year Bachelor of Education (Primary) program were involved in the data collection process. An outline of the Bachelor of Education (Primary) course program is contained in Appendix B.

3.2.3 K-6 Science Education Units

During the four years (full-time equivalent) of study, students are required to study two science-based units (described below) totalling 12 credit points from a total of 192 credit points required for the award of the degree.

Primary Science and Technology Curriculum Studies, EDSE213, is a 6 credit points, one semester unit designed to examine strategies for implementing science and technology curricula in the K-6 years of schooling. Students participate in a range of experiences consistent with contemporary approaches to learning and teaching, including the development and trialling of materials. Refer to Appendix B for a unit outline and list of specific outcomes.

Primary Environmental Science for Sustainability, EDSE412, is a 6 credit points, one semester unit, which focuses on implementation strategies to facilitate children's learning consistent with contemporary, constructivist views of learning and teaching in the K-6 primary school. The unit integrates selected syllabus-defined content, and specific pedagogies for primary Science and Technology. The unit emphasises lesson planning and effective ways to assess student learning. Current state and Federal government policies relating to environmental education are also examined. Refer to Appendix B for a course outline and the list of specific outcomes.

3.3 METHODOLOGICAL AND PHILOSOPHICAL PERSPECTIVES

To comprehensively address the research questions, I chose to adopt a multi-methodological approach. This decision was guided by the view that the selection of a single research methodology and following the prescribed path dictated by such a choice might obscure other valid perspectives.

3.3.1 Rationale

Brown (1992) recognised the complex nature of the classroom as an interactive environment where many different factors interplay to promote learning. He considered the shortcomings of a single research instrument when working in school-type learning situations and proposed a 'mix and match of qualitative and quantitative methodologies' (156) to suit the data.

Similarly, Kagan (1990) has criticised research designs in which only one method or instrument is applied. She argues that such designs are problematic because a single instrument, as applied to the classroom environment, cannot accurately capture the complexity of teacher-student interactions or of knowledge building. Kagan, therefore, suggests the application of multi-method designs, which focus on specific, well-defined aspects of how knowledge may be imparted to the learner. Kagan further recommends the use of techniques that 'yield qualitative, molar descriptions' and concludes that 'the use of multi-method approaches appears to be superior, not simply because they allow triangulation of data, but because they are more likely to capture the complex, multifaceted aspects of teaching and learning' (Kagan 1990:459). Cohen, Manion & Morrison (2007) support Kagan's argument, citing the propositions of Lin (1976) and Smith (1975) that reliance by the researcher on one method 'may bias or distort the researcher's picture of the particular slice of reality' (141) under investigation.

Informed by several philosophical viewpoints, this study employed multiple method perspectives in order to collect and analyse the data as objectively as possible. However, as the researcher, I considered the inherent danger of adopting multiple methodologies in that it may lead to a confusion of different research methods, tools and procedures, as each methodology and its associated research tools imports a unique set of underlying principles and assumptions. To minimise confusion between the differing research purposes and procedures employed, each research component was kept separate during the data collection and analysis phases.

3.3.2 Foundations for Selecting an Educational Research Methodology

> *Good research practice obligates the researcher to triangulate, that is, to use multiple methods, data sources, and researchers to enhance the validity of research findings* (Mathison 1988:13)

As researcher, I considered that the research plan would benefit from the utilisation of a range of methodologies and associated research tools, thereby increasing the perspectives from which the collected research data can be considered. The interplay between methodology and philosophy throughout the predominantly qualitative research processes undertaken during this project strongly supports the argument for using multi-methods, without compromising the integrity of each of the different methods. As the collected data is defined by the perceptions of individuals, and therefore is able to be categorised within the realm of social reality, the use of multi-methods provides a strategy that assists in the removal of bias and extraneous explanations to ensure a truthful proposition about the observed phenomenon is constructed (Campbell & Fiske 1959; Denzin 1978)

Cohen, Manion and Morrison's analysis of social reality (2007:7-9), which was based on the work of Burrell and Morgan (1979), identified four sets of assumptions with which to approach an understanding of the relationship between social reality and research. These are:

Ontology

Ontological assumptions are those that are made about the nature or essence of the social phenomena being investigated and beg consideration of the question 'is social reality external to an individual's (a given in the world), or is it the product of the individual's consciousness (created in one's own mind?)' (7). The question itself reflects the nominalist-realist debate. *Nominalists* view objects of thought merely as descriptions, believing that there is no independent accessible thing constituting the meaning of the word within the description. *Realists* contend that objects have an existence and are not dependent for it on the knower. To inform this study about the social aspect of knowledge construction, I adopted the assumption that social reality is a product of individual consciousness — that is, created by one's own mind. Therefore, I operated within the nominalist ontological framework.

Epistemology

Epistemological assumptions concern the very basis of knowledge; its nature and forms, how it is acquired, and how it can be communicated to others. Positivists regard knowledge as objective; hard and tangible and demand that the researcher simply take an observer role. Anti-positivists (or 'post-positivists' (Littledyke & Manolas 2010)) view knowledge as subjective, personal, and unique, requiring the researcher to be 'involved' with the participants in the research.

In considering my own epistemological beliefs, I examined my assumptions about the learner's epistemological stance. Up until recently, researchers have usually adopted what has been referred to as a 'unitary ontology' (Hammer *et al*. 2005) to describe a learner's singular and consistent approach to epistemological beliefs. However, this thinking has given way to a 'manifold ontology' to describe learners' epistemology, suggesting that learners operate in different epistemological modes depending upon the context. In support of this notion, Hammer and Elby (2002) propose that learners possess epistemological resources ('knowledge as propagated stuff', 'knowledge as free creation', 'knowledge as fabricated stuff' (12)) that are analogous to diSessa's (1993) phenomenological primitives (p-primes). A learner invoking the 'knowledge as propagated' notion treats knowledge as an entity that can be passed from a source to a recipient. Other learners who invent their personal explanations are invoking the 'knowledge as free creation', while learners who invoke the 'knowledge as fabricated' resource, treat knowledge as something inferred or developed from other knowledge.

In looking at the variation in students' knowledge construction and model construction of fundamental electrical and magnetic phenomena for the purposes of this research, I chose to adopt the anti-positivist assumption that knowledge is personal, subjective and unique, and hence can inform teaching methods. Moreover, I subscribe to the view that learners activate a variety of epistemological resources in constructing and/or reconstructing their knowledge. In examining students' construction and reconstruction of their mental models, I sought to identify the epistemic mode that learners operate under and the epistemological resources that they use.

Human Nature

The third set of assumptions concerns human nature, particularly the relationship between human beings and their environment. Since learning by the human being is both the subject and the object of this study, the consequences for research of assumptions of this type are extensive (Cohen, Manion & Morrison 2007). Burrell and Morgan describe two images of the human being that can emerge from such assumptions:

> *…we can identify perspectives in social science which entail a view of human beings responding in a mechanistic or even deterministic fashion to the situations encountered in their external world. This view tends to be one in which human beings and their experiences are regarded as products of the environment; one in which humans are conditioned by their external circumstances. This extreme perspective can be contrasted with one which attributes to human beings a much more creative role: with a perspective where "free will" occupies the centre of the stage; where man is regarded as the creator of his environment, the controller as opposed to the controlled, the master rather than the marionette. In these two extreme views of the relationship between human beings and their environment, we are identifying a great philosophical debate between the advocates of determinism on the one hand and voluntarism on the other. Whilst there are social theories which adhere to each of these extremes, the assumptions of many social scientists are pitched somewhere in the range between.* (Burrell & Morgan 1979, cited in Cohen & Manion 1994:7)

The nature of this study, in terms of exploring how individuals construct their perceptions and understandings of particular phenomena, is best supported by the adoption of a voluntarist emphasis within the continuum of social theory.

Methodology

The fourth set of assumptions concerns itself with methodology. Kaplan (1964) suggests that the aim of describing a methodology is to help understand the processes that make up the research, rather than the results or products of that research. Two initial ways of looking at social reality defined by Cohen, Manion and Morrison (2007) are the traditional, which holds social and natural sciences as essentially the same, and a more recently emerging radical view which emphasises how people differ from inanimate natural phenomena and indeed each other (8-9). The first, which may be referred to as *nomothetic*, implies that the research should be directed at relationships between pre-determined factors as they occur in the natural world with the methods and procedures designed to discover general laws. The second view is more aligned with the methodology of this project in that it considers social reality in terms of the subjective experience of the individuals who have contributed to the study and the different ways their experiences may be considered. This approach may be referred to as *idiographic*.

Researchers' assumptions about human nature, ontology and epistemology have a great impact on the choice of appropriate methodologies. I believe that as a researcher, the philosophical perspectives that I have adopted for this study dictate my choice of methodology and research tools.

Mertens (2005) outlined four research paradigms that he based on different philosophical assumptions to guide and direct thinking and action: post-positivism, constructivist, transformative and pragmatic. In this research, the constructivist and pragmatic paradigms were adopted to guide and respond to the diverse purposes of this study. This notion is consistent with Holloway's view that:

> *…a researcher selects the methodology which encapsulates the philosophy, principles, and assumptions they hold about the nature of their research. It consists of the ideas underlying data collection and analysis.* (Holloway 1997:105)

3.3.3 Multi-methodological Considerations

In order to conduct a valid multi-method research study, a number of elements were reviewed to address validity and reliability issues of the data and its analysis, and reproducibility of the research situation and context. Processes identified that contribute to the integrity of the project are described below.

Reflexivity

Alfred Schutz, an influential existentialist who was interested in understanding the meaning and structure of everyday life, is credited with introducing the concept of reflexivity, in which people interpret meaning from a stream of consciousness by reflecting on what has been occurring (cited in Koch & Harrington 1998). Holloway (1997) describes reflexivity as a monitoring process that includes reflection about the researcher's reaction to the people and events in the research setting. Essential components of qualitative phenomenological research and inquiry is: awareness of the impact of the researcher's personality, preconceptions and assumptions; and attempted understanding of how these factors may effect the findings. In recognising this effect, I endeavoured to frequently reflect on its possible influence on the learning activities of the participants and the data collection methods. Investigator triangulation, as described below, was used to minimise undesirable bias in these processes, in the analysis of the accumulated data and to maintain a high level of validity.

Developing Theoretical Sensitivity

The researcher's theoretical sensitivity provides a platform for multifaceted examination of the collected data and helps to overcome fixation on the obvious. In this study I was guided, informed and had my theoretical sensitivity developed throughout the research project by: reviewing related literature; and having discussions with a wide range of practitioners in both teaching and research settings, and during the processes associated with the data management and analysis.

Triangulation

As has been implied, constructivist approaches to learning value the exposition of the multiple realities that people may have which explain their understanding of phenomena. Therefore, to acquire valid, multiple and diverse realities, multiple methods of searching or gathering data are in order. This calls for the use of triangulation in the constructivism paradigm; the use of investigators, method and data triangulations to verify the construction of reality is appropriate (Johnson 1997).

Triangulation in this research constitutes a process by which the same phenomenon is investigated from more than one perspective. Miles & Huberman (1984:235) make the point that '…triangulation is supposed to support a finding by showing that independent measures of it agree with it or, at least, don't contradict it'. Cohen, Manion & Morrison (2007:141) refer to triangulation as the use of two or more methods of data collection in the study of human behaviour to improve validity and overcome bias. Denzin (1978) suggest that the type of triangulation used in social research is dependent on the nature of the research project and defines four main types of triangulation that can be used in qualitative research situations. In brief, these may be described as:

- *Data triangulation:* the use of a variety of data sources in a study including time, space and person on the assumption that understanding a social phenomenon requires its examination under a variety of conditions.
- *Investigator Triangulation:* the use of several different researchers and/or data analysts to address the fact that most studies simply require more than one individual to accomplish the necessary data collection and analysis processes.
- *Theoretical Triangulation:* the use of multiple perspectives to interpret a single set of data and 'is most appropriate for the theoretically uncommitted, as well as for analysis of areas characterized by high theoretical incoherence' (Denzin 1978:307).
- *Methodological Triangulation:* the use of multiple methods to study a single phenomenon. Denzin further classified methodological triangulation as:
    - *Within-method*: using at least two data-collection procedures from the same design approach; and
    - *Between-or-across-method*: employing both qualitative and quantitative data collection methods in the same study.

Denzin suggests that the within-methods triangulation approach has limited value, because essentially only one method is being used, and declares the between-methods triangulation strategy more satisfying. 'The rationale for this strategy is that the flaws of one method are often the strengths of another: and by combining methods, observers can achieve the best of each while overcoming their unique deficiencies' (Denzin 1978:302).

This study utilises data, investigator and methodological triangulation to address validity and possible researcher bias. Specifically, data triangulation involved data collection from several different groups of students from within the same cohort (2nd year undergraduates) at different times during Phases II and III. Similarly, different groups within a different cohort (4th year undergraduates) provided another data source for Phase IV. Peer debriefing was implemented as a form of investigator triangulation when I engaged in discussion with my advisors and colleagues in the UNE Science Education Team about my analysis and conclusions. Members of this team also observed the data collection and analysis process and were interviewed at different stages to confirm consistency of process. Methodological triangulation was incorporated within this study by employing a range of within-method procedures to collect data including survey scripts, diagram analysis and focus interviews. In this study, it was also deemed important to incorporate between- or across-method triangulation by employing both qualitative (participant observation) and quantitative data collection (Likert-type scale and response counts) methods.

3.4 CONSTRUCTIVIST APPROACH

For the purposes of this project, a combined cognitive and social constructivist approach was adopted. This incorporated verbal, written and diagrammatic responses in the data set, as well as recorded observations of a level of physical skill attainment derived from individual constructions and peer interaction, discussion and consensus.

3.5 PHENOMENOLOGICAL PHILOSOPHICAL APPROACHES

Most qualitative research works are anchored in phenomenological philosophy. Phenomenology has had an impact on philosophical thinking and has served as a basis for qualitative research in areas of health and illness, psychology, and in educational inquiry. Phenomenology is a philosophical approach to the study of phenomena and human experience; it has been adopted as the primary philosophical standpoint for this study.

The 'father' of phenomenology, Franz Brentano, developed the concept of *intentionality* as an idea central to the philosophy. Intentionality is 'the internal experience of being conscious of something' (Moustakas 1994:28). When studying someone's understanding of a phenomenon, their consciousness is always directed at an 'object'. Therefore, they are aware of, perceive, understand or describe 'something'.

Edmund Hurssel, Brentano's student, enlarged the field of phenomenology during the period commonly referred to as the German phase of phenomenology (van Manen 1990). Two important concepts were developed by Hurssel; *intuition* and *phenomenological reduction*. Hurssel believed that the phenomenologist intuitively understands human experience. He proposed that to reach such an understanding, researchers must become immersed in the phenomenon and become aware of their own as well as other people's perceptions of the same phenomenon. Phenomenological reduction occurs when objects or phenomena are viewed without prior judgement or assumptions about their place in reality. They are seen and described as they appear, through observation and experience. This suspension of preconceptions is also called *bracketing.* It must be acknowledged, however, that complete reduction is never possible because the researcher is subject to the vagaries of human experience too. Therefore, in attempting to understand phenomena using this method, it is necessary to clearly identify preconceptions of both the subject and the researcher.

An alternative approach is proffered by existential phenomenologists such as Gabriel Marcel, Jean Paul Sartre and Maurice Merleau-Ponty (representatives of the French phase of phenomenology), who did not believe in reduction or bracketing (Dowling 2006). They proposed the notion that human beings cannot be separated from their perceptions. In everyday life, people interpret the behaviour of others and the world around them by classifying and organising concepts and encounters into 'ideal types' from their previous experiences and social interactions.

According to van Manen (1990) phenomenology describes how one orients to lived experience. The feature that distinguishes phenomenological research from other qualitative research is its focus on the subjective experience resulting from that inquiry. Patton (2002) describes phenomenological research as looking at the meaning, structure and essence of the lived experience of a given phenomenon for a particular person or a group of people. The intent of the researcher should be then to understand and describe an event from the point of view of the person experiencing it. Phenomenology is not, however, a method in itself. Hence researchers who use this approach are reluctant to describe specific techniques. Rather, they describe phenomenology as a guiding principle that shapes the way in which they conduct their research (Holloway 1997). Under the banner of phenomenology, there are no hard and fast rules for conducting analysis.

However, several practitioners (Colaizzi, 1978; Giorgi, Fischer & von Eckartsberg 1971; van Manen, 1984) have developed analytic strategies that allow phenomenology to be applied at a practical level.

3.5.1 Collaizzi's Seven Steps of Phenomenological Analysis

For each phase of this study Colaizzi's (1978) seven-step process of phenomenological analysis was employed to reduce the data. The seven steps as used during Phase I are described in Table 3.1. For a more detailed description of their application, see Section 4.4.1 and Appendix C.5.

The initial analysis consisted of coding and categorising, and involved a line-by-line analysis of the transcript documents and matching them with, and mapping to, the personal memo-notes recorded during the interviews or observed during the teaching interventions. The key feature of the codes and categories generated by this analysis is that they are based directly on the data.

Colaizzi's Seven Steps of Phenomenological Analysis	Coding Steps, Grouping and Analysis
1. The researcher reviews the collected data and become familiar with it. Through this process they gain a feeling for the subject's **inherent meanings**.	Personal Log Coding (Interview) Inherent Meaning Coding (Interview)
2. The researcher returns to the data and focus on those aspects that are seen as most important to the phenomena being studied. From the data they **extract significant statements**.	Identification of Important Statements Coding (Interview)
3. The researcher takes each significant statement and **formulates meaning** in the context of the subject's own terms.	Analytical Log Coding (Interview)
4. The meanings from a number of interviews are grouped or organised in a **cluster of themes**. This step reveals common patterns or trends in the data.	Scheme Grouping (Interview) Theme Identification (Entire Dataset)
5. A detailed, analytic description is compiled of the subject's feelings and ideas on each theme. This is called an **exhaustive description**.	Analytical Log Grouping (Interview) Final Categorisation (Entire Dataset)
6. The researcher identifies the **fundamental structure** for each exhaustive description.	Key Feature Grouping (Interview) Final Categorisation (Entire Dataset)
7. The findings are taken back to the subjects who check to see if the researcher has omitted anything - **member check**.	Post Interview agreement of participants with analysis findings

Table 3.1: Colaizzi's (1978) seven steps of phenomenological analysis mapped against the coding and analysis steps.

3.5.2 Phenomenographic Influence – Capturing Variation

Phenomenography is the empirical study of the differing ways in which people experience, perceive, apprehend, understand and conceptualise various phenomena and aspects of the world around them (Bowden *et al.* 1992). The words 'experience', 'perceive' etc., are used interchangeably. The nature of phenomenography is basically descriptive and methodologically oriented. It is a research approach that focuses on particular phenomena and the range of people's understanding of those phenomena. The principal areas of interest include the identification of people's conceptions of social and natural phenomena and documenting the 'distinctly different ways' in which people interpret these phenomena. Phenomenography was developed in the 1970s by Ference Marton (1981) and has been used extensively in science education research (Prosser 1993; Walsh *et al.* 1993). It is 'a research method for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of, and phenomena in, the world around them' (Marton 1986:31), and it is the researcher (or the teacher if applied to the classroom situation) who senses this variation. The phenomenographic approach is based on the principle of an intentionality that affords a non-dualist view of human understanding, and that depicts experience as the internal relationship between the learner and the world.

Regarding the phenomenographic process for identifying categories of the recalled experience applied in this study, two important cautions are needed. First, recognising that the primary purpose of the approach is to identify, label and categorise the variations in the experiences; a different cohort or situation could add new categories. In practice, a point of diminishing returns was identified where successive data samples simply added examples to existing categories. Second, it is recognised that the purpose of the phenomenographic approach is not to provide quantifiable data about the identified categories.

It is also acknowledged that, from the constructivist point of view, there are the potential dangers of adding or adjusting categories where this is not supported by the data; imposing a logical framework on the data where this is not justified; and analysing the data from the researcher's or content expert's framework, so that the interpretation of the data is skewed towards an accepted scientific view of the phenomenon. To minimise the problem of researcher bias in this study, colleagues with experience of phenomenographic analysis and who are alert to such potential problems, were enlisted. They also established the inter-rater reliability of the categorizations and coding independently (Prosser 2000).

3.5.3 The 5Es Approach as a Learning Cycle

Constructivist models for teaching have been developed to support teachers in helping students make meaningful sense of phenomena. For the purposes of this project, the 5Es model first proposed by Bybee (1997) and developed by the Australian Academy of Science Primary Connections project (Australian Academy of Science 2007) has been selected as the scaffold upon which the teaching and learning sequence undertaken in Phases II and III were built. Based on an inquiry and investigative approach, students conduct investigations to construct meaningful explanations for phenomena and this model is therefore consistent with contemporary constructivist theory. As part of the normal coursework experience, the participating pre-service K-6 teachers were both students learning and teachers practicing. As students, it was anticipated that they would increase their depth of knowledge about the identified concepts from Phase I during opportunities to represent, re-represent and personally assess their developing understandings using a wide range of experiences including collaboration. As teachers, they would be practicing the methods espoused by the Primary Connections approach that develops unit sequences containing five elements:

> **ENGAGE**: To create interest and inspire the students and elicit prior knowledge;
>
> **EXPLORE**: To provide hands-on shared experiences of the phenomenon;
>
> **EXPLAIN**: To develop scientific explanations for their personal experiences in terms of conceptual understanding;
>
> **ELABORATE**: To extend or apply their understanding to a new context, or make connections to additional concepts through a student-planned investigation; and
>
> **EVALUATE**: To celebrate the learning, the students re-represent their understanding and reflect on their learning journey. It is in this stage that teachers actively collect evidence of achievement and outcomes.
>
> (Australian Academy of Science 2007)

3.5.4 Teaching Strategies

During this project, a *reciprocal peer-learning* environment as described by Boud, Cohen and Sampson (2001) was created. They describe the peer teaching process as:

> *Peer teaching involves students learning from and with each other in ways which are mutually beneficial and involve sharing knowledge, ideas and experience between participants. The emphasis is on the learning process, including the emotional support that learners offer each other, as much as the learning itself.* (cited by Longaretti *et al.* 2002, online)

This involved participants undertaking hands-on activities (Peterson *et al.* 1989) cooperatively (Crouch & Mazur 2001; Mazur 1997; Nelson 1994) to explore specific phenomena using a Predict-Observe-Explain technique (Champagne, Klopfer, & Anderson 1980; Gunstone & White 1981) as explained by Palmer (1995) and amended to include a *'Share'* component. The process is a reflection of the social constructivist approach and was adopted with the specific intention of increasing participant awareness of the methods used to develop their conceptions, and the processes they personally adopted to build their own understanding. An approach similar to that used in action research (Rebello & Fletcher 2006) was used to evaluate the effectiveness of the elements developed for the teaching module.

Initially working individually, participants were invited to:

PREDICT: describe what they expect to be the outcome of specified activities;

OBSERVE: record their observations of the actual event; and

EXPLAIN: record an explanation of what happened in their own words, and identify how their prediction varied from the actual observation.

Participants then collaborated with their peers to:

SHARE: discuss the variation in their observations and explanations in small groups, eventually arriving at an agreed, shared description.

Comparison of the individual and negotiated explanations provided a means of observing and qualitatively measuring conceptual shift (Brousseau 1992).

Whilst knowledge of science entails knowledge of scientific concepts, laws, and theories, it also entails knowledge of the processes of science and its epistemic base. The incorporation of Predict-Observe-Explain-Share in the 5Es approach, with peer learning as an active component, was developed as a means to cycle learning toward built or enhanced meaning in both content and pedagogy. Collins *et al.* (2001) succinctly state: 'The overemphasis on 'what we know' at the expense of 'how we know' results in a science education which too often leaves students only able to justify their beliefs by reference to the teacher as an authority' (5). The problem is compounded, however, when we consider that the K-6 teacher is rarely an authority on matters scientific and would in fact rather not be teaching it (Appleton 2003). Empowering K-6 teachers to have confidence in 'finding out', 'exploring', 'investigating', 'trying different ways' etc. is the essence of encouraging their students to adopt similar scientific approaches to solving everyday problems.

3.5.5 Taxonomies

To provide a framework and inform the development of the main research instrument and to assist in the analysis of student responses, two taxonomies were selected: the taxonomy of observed learning outcomes (SOLO); and Bloom's modified taxonomy of educational objectives. These were considered the most appropriate because of their complementary nature and compatibility with the constructivist philosophy.

The Structure of the Observed Learning Outcome (SOLO) Taxonomy

The SOLO taxonomy first developed by Biggs and Collis (1982) is gaining support in educational research as it provides a systematic way of describing how a learner's performance grows in complexity when experiencing defined tasks, particularly the sort of tasks undertaken in school classroom situations.

Five learning outcome categories (pre-structural, uni-structural, multi-structural, relational and extended abstract) have been previously used to describe the quality of learning resulting from small learning tasks (van Rossum & Schenk 1984; McPhan 2008). In this study, the five categories (see Figure 3.1) are incorporated to assist with the identification of causal relationships between change in understanding and the component of the intervention sequence responsible for the change.

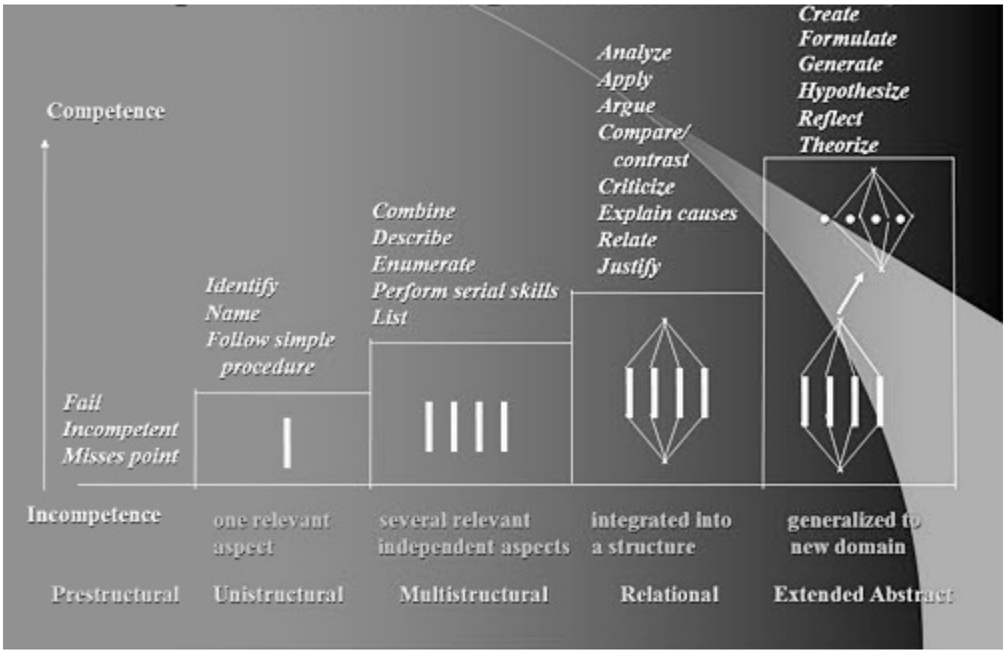

Figure 3.1: The Solo taxonomy with sample verbs indicating levels of understanding (Biggs online).

These categories were developed and a workable model is described in Table 3.2, which outlines how categories may be exemplified in the student's responses to the Predict-Observe-Explain-Share activities.

Level of Learning Category Demonstrated	**Examples of Student Response**
Pre-structural	• student responds with expression of not having an exploration for the phenomenon in question, or • explanations draw on pieces of apparently unconnected information without any organization to make sense of the observations.
Unistructural	• student offer explanations that make simple and obvious connections between observations, past experience, and conceptual knowledge. • the significance of the connections is not demonstrated.
Multistructural	• student explanation contains two or more pieces of relevant information – may make a number of connections between activity driven observations and new and previous knowledge. • there is no demonstration of the significance of the relationship between connections.
Relational	• as part of the explanation to their peers, the student demonstrates a relevant relationship between connections they are making with their observations and other knowledge - these are related to the whole concept being explored.
Extended abstract	• student makes connections beyond the immediate phenomenon, demonstrating the application of connections to other personal observations • demonstrates transfer of learning to personally derived explanations of other phenomena, offering analogies to their explanations to peers.

Table 3.2: SOLO Categories related to student responses (adapted from Biggs & Collis 1982)

Bloom's Modified Taxonomy of Educational Objectives

Bloom's Taxonomy (1956-1964) of the cognitive domain attempted to categorise thinking skills as cognitive processes of increasing complexity. Anderson and Krathwohl revised Bloom's continuum in 2001, using verbs rather than nouns to describe each of the categories, and proposed that Evaluation and Creation demonstrated the highest order of thinking skills (see Table 3.3). Key verbs attached to each category have gained popular use by teachers in planning classroom activities to describe desirable, achievable and demonstrable outcomes. They do not, however, address the newer objectives, processes and actions presented by the impact of collegial (social) learning on the learning of students.

Bloom's Revised Taxonomy Sub-categories of the Cognitive Domain	Associate Key Verbs
Lower Order Thinking Skills	
Remembering	Recognising, listing, describing, identifying, retrieving, naming, locating, finding
Understanding	Interpreting, summarising, inferring, paraphrasing, classifying, comparing, explaining, exemplifying
Applying	Implementing, carrying out, using, executing
Analysing	Comparing, organising, deconstructing, attributing, outlining, finding, structuring, integrating
Evaluating	Checking, hypothesising, critiquing, experimenting, judging, testing, detecting, monitoring
Creating	Designing, constructing, planning, producing, inventing, devising, making
Higher Order Thinking Skills	

Table 3.3: Bloom's Revised Taxonomy Sub-categories and associated Key Verbs (Anderson & Krathwohl 2001).

To categorise the pedagogical relationship between effective learning and peer interaction (for both cognitive teaching and teacher education), Churches (2008) proposed that *collaboration*[1] should be regarded as a separate taxonomical element. This should be considered as parallel to the increasing complexity of the thinking skills as it can manifest itself in many ways (sharing, negotiating, debating, questioning, collaborating etc.) and the value of the collaboration (real and perceived) to the participant can vary hugely. Churches also points out that collaboration need not be a required component of the learning process for the individual, in that it is not necessary to collaborate to learn. He concludes, however, that learning is often enhance by the collaborative and peer interaction process(es), recognising that collaboration is a 21st Century skill of increasing importance and one that is used by students throughout the learning process (6). It may also be argued that collaboration, as a learning process, is an integral part of the Vygotskian social-constructivist framework (1978).

Although taxonomies related to Bloom's affective domain (that relate to the feelings and emotions of students), are used less commonly than those of the cognitive taxonomies for planning teaching, Bloom proposed a categorisation that classifies affect according to how committed students feel toward what they are learning (Krathwohl, Bloom, & Masia 1964/1999). It was considered that these indicators would most readily

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[1] *Collaboration* in this context refers to two or more individuals working together to create a shared understanding. Verbal collaboration facilitates the consideration of other perspectives that may influence their own, or may promote the defence of their own perception. This process promotes the sharing of evidence to support or question understanding in the individuals involved in the collaboration.

translate into an assessment of change in student enjoyment in undertaking the activities and this, in turn, would be a reflection of student confidence.

3.5.6 Data Gathering Tools

To answer each of the research questions as fully as possible, a suite of tools were employed to gather a wide range and quantity of data. These included:

- Semi-structured interviews (Minichiello, Aroni & Hays 2008) with experts and observers;
- Informal interviews (Cohen, Manion & Morrison 2007) with small groups of volunteer participants;
- Surveys containing
    - open-ended and Likert-type questions (Cohen, Manion & Morrison 2007); in combination with
    - student work samples hands-on inquiry-based tasks (Peterson *et al.* 1989);
- Transcripts of audio-visual recordings of small group interactions; and
- Memo notes recording the observed effectiveness of the applied strategies.

Interviews

> *The qualitative research interview seeks to describe the meanings of central themes in the life world of the subjects. The main task in interviewing is to understand the meaning of what the interviewees say*. (Kvale1996)

To seek the opinions of experts, participants and observers about fundamental aspects of electricity and magnetism, and about the effectiveness of developing teaching sequences and strategies, interviews were selected as a principal data collection tool. Interviews were chosen because they provided the opportunity to ask questions about a wide range of subjects, to probe issues more completely and explore unknown issues as they arose.

A consistent interview protocol was developed and applied for the following purposes:

- To increase the validity and reliability of the interview process and the data collected;
- Provide an appropriate yet flexible format for interviews;
- Provide a reliable system of data recording; and
- Provide a framework for data analysis.

The interview protocol, questions asked and analysis techniques adopted to distil the participant responses are detailed in Section 4.3 for the semi-structured interviews, and in Sections 5.5 and 6.3 for the informal interviews.

Semi-structured Interviews

To collect the opinions of a range of experts about what they considered to be the fundamentally important concepts that school children graduates of Year 6 should be familiar with regarding electricity and magnetic phenomena, it was determined that semi-structured interviews should be conducted. The semi-structured interview method was chosen for its flexibility. It enables the respondent's vocational and experiential foundation to be considered through the application of a fairly open framework that allows for focused, conversational, two-way communication.

Before using this type of data collection, I developed and trialled a set of seed questions with members of the research team. During each interview, I facilitated a relaxed, conversational and flexible environment where I could change the order of the questions or the way they were worded. This allowed probing for additional details and discussion of identified issues. Although I followed the pre-determined interview guide, I was able to follow topical trajectories in the conversation where necessary and appropriate. Two underlying principles guided the conduct of the process:

- I consciously avoided leading the interview or imposing meanings; and
- I actively strove to create a relaxed and comfortable conversational atmosphere.

The interviews were usually conducted at the place of employment of the respondents following the protocol detailed in Chapter 4.3. Each conversation was recorded electronically for later analysis and to facilitate matching with my personal memo-notes of observations that may have impacted on the nature of the responses during the interview. From the audio recordings, a transcript was made and returned to the respondent for validation.

Informal Interviews

To seek feedback regarding aspects of the teaching sequences, learning activities and formative assessments employed, discussions in the form of informal interviews were held with participants before, during and after each component. The format of these discussions varied and was usually driven by questions posed by the participants prompting further discussion. Each of these interviews was electronically recorded, matched with memo-notes written during the discussions, and a précis was subsequently generated and returned to each respondent for confirmation of the comments expressed to ensure validity of the information.

Guided Activity Survey Booklets

To explore depth of knowledge held by participants about particular electric and magnetic phenomena, and how that knowledge builds as a result of the intervention strategies experienced during a specific sequence, a series of survey-type activities were designed. A survey in this format was chosen because it facilitated the gathering of data at similar points of time during the components of the intervention with the intent of determining the level of understanding of the participants. The survey was also used to determine relationships that exist between the interventions applied during the teaching sequence.

In constructing the survey, Rosier's (1997) planning processes were applied (cited in Cohen, Manion and Morrison (2007:209). The survey objectives were discussed with members of the research team resulting in the generation of a booklet containing a range of questions (described below). The booklet was piloted with a sample (n = 11) third year pre-service secondary science teachers to ensure that the survey yielded data that was appropriate to the objectives and research questions.

The guided activity survey booklets served as both a source of data for the researcher, and as a record of the student's experiences enabling them to identify and reflect upon their progress during the interactive lectures[2] (Hake 1998; Mazur 1997; Nelson 1994; Steinert & Snell 2007) and workshops. To collect the data and facilitate its initial analysis to inform subsequent activities, at the end of each workshop and lecture component, the booklets were collected, copied (with participant written permission) and returned prior to any further interaction or intervention.

The underlying purpose of booklet was to survey students' knowledge and perceptions before and after experiencing the initial instrument. Cohen, Manion and Morrison (2007) and Kitchenham and Pfleeger (2002) suggest that a combination of survey and questionnaire items would yield rich data, which, in this project, reflect change in conceptual understanding in the respondents, and contribute toward the identification of the specific methods responsible for the change.

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[2] The interactive lectures involved a combination of discussions (in small groups and as a whole with representatives of each group sharing the overall results of the discussion), Predict-Observe-Explain-Share activities (see Section 5.2.2) and participatory demonstrations (where the group informed a peer of what to try next with the exploratory activity).

The interactive work booklet comprised a combination of survey and questionnaire components including:

- A variety of open response questions to explore the participant's conceptual understanding relating to each of fundamental electric and magnetic phenomena; and
- Likert-type scales, where each student was asked to rank and optionally comment on the effectiveness of their level of confidence to teach the identified concepts.

Memo Notes and Field Diary

During the interviews and activity-based intervention components, observations of participant behaviour and possible links to causes of conceptual change were recorded during or as soon as possible following the task. This was to provide a source of reflective consideration of the factors that may have impacted on the effectiveness of the interview processes and on the learning opportunities to be provided to the participants during the project. Personal diary entries were recorded at the end of each day and detailed a reflection of the day's activities in terms of working toward the achievement of the desired goals during each component of the project and factors that would need to be considered to seek answers to the research questions.

Observations

Memo notes were used to record observations of such things as the environment for the activity, participant behaviour, interactive relationships during peer-learning situations, demonstrated skills during hands-on activities and verbal stances as they related to shared explanations of particular phenomena. These *observation notes* were recorded as a source of feedback information on the value of peer-interaction as a facilitator of conceptual change, as well as causal links between activities and achieved change in conceptual understanding. The notes also provided a means to record observations of the development of manipulative skills in the participants and its apparent relationship to the confidence of the participant to share their experience with their peers during small-group informal interviews.

Diagrammatic representations

Participants drew diagrams of pieces of apparatus and models of their understanding as part of their attempt to explain observed phenomena. The format, detail and labelling of the diagrams provided an additional qualitative measure of the participant's knowledge of the phenomena being explored and of their awareness of the use of diagrams as pedagogical tools.

3.5.7 Data Analysis Tools

Phenomonology

The semi-structured and informal interviews were analysed individually using Colaizzi's seven-step model (1978) and then together in an effort to challenge developing assertions and conceptualizations. In this analytical approach, conceptions to explain the importance or nature of identified phenomena are continually built as the data is analysed. Emerging themes and explanations were consistently tested against subsequent data (memo-notes, student work samples, collegial discussion) and typically expanded to encompass new elements of concept building processes (in this situation, other participants) that conflicted with previous formulations. The ultimate goal was to arrive at a relatively universal explanation (exhaustive description for the particular concept under investigation) that has been derived from the consistent formulation and then reformulation of emerging explanations. The numerous sources and types of data allowed for triangulation of data and the construction of valid profiles of each respondents beliefs and conceptual understanding building processes. Following the construction of exhaustive descriptions for identified concepts, the respondents were asked to comment on the overall picture presented by the collection and analysis of the data. Without exception, the respondents confirmed the overall accuracy of the descriptions that were constructed, lending further credibility to the validity of profiles.

Phenomenography

As described in Section 3.5.2, whatever phenomenon or situation people encounter, it is possible to identify a limited number of qualitatively different and logically interrelated ways in which the phenomenon or the situation is experienced or understood. The variation in perception and understanding was identified and explored using written responses in the student work-booklet and through written recordings of observations by myself and other members of the research team, making the learning process the object of the research.

Participant responses to the guided activity survey booklets were analysed before and after participation in the interactive sequences to identify change in understanding. This was done to provide a measure of the effectiveness of the designed sequences and to identify components that may require modification or enhancement. The identification of shortcomings in terms of a fundamental understanding and pedagogical awareness enabled them to be addressed during subsequent phases of the project.

In adopting Colaizzi's analytical approach, I was conscious of the need to bracket preconceived understandings exemplified by the written responses. This was done instead of attempting to judge to what extent responses reflected a desired scientific understanding of the phenomenon in question. I was therefore able to focus on similarities and differences between the ways the phenomenon appear to the participants, and how their perceptions were constructed and changed by specific intervention strategies.

Likert-type Scales

Likert-type scale ranking responses before and after the interventions were analysed using simple ordinal procedures. Numeric counts of participant perceptions of their confidence were reported in whisker plots with lower, median and upper quartiles displayed. The mean and standard deviation were identified as a measure of the change in the confidence of the participants to teach about the identified concepts.

Participant Diagrams

To analyse the diagrams recorded by the participants in their work-booklets, I adapted Colaizzi's seven steps to a subset of steps 1, 2, 4, 6 and 7, concentrating on the value to the learner of recording their observations using such a technique. Discussion relating to the pedagogical value of diagrams was conducted with the cohort of participants prior to subsequent involvement in sequence components and changes in diagram format, accuracy and perceived value was noted.

3.6 RESEARCH PLANNING

As stated earlier, the primary aim of this project was to explore the effectiveness of an activity-based sequence with iterative components at enhancing pre-service K-6 teacher knowledge about and confidence to teach specific fundamental concepts of electricity and magnetism. Discussions with my supervisors, members of the UNE science education team and practicing teachers culminated in the adoption of six research questions, answers to which would guide the data collection during the project. Subsequent negotiation with my supervisors resulted in the development of a three-phase research plan to address the research questions in depth. The tables below describe the phases and present an initial timeline for the completion of each of the components of each phase.

3.6.1 Timeline

Phase	Details of Activity	Time Conducted
Phase I Expert Interviews	Conduct of semi-structured interviews with experts. Ongoing review of available literature.	April 2008 – June 2008
Phase II Initial Instrument	Survey of participant knowledge and confidence. Development of teaching sequence with EDSE213.	June 2008 – April 2009
Phase III Refining the Sequence	Survey of participant knowledge and confidence. Modelling of teaching strategies with EDSE213. Identification of shortcomings in sequence and development of refinements.	March 2010 – May 2010 March 2010 – June 2010 April 2010 – July 2010
Phase IV Peer Teaching	Refinement of sequence incorporating formative assessment during peer teaching opportunities with small groups from EDSE412.	July 2010 – October 2010
Analysis and Write-up		January 2009 – March 2011

Table 3 4: Initial Timeline planned for the conduct of the investigation.

A timetable for the completion of the project was constructed incorporating the three phases, the latter two being defined by the availability of K-6 pre-service teachers (EDSE213 and EDSE412[3]). Table 3.4 outlines the timeframe for the conduct of the research project.

3.6.2 Outline of the Phases

Phase I – Expert Interviews

Semi-structured interviews were used to ascertain the opinions of a group of experts about what concepts they consider to be fundamental to gaining an everyday understanding of electricity and magnetism,. Results of the analysis of these informed the development of the initial research instrument.

Phase II – Initial Instrument

The conduct of this phase served two purposes. Firstly, to establish a baseline of, and measure the variation in, knowledge, understanding and perceptions of science teaching confidence held by second year pre-service K-6 teachers. Secondly, this phase was designed to evaluate the initial intervention activities developed to improve participant concept knowledge and confidence. The initial sequence was implemented with the cohort of pre-service K-6 teachers enrolled in EDSE213 during first semester 2009.

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[3] Details of the courses are provided in Appendix B.

Phase III – Refined Instrument

The results of the analysis of Phase II and a review of available literature informed the refinement of the sequence for assessment of effectiveness and validation with the subsequent 2010 EDSE213 cohort. Pre- and post-intervention survey data was supplemented by transcripts of informal interviews with small groups of participants and observers, and memo-notes were utilised to evaluate the effectiveness of the refined sequence and the elements contained therein.

Phase IV – Peer Teaching

This component facilitated the consolidation of the sequence with the trial of particular elements with final year students (EDSE412) teaching small groups of second-year students (EDSE213) in a practice teaching environment. The peer teaching episodes and subsequent small-group informal interviews were conducted with the volunteers when participants were available for two, two-hour periods that were coincident with accessibility to a suitable teaching space.

3.6.3 Constraints

The Phase I semi-structured interviews were conducted at the workplace of the interviewee where possible. This required negotiation with the interviewee to identify a suitable time, and to give them the opportunity to consider the purposes of the research detailed in the Participant Information Sheets[4].

The conduct of Phases II and III required negotiation with the course lecturers to allocate a suitable and sufficient block of time that coincided with the availability of a suitable learning space resembling a typical K-6 classroom. This limited the available time to a block of three weeks situated in the middle of Semester 1 in both years.

As the participants undertaking this Peer-Teaching component were volunteers participating outside of normal allocated timetabled periods, it was necessary to negotiate with small groups of second-year students and pairs of fourth-year students to find two-hour blocks of time where a suitable learning space was available. This meant that this component stretched over most of Semester 2 in 2010.

[4] For a copy of this information, please refer to Appendix C.2.

3.6.4 Mapping Research Questions to Data Collection and Analysis Tools

Introduction

Considering the range of data required to answer the research questions, a multi-methods approach was adopted. The data collection processes involved the analysis of one-on-one semi-structured interviews, small group informal interviews, written responses to guided activity booklets, diagrams and observations of participant manipulative skills and interaction.

Phase I – Expert Interviews

To answer Research Questions:

1. *From a broad community context, what are fundamental key concepts in the study of electricity and magnetism that should be explored by K-6 school students?*; and
2. *What are the perceived barriers that may limit the successful teaching and learning about fundamental electric and magnetic phenomena?*

and to contribute to the design of teaching and learning sequences, a series of 23 semi-structured interviews were conducted.

Three categories of respondents representing the education sector, electrical trades and members of the general public were asked similar questions (see section 4.3). Each of the interviews was of approximately 40-minutes duration and was electronically recorded and analysed as soon as possible afterwards. Memo-notes describing environmental factors and gestures that may have contributed to the depth of the expression in the answers were recorded by hand during the interview.

Proposed Strategy to Analyse the Collected Data

The collected audio recordings were converted to written transcripts, matched with the memo-notes and Colaizzi's seven-step analysis process was applied to construct exhaustive descriptions of a set of fundamental electric and magnetic concepts able to be developed in K-6 students.

Application of the Results

The resultant identified concepts informed the construction of a sequence of teaching strategies involving hands-on activities adopting a Predict-Observe-Explain-Share approach within the context of a 5Es scaffold

Phase II – Initial Instrument

Assessment of the baseline and range in understanding of a cohort of second year pre-service K-6 teachers in the identified fundamental concepts of electricity and magnetism was required to provide a framework to guide the construction of answers to the research questions:

3. *Within the context of pre-service K-6 teachers, what are the variations in the understanding of the identified fundamental concepts?*; and
4. *How is the variation in understanding in the identified fundamental concepts of electricity and magnetism reflected in the confidence level of pre-service K-6 teachers to teach them?*

Prior to undertaking the initial sequence, participants were surveyed to determine their baseline level of understanding of the identified fundamental concepts. The participants were surveyed again at the completion of the sequence to determine the change in their depth of understanding. The designed sequence was applied over three weeks during two two-hour workshop sessions separated by a two-hour whole cohort lecture as part of the normal EDSE213 coursework. To ascertain possible mechanisms responsible for the building of conceptual understanding and to determine the effectiveness of the elements of the sequence necessary to answer research question 5, participant responses in guided activity work -booklets were collected, copied and returned prior to the next intervention component. Answers to specific questions, free-response diagrams, Likert-type scales annotations and general comments about the effectiveness of the sequence were recorded in the guided activity work-booklets. Participants were also invited to provide additional feedback and comments during small group interviews at the completion of each element of the sequence.

Proposed Strategy to Analyse the Collected Data

Colaizzi's phenomenological analysis process was again applied to the collected data to reveal the conceptual models of understanding pre- and post- intervention. To construct an image of the range of understanding, a phenomenographic approach was adopted. This led to a Likert-type scale measurement of the confidence of the participants to teach the identified concepts and provided an evaluation of the effectiveness of the sequence to: develop conceptual understanding; model successful teaching strategies; and positively impact on the confidence of the participants to teach the identified concepts. Samples of participant course notes were collected including diagrams. These were analysed to measure the change in understanding demonstrated by different diagrammatic representations.

Application of the Results

While it was demonstrable that the applied sequence did enhance the level of participant understanding and their level of confidence to teach the concepts, analysis of the effectiveness of the sequence elements revealed that some were not as effective as was anticipated. Additional feedback from small-group informal interviews, discussions with teachers and members of the research team led to recommendations for replacement of some elements and modification of others. These were incorporated in the final sequence.

Phase III – Refined Instrument

As in Phase II, a cohort of second year EDSE213 pre-service K-6 teachers experienced the refined sequence as part of their normal coursework. However, the format of the sequence was slightly different: the sequence began with two one-hour lectures with the whole cohort and was followed by two two-hour workshop sessions that were made up of three groups, which each group containing approximately 27 students. Although the application of the sequence sought to confirm the results of Phase II and refine answers to the research questions:

3. *Within the context of pre-service K-6 teachers, what are the variations in the understanding of the identified fundamental concepts?*; and
4. *How is the variation in understanding in the identified fundamental concepts of electricity and magnetism reflected in the confidence level of pre-service K-6 teachers to teach them?*

the data collected sought to provide sufficient data to answer research question:

5. *Does the integration of Predict-Observe-Explain-Share strategies into the 5Es pedagogical model provide an effective means to support and enhance K-6 pre-service teachers' learning of fundamental concepts?*

Proposed Strategy to Analyse the Collected Data

A phenomenological analysis of the guided activity work booklets (Colaizzi 1978) enabled comparisons to be made of the results collected during Phase II with respect to the level of and variation in knowledge about the Phase I-identified concepts. The pre- and post-intervention survey responses were nominally assessed, using a pre-prepared marking sheet, by two members of the research team other than the researcher, to validate the analysis. Further, the change in confidence level before and after the interventions, and between the two cohorts of EDSE213 participants was identified.

At the completion of the sequence, small group informal interviews were analysed phenomenologically (Colaizzi 1978) to identify emergent themes specifically relevant to the Predict-Observe-Explain-Share strategy in terms of its perceived effectiveness.

Informal interviews conducted with the course presenter and members of the research team sought to illicit personal comment from these experienced educators about the effectiveness or otherwise of sequence elements or any other factors that may have contributed to the learning outcomes.

Application of the Results

It was anticipated that the modified and additional elements applied during this phase would be confirmed as more effective at building conceptual understanding and enhancing participant confidence to teach the concepts. Similarly, a measure of the decrease in variation in understanding at the completion of the sequence, and the considered opinions gleaned from the small group and observer interviews would provide a qualitative measure of the effectiveness of the whole sequence.

Phase IV – Peer Teaching

Peer interaction was an integral component of the implementation of the sequence during Phases II and III. However, it was not until the sequence had been refined, that volunteer fourth-year pre-service teachers were enlisted to practice applying elements of the sequence. This was trialled, using strategies defined by the sequence in a series of peer-teaching episodes (see Chapter 7), with small groups of second-year volunteers. Observation and small-group interviews provided data to evaluate the effectiveness of the elements and pedagogies being applied in order to respond to research question:

6. *Can a peer-learning inquiry-based pedagogy be adopted and used as a framework in pre-service science teacher education for learning and as a model for teaching?*

Proposed Strategy to Analyse the Collected Data

Transcripts of the small-group interviews conducted immediately after the peer-teaching sessions with the 'teacher', 'observer' (EDSE412 volunteers) and 'students' (three or four EDSE213 volunteers) were phenomenologically analysed (Colaizzi 1978). As the questions asked sought opinion and comment about the effectiveness of peer teaching as a pedagogy, the emergent themes were categorised into 'teacher' and 'student' understanding of effectiveness. Please note, it was anticipated that both the 'teacher' and 'student' would regard themselves as 'learners' during the peer-teaching process.

To identify the impact of peer-teaching on the teacher and students, informal interviews were again analysed (Colaizzi 1978) seeking descriptions of the participant opinions as to the effectiveness of this component at enhancing student understanding and teacher confidence. The interviews were conducted with members of the research team and volunteers of the fourth-year EDSE412 who had been specifically allocated observer roles during the peer-teaching sessions.

Application of the Results

The findings from this Phase led to recommendations for further research into the pedagogical relationships between small-group, hands-on collaborative learning strategies developed in reiterative sequences, the effectiveness of the sequences in real classroom situations, and the contribution that the sequence could make to the learning of other aspects of K-6 science teaching and learning by pre-service teachers.

3.6.5 Contribution to Knowledge and Practice

It was anticipated that major contributors to knowledge about learning and teaching and pre-service education and classroom practice would be:

- A sequence that could be utilised confidently by beginning teachers reflecting modern pedagogical approaches to constructivist learning.
- Recognition that the confidence level of the teacher in teaching the desired concepts contributed to the effectiveness of the learning process was identified.
- The building of confidence using developed sequence as a component of pre-service teacher education courses as a positive contributor to the enhanced teaching of science, particularly among teachers as they begin their career.
- The promotion of peer-teaching and peer-interaction as effective teaching and learning strategies were also to be tested.
- The verification that hands-on activities conducted in a Predict-Observe-Explain-Share framework promote conceptual understanding.

3.7 FULLY DEVELOPED RESEARCH PLAN

The preliminary research plan was refined as more details of each of the three phases were incorporated. This plan served as a guide to the research process and ensured meaningful communicating between other researchers, peers, participants and myself. The processes involved in the preparation of this plan also addressed some aspects of the issue of reliability often associated with qualitative research.

The Tables presented below detail the components of the methodology that led to the planning of the investigation.

Phase I Part a): Literature Review		**(February 2008 –June 2008 - ongoing literature review)**	
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
Review initially covering the following areas: • Science Education • Learning Theories • Pre-service Teacher Education • Teaching Sequence Construction • Text books • Teaching resources • Syllabi and curricula Consideration of this review informed components of the subsequent Phases and extended into related areas of the project.	Library databases, research publications, a range of books, reports, conference proceedings, examination reports, and governing educational authority documentation.	Establish and maintain an open research environment. Clear understanding of the scope of related research in terms of trends and relationships. Construction of an annotated bibliography as an integral component of the thesis.	Appropriate incorporation of knowledge gained from review into each phase. Incorporation of the literature review within the framework. N.B. (a formal review of the available literature is included – Chapter 2).

Table 3.5: Phase I – Literature Review to inform Interview Process - Identify Key Aspects Associated with Electricity and Magnetism

Phase I Part b): Identify Fundamental Concepts in Electricity and Magnetism across a range of sectors (June 2008 – April 2009)			
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
Focus group discussions Trial of interview protocol (n = 2) Identify and interview range of experts (n = 23) Focus of identified fundamental concepts to those applicable to K-6 learning environment.	Teacher training colleagues Lecturers, researchers, teachers, trades people, including various professionals drawing from the experience of trades people, medical, communication, engineering. Interview transcripts and memo notes.	Construction, trial and refinement of interview protocol Mapping of skills, knowledge and experience and expertise of discussion participants. An aspect of this process is to include: • education, • industry, • understandings of E & M (vocational and personal) Identification of a set of preliminary key aspects and concepts associated with E & M as a product of the group discussions. Concepts to be explored establishing levels of understanding in Phase II.	Exploration of interview techniques (Minichiello *et al*. 2008) Mapping transcripts of audio recorded interviews with memo and diary notes and any collected other data sources (school/teacher programs). Phenomenological analysis approach (Colaizzi 1978).
Compare identified concepts to those specified in syllabus documents and learning and teaching resources	Syllabus and support documents (K-6, 7-10), texts, simulations, demonstrations, audio-visual sources (media, computer)	Adaptation of appropriate data collection methods and analysis tools	Ensure regular/constant and continual comparison across all datasets – member checking and triangulation.

Table 3.6: Phase I – Conduct of Expert Interviews - Identify Key Aspects Associated with Electricity and Magnetism

Phase I Part c): Reflection and consolidation of research approach (April 2009)			
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
To reflect upon the findings of the study so far. Re-enter the field maintaining an open and responsive research outlook.	Mentors within the University of New England faculties of The Professions, The Arts and Sciences and external academic colleagues	Fine tune the research method to further clarify the dimensions of the categories and themes identified.	Utilisation of a phenomenological analysis approach (Colaizzi 1978). Further develop theoretical sensitivity to direct the study towards • key concepts associated with E & M • development of teaching sequence • identification of effective teaching practice.

Table 3 7: Phase I – Consolidation of Methodology - Identify Key Aspects Associated with Electricity (E) and Magnetism (M).

Phase I Part d): Fully describe categories and themes to identify the key ideas and concepts associated with E & M (May 2009)			
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
Based upon the findings a continuation of collegial discussion and interview processes will be conducted in order to clarify areas of specific to this investigation.	All datasets, coding and categorisation. Until saturation from each category.	Development of a set of interview questions.	Adapt the selective coding process to isolate core categories and themes.
Utilising iterative reliability techniques to finalise and consolidate the analysis.		Awareness of emerging concepts. Identification of a set of key teaching strategies and barriers	Regular review of evidence for emerging themes, categories and concepts (fundamental key concepts to contribute to Phase II.
Organise categories and themes into a range of sequences and representations for presentation to the expert panel in Phase II.		Construction of Initial Sequence	Fine tuning of the fundamental concept list able to be incorporated in teaching sequences in preparation for next phase.

Table 3.8: Phase I – Analysis of Data to Reveal Categories and Themes taken forward into Phase II.

Phase II: To identify conceptual knowledge of key elements to take forward and develop into teaching sequence(s) (Semester I 2009)			
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
Ascertain variation in conceptual development in a cohort of 2nd year pre-service generalist K-6 teachers as part of normal coursework to assist in the identification of key elements for teaching sequence development	Tutorial workshops and iterative lecture with follow-up small group workshops to consolidate findings from the initial phase of the study.	Identification of focused key concepts, and successful strategies to take forward into Phase III.	**Phenomenology/Phenomenography – (**Colaizzi 1978; Marton 1986) The analysis will provide verified and triangulated categories and themes derived from enunciated student understandings of the identified concepts that will allow the researcher to make final informed selection to take into Phase III.
Select the final key elements that will inform the further development of teaching sequences in Phase III.	Student workbooks. Collaboratively designed student work samples.	Identified key concepts and successful strategies and concepts where the currently employed teaching strategies are in need of review to enhance success	Modification of existing elements and incorporation of new activities into the sequence for application during Phase III

Table 3.9: Phase II – Developing the Initial Teaching Sequence

Phase III: To develop trial and improve teaching sequence(s) incorporating reflective feedback October 2009 – August 2010			
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
Development of refined sequence	Consideration of recommendations from Phase II.	Refined sequence effectively modelling successful teaching strategies and modern pedagogical approaches applicable in the beginning teacher classroom.	Refined sequence applied to subsequent cohort of second-year pre-service K-6 generalist teachers to provide **iterative verification** of sequence effectiveness at building conceptual knowledge and 'teacher' confidence to teach the concepts.
Participation in the sequence by a subsequent cohort of EDSE213 pre-service K-6 teachers. Observations recorded by members of the research team. Small-group post experience informal interviews recorded, transcribed and analysed.	Introductory interactive lecture (Mazur 1997) Tutorial workshops Refined sequence elements incorporating hands-on investigative activities.	Validated sequence Enhanced participant conceptual understanding Reduced range in conceptual understanding Enhanced participant confidence to teach the identified concepts.	Pre- and post-intervention surveys analysed to determine base-line understanding – comparable to Phase II Guided-activity work booklet responses analysed to ascertain range of knowledge before and after intervention. Interview transcripts of observers and small groups of participants melded with memo-notes to evaluate effectiveness of Predict-Observe-Explain-Share, sequence and hands-on activities

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Phase III: **To develop trial and improve teaching sequence(s) incorporating reflective feedback**			**October 2009 – August 2010**
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
Participant developed, trialled and refined formative assessment strategies using an iterative approach.	Participants in small groups.	a. Recognition of value of formative assessment strategies to inform subsequent learning experiences and teaching strategy effectiveness b. assessment and feedback mechanisms for i) student ii) teacher c. sustained progression through the sequence in conceptual, context and content development.	Small group informal interviews used to reveal participant perceptions of value of formative assessments to guide direction of teacher imposed learning interventions in response to identification of student need in terms of extension or remediation. Confirm iterative approach to activity cycles.
Implement strategies/sequence with a pre-service cohort emulating Year 4 classroom environment.	EDSE213 cohort. Classroom-like environment Hands-on activities	Analysis of the sequence in terms of needs in school and social contexts	Exploration of the value of Predict-Observe-Explain-Share and hands-on activities in building conceptual knowledge, manipulative skills, social interaction skills of co-operation and team building.
		Verification of effectiveness of new elements of sequence.	Comparison of participant perceptions of effectiveness linked to comparison of pre- and post-intervention survey results

Table 3.10: Phase III: Development and Testing of Refined Teaching Sequences Incorporating Recommended Improvements

Phase IV: To evaluate teaching sequence(s) utilising peer-teaching and peer-interaction August 2010 – October 2010			
Proposed Strategy	*Resources*	*Outcome*	*Methodology Guide Notes*
Selection of a strategy to produce and test sequences	From Phases I and II and the literature	Selection of appropriate strategies	Micro-teaching (Rebello & Fletcher 2005)and peer-teaching (Boud *et al.* 2001) environments involving volunteer fourth year students to work with small groups of voluntary second years.
EDSE412 volunteers evaluate specific sequence elements with small groups of EDSE213 students.	Refined and additional activities. Readily available equipment.	Justification of peer interaction Enhanced confidence to implement Predict-Observe-Explain-Share strategies in 5Es scaffold.	Peer teaching within the EDSE412 environment

Table 3.11: Phase III: Validating Teaching Sequences Incorporating Peer-Teaching