CHAPTER 4

PHASE I - EXPERT INTERVIEWS

4.1 INTRODUCTION

This chapter reports on the design and refinement of the interview protocol for application to a range of experts from the fields of education, small business, electricity retail, electrical installation, and members of the general public. The conduct, recording and analysis components of the interviews are outlined.

The chapter concludes with a description of a set of electric and magnetic concepts, an understanding of which was identified as fundamentally important to today's society, and that school students should have explored by the end of their K-6 schooling.

4.2 PURPOSE

To ground the research, it was deemed necessary to define the fundamental concepts and the level of understanding desirable in prospective K-6 teachers to facilitate effective teaching of the students in their classes. A series of semi-structured interviews was employed to explore two 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?*

   (to determine a suggested set of key concepts to guide the construction of a sequential set of learning experiences that model constructivist teaching strategies); and

2. *What are the perceived barriers that may limit the successful teaching and learning about fundamental electric and magnetic phenomena?*

   (to identify factors that may negatively impact on successful learning of the identified concepts in K-6 classrooms, a thereby provide an insight into what may be addressed when designing effective teaching activities.)

Based upon collegial discussions with teaching professionals at both a school (n = 5) and tertiary (teacher education n = 3) level, it was broadly agreed that the most effective way to answer the two research questions was to seek personal, face-to-face and flexible interaction with the respondents. That the interviewer can modify the questions when necessary to clarify doubt and probe a depth of understanding unavailable in written or survey-type instruments, was identified as the main advantage of employing the semi-structured interview.

4.3 DEVELOPMENT OF THE INTERVIEW PROTOCOL

As the primary aim of this Phase was to explore the nature of the participants' beliefs about what constitutes fundamental concepts, it was important to ensure that participants felt at ease and able to share their personal opinions. To create a relaxed and informal atmosphere, the construction of the interview protocol was guided by Bloom's (1998:17-18) ideas about the collection of data in qualitative methodologies using interviews. She stresses that interviews should be interactive, open-ended and dialogic in that both the researcher and respondent reveal themselves and reflect on these disclosures. Bloom also emphasised that researchers should give focused attention to non-judgmental validation of respondents' personal narratives, reflecting that participation is grounded in a sincere desire to explore and share personal experiences; in this case, of the learning, teaching and working with fundamental electric and magnetic phenomena.

4.3.1 Question Types

Informal discussions with teaching colleagues and representatives from the electrical trade and supply industries resulted in the generation of an initial set of open-ended questions with components from each of the four types, descriptive, structure, opinion and probing type questions. Bloom (1998:19) emphasises the importance of beginning with a 'general question such as, "tell me about X".' Most of the initial questions to experts in this study were phrased in this way.

Questions asked were of the following types (Minichiello, Aroni & Hays 2008):

Descriptive Questions

Were used primarily at the start of each interview, or when moving to a new aspect for discussion. This type of question enabled participants to express their experiences using language and words that are meaningful to them. For example: 'Please tell me about what you think are the most important aspects of electricity and magnetism that you learned at school'.

Structural Questions

Explored how the participants organize their personal knowledge. These questions encouraged the participant to reflect, and think metacognitively about where familiar aspects of electricity and magnetism actually fit into their existing real world experience.

For example: 'How does your classroom program link the syllabus requirements to your classroom practices?' or: 'How does the knowledge you acquired during your training reflect in the practises you employ in your work?'.

Opinion or Value Questions

Were employed to determine participants' opinions about particular issues and to reveal their feelings and emotions, not simply promoting concentration on what may be regarded as the 'correct' answer. For example: 'Do you think what the kids learn about electricity and magnetism in school science makes sense and is relevant to today's students?'.

Probing or Nudging Questions

These elicited more information from the respondents about a particular topic, or the demonstration of an awareness of the factors necessary to build deeper understanding in the learner. This question type was utilised extensively to follow up responses given by participants to some of the previous questions.

During the actual interviews, I adopted a flexible approach to the ordering of the questions asked. The depth of additional probing questions was dependent on the understanding described by each participant. Essentially, the major questions asked were the same or very similar in the different sets of interviews. For example: 'Do you have an opinion about why we are seeing the decrease in enrolments in school physics?' or: 'Why do you think it is increasingly difficult to find students willing to undertake courses related to your trade?'.

4.3.2 Question Categorisation

The questions used may be also categorised in terms of what they were intending to elicit from the respondents:

1. *Reflection on what they recognise as important aspects of electricity and magnetism that they were taught at school* (contribute to answering Research Question 1);
2. *Descriptions of memorable aspects (value judgements) of their study of electricity and magnetism at school and effective teaching strategies utilised, as a learner and as a teacher where applicable* (contribute to answering Research Question 1);

3. *Specification of aspects of study of school electricity and magnetism studies that were poorly taught (and why), or a hindrance to effective learning of predefined concepts. These could be considered as barriers to learning or difficulties in teaching* (contribute to answering Research Question 2)*;*

4. *Opinions as to the perceived relevance of what is currently taught, and what they considered to be desirable aspects of the study of electricity and magnetism deemed fundamentally necessary to be learned before graduating from the K-6 school environment* (contribute to answering Research Question 1).

4.3.3 The Final Seed Question Set

Eight seed questions were developed to scaffold the semi-structured interview protocol. Table 4.1 describes the relationship between the question types asked and their intention as information collecting instruments. Whilst the questions were similar for each respondent, consideration for the range of participants led to some variation (for examples the questions asked see Appendix C.3). Throughout all of the interviews, however, questions were specifically oriented toward gleaning individual opinions about what they thought should be taught in schools in the field of electricity and magnetism.

4.3.4 The Interviewees

Colleagues in the teaching profession were approached to become participants and, subsequently, were asked to recommend others, from within and beyond their profession, '…from people who know what cases are information-rich; that is, good examples for study, good interview subjects' (Patton 1990), and who they considered as having an intrinsic interest in, knowledge of, and opinion about 'what should be learned, by whom, and when?' (respondent 13PAP-ACPS-07_03). This *respondent-driven sampling* technique (Salganik & Heckathorn 2004) is a variation of the *snowball sampling* technique (Coleman 1958; Goodman 1961; Patton 1990). When considering the possible disadvantages of the technique, it was recognised that the process may be subject to inherent bias; that is, it is possible for the recommended participants to be familiar with, and therefore may hold similar views to, the respondent making the recommendation. To overcome this possible issue, respondents were asked to suggest possible participants from a field other than their own. The anonymity of the recommender was therefore assured.

Question Category	Question Example	Question Type	Purpose
Reflection	Please tell me about what you think are the most important aspects of electricity and magnetism that you learned at school.	Descriptive	Illicit from respondent's memories, rich descriptions of school science learning experiences
Value	Why do you think these experiences are memorable or valuable to you?	Probing	Seek a personal value statement as to what learning experience was effective to the learner.
Opinion	Do you think that these elements are valuable or make sense to today's students?	Value	Explore the issue of relevance of existing and desirable fundamental aspects.
Specification	Can you recall any aspects of your own experience learning about electricity and magnetism that was counterproductive to learning?	Probing	Identify barriers to the effective conceptual understanding.
Opinion	What about the basic elements of electricity and magnetism – what sort of basic skills or knowledge do you think students need to have for example, when they leave primary school?	Structural	Focus on specific concepts deemed valuable to K-6 students as a foundation for life long learning.
Value, Opinion	In terms of these fundamental concepts – if I were to come to you and say I'm as dumb as they come – teach me a bit about electricity and magnetism – where would you start?	Descriptive	Ascertain personal, professionally informed starting points for the development of sequential activities.
Opinion	What sort of skills or knowledge do you think students should gain in high school in this area?	Structural	Establish succession of concepts for development beyond K-6 schooling
Reflection, Opinion	Do you have any other suggestions of aspects of electricity and magnetism and their interactions that you think are valuable to today's students?	Probing	Seek suggestions for extension of conceptual understanding in terms of relevance.

Table 4.1: Mapping of examples of Question Categories to specific question types as described by Minichiello et al. (2008) pp. 98 – 103 using questions asked of all respondents.

The process resulted in 23 interviews being conducted with three categories of respondents comprising:

- 13 representatives from the educational sector
    - K-6 teachers (n = 4);
    - 7-10 teachers (n = 3);
    - 11-12 physics teachers (n = 3);
    - tertiary physics (n = 2);
    - TAFE electrical trades teacher (n = 1);
- 4 members of the electrical industry
    - mining electrician (n = 1)
    - household electrician (n = 1)
    - auto electrician (n = 1)
    - electricity supply linesman (n = 1)
- 6 members of the general public
    - licensed builder (n = 1)
    - retail electrical goods shop assistant (n = 1)
    - cattle breeder (n = 1)
    - hairdresser (n = 1)
    - local council engineer (n = 1)
    - bus driver (n = 1).

4.3.5 The Interview Process

An informal invitation to participate was initially made by a phone call to each recommended participant. Upon acceptance, a date, place and time for the interview was negotiated and a written description of the project, the interview protocol and ethics details posted to the participant.[1]

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[1] A copy of the ethics approval granted to conduct this investigation and of the Information and Consent documentation is included in Appendix A.

The interviews were conducted at the workplace of the participant (this provided a safe, non-threatening environment that had suitable furniture, lighting, refreshments and familiar resources) at a time negotiated as suitable for the allocation of approximately one hour for the conduct of the interview.

The nature of the ethics approval was discussed in terms of their voluntary participation, anonymity and how their responses would be used. The participants were asked to provide written evidence of their informed consent. To create a relaxed atmosphere and form a rapport with the interviewees, a light discussion about the workplace role that each was undertaking at the time was undertaken before the initial questions were posed.

Each interview was brought to a close after approximately forty minutes with a series of reflective questions designed to affirm the opinions expressed during the interview. As a member-check the participants subsequently received an electronic copy of the entire interview (.mp3), a copy of the written transcript and a description of the analysis involving their own and the opinions of the other experts interviewed during this phase. None of the participants questioned any of the data and 13 responded with affirmative feedback confirming the analysis of the interviews.

4.4 ANALYSIS

Consistent with a Vygotskian perspective (Vygotsky 1962-1986), I consider the socio-cultural context to be inseparable from individual perceptions. Hence, my primary concern was to interpret the network of relationships between the expert's beliefs of what is fundamental, their perceptions of what is prescribed subject matter and the learning context in terms of how it is experienced by the learner.

4.4.1 Application of Colaizzi's Analysis Process

In making the data generated more manageable, I adopted Colaizzi's seven steps of phenomenological analysis (Colaizzi 1978). Additional detail about the application of the analysis process is to be found in section 3.5.1 and Appendix C.5.

4.5 RESULTS

A summary of the final exhaustive description and fundamental structure analysis is provided below. Please refer to Appendix C for a copy of a final coding sheet and a detailed description of the analysis, statistical data and representative participant responses.

4.5.1 Summary of Exhaustive Description Analysis for Research Question 1

Research Question 1 sought to identify fundamental key concepts in the study of electricity and magnetism that should be explored by K-6 school students.

Consideration of the exhaustive descriptions for each of the emergent clusters of themes led to the distillation of four concept-based themes the respondents deemed should be included in K-6 school study.

Theme		Description
1	*Safety with Electricity - at home and in the work-place*	To minimise injury and death from electricity related accidents, young students should be made aware of the concept of 'insulation'. Components should include: • All substances can conduct electricity if the voltage is high enough. Some things (like metals [wires]) conduct better than others; • Water conducts electricity and therefore we should not use electrical appliances when we, or they, are wet; • To avoid being 'shocked by electricity'[2], we should always be insulated from the electricity; • If we see someone who is being electrocuted, we should know what we could do to help them without getting hurt ourselves.
2	*Efficient use of Electricity*	In order to realise why it is important to turn off electrical appliances, an understanding of what is electrical power is suggested. This is in terms of: • Using electricity has an impact on the environment (through its generation); • The higher the power rating of an appliance, the more it costs to run; • Most appliances use some power until turned off at the power-point; • What do the energy star ratings on appliances mean?; • What information can we read from a power bill?

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[2] Use of this phrase is in preference to 'electrocuted' as suggested by a teacher of Year 2.

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3	*Efficient generation of Electricity*	To promote energy (electricity) conservation at a household and personal level, students should be made aware of: • Electricity is not a never-ending resource. • Making electricity for us to use requires energy (heat, light, wind, etc.); • Ways of making electricity; • Making electricity has an effect on the environment; • Is solar electricity better than power station electricity? • How else can we make electricity? • How do batteries work?
4	*The Motor Effect*	A fuller understanding of the generation and use of energy in the form of electricity can be encouraged by developing the principle of the Motor Effect in its simplest form. Many activities relating the 'moving a magnetic field can make an electric current', and 'moving electric charges can make a magnetic field' lead to an understanding of the mechanical generation of electricity.

Table 4.2: Outline of the results of the exhaustive description and the fundamental analysis process for the four identified themes.

4.5.2 Summary of Exhaustive Description Analysis for Research Question 2

Research Question 2 sought to identify perceived barriers that may limit successful teaching and learning about fundamental electric and magnetic phenomena.

Consideration of the exhaustive descriptions for each of the emergent theme clusters led to the distillation to one theme that could be identified as a significant barrier to the effective teaching of electrical and magnetic concepts to K-6 students, as required by present societal expectation and syllabus documents[3] (in NSW). The confidence of the teachers to provide the appropriate pedagogical experience was variously related to their:

- perceived ability to understand, interpret and implement the syllabus;
- background knowledge to enable them to adequately prepare and deliver the requisite experiences to the students; and
- limited skill in assembling and demonstrating the necessary resources described in books and other teaching support materials.

Descriptions of elements identified derived from clusters of themes emergent from the analysis are detailed in Table 4.3 below.

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[3] When asked if they knew what the NSW K-6 Science and Technology Syllabus and Support Documentation (1993) required in the areas of electricity and magnetism, most respondents (74%), including teachers, stated that their knowledge was non-existent, or 'scant at least'.

Theme Cluster	Description
Background Knowledge	K-6 teachers acknowledged that they have very little science content knowledge. Most (75%) cited that they had not 'done' any science since Year 10 at high school and this contributed to their lack of confidence to present science related material because: • The students may ask questions to which the teacher may not know the answer – hence negatively impacting on the teacher's credibility; • Too much time (relative to other 'subjects' is needed to adequately prepare for science lessons); • Too often, the recommended experiments and science investigations do not always work as expected; • Unexpected results are often inexplicable by the teacher, again contributing to decreased credibility in the classroom. Trades-persons acknowledged that their school experiences with electric and magnetic concepts had not or had only minimally contributed to their fundamental understanding that could be applied to their vocation or life experience.
Personal Experience with science learning	Contributing to the lack of background knowledge were statements that acknowledged they had forgotten most of the science they had learned at school because: • It was taught to them using boring transmissive teaching strategies; • They could not see the relevance to living in modern society; • There were too many 'useless' facts with no reason to learn them and therefore science was too hard.
Syllabus	Being variously described by teachers as: • Outdated; • User unfriendly; • Too complex; and, • Too open to variable interpretation, the syllabus was identified as a major contributor to its limited application in the NSW K-6 classroom.
Resources	A concern that most K-6 learning spaces are set up as normal classrooms was expressed by most (80%) teacher respondents. This was echoed by other experts who provided comment on the types of activity able to be conduced in K-6 learning space stating: • K-6 schools are not adequately equipped in terms of the provision of basic science equipment needed to complete the desired, exciting and relevant hands-on investigations • The equipment necessary for recommended activities (as defined by syllabus support documents and popular texts) is too expensive or not readily available; • The manipulation of the equipment takes too much time and practice if it is to work well; and, • Students are not capable of using the equipment properly.

Table 4.3: Outline of the results of the exhaustive description and the fundamental analysis process for the theme of K-6 teacher confidence. It was acknowledged that these factors contributed to a reluctance to teach science, or at least pay 'lip-service' to its inclusion in the teaching and learning program.

4.6 SEQUENCE ELEMENTS AND TEACHING ACTIVITIES

Most of the experts interviewed (74%) initiated a discussion relating to the need for the K-6 students to be given the opportunity to explore the set of identified fundamental concepts for themselves.

> *"[a] collection of facts presented to the students for them to learn because the teacher said so is meaningless and counterproductive to the application of scientific process. ... If we want students to adopt scientifically-based, informed decision-making processes later in their lives, we must begin by creating an inquisitiveness and this is best begun with simple concepts that are familiar to the students, but which they do not necessarily understand".*
> (comments proffered by respondent 14PAT-UCS-09_03)

During the interviews, several respondents recommended activities that they felt would develop conceptual understanding, be relevant to the experience of the pre-service teachers, and exemplify the need to ensure relevance to the learner's everyday life. They further stressed the need for teachers to be able to prepare and appropriately conduct activities that would result in the building of conceptual understanding in their students. Common among most respondents (57%), including tradespersons and members of the public, was an expression of the need to map the development of understanding. Hence several discussions led to recommendations for the incorporation of formative assessment into activities to inform the teacher about how the learner was building their understanding.

The K-6 teacher respondents reported that the availability of resources needed to effectively build understanding in electricity and magnetism were not commonly available. This was countered by two of the electrical tradespersons who expressed a willingness and desire to be invited to talk to K-6 classes, and to discuss the relevance of the concepts to the students' everyday life.

Additional activities to explore simple magnetic and electric phenomena included:

- Playing with magnets – different shapes, sizes.
- Testing materials for magnetic properties.
- Making electromagnets.
- Building a compass.
- Making (and breaking) simple circuits (making a conductivity tester).

- Testing common materials for conductivity, with particular reference to insulation as a property of some substances.

4.7 SUMMARY AND CONCLUSION

This chapter has described the evolution of the data collection, analysis and results from Phase I of this research project to answer research questions 1 and 2.

4.7.1 Research Question 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?*

The phenomenological analysis of the 23 Expert Interviews revealed an overall opinion that the fundamental electricity and magnetism concepts that K-6 students should explore and become familiar with related to:

Safety — a significant proportion of childhood death and injury results from accidents involving electricity. It was stated that although children are told not to undertake particular behaviours around sources of electricity, the abstract nature of the warnings is too often not being heeded. It was also reported that children are for the most part unaware of how to treat victims of electric shock, particularly in terms of the safe removal of the injured person from the source of the electricity. This led to the recommendation that a greater emphasis be placed on safety with electricity in the K-6 years of schooling. It was deemed important that the insulation properties of materials be incorporated into a specific learning sequence, incorporating a hands-on, activity-based approach to overcome the abstract nature of the phenomenon.

Efficient Use of Electricity — the respondents were almost unanimous (91%) in their identification of electricity waste as a major concern as parents and energy consumers. That children tend to leave lights and other appliances on when not used, coupled with the insatiable appetite for batteries (cells) to power toys and other entertainment devices, exemplifies the need for K-6 students to be aware of the impact that such consumption has, not only on the family budget, but also on the environment. An awareness of ways to decrease electricity use was therefore recommended as being a desirable outcome of K-6 schooling. Such things as identifying inefficient appliances, understanding the meaning of energy ratings on appliances and therefore the costs of running appliances (as reflected in the household power bill), were suggested as possible inclusions in the curriculum to achieve this outcome. Coupled with this, participants identified a need for K-6 students to be aware of where electricity 'comes from' and that there are costs (financial and environmental) associated with its generation.

Efficient Generation of Electricity – respondents linked electricity use with electricity generation by suggesting that in order to promote energy (electricity) conservation at a household and personal level, students should explore different ways of making electricity. It was attested that recognition that electricity is not an inexhaustible resource and generating electricity requires energy (heat, light, wind etc.) would lead to an appreciation of the impact that different means of electricity generation have on the environment. It was recommended by the majority of respondents that students investigate how portable sources of electrical energy such as cells are made, and the impact their manufacture and disposal has on the environment.

The Motor Effect - A fuller understanding of the generation and use of electrical energy can be developed by exploring the motor effect in its simplest form. Respondents suggested that undertaking simple hands-on activities could establish that '*moving a magnetic field can make an electric current*', and '*moving electric current can make a magnetic field*'. It was attested that by empowering the students to investigate these interactions, an understanding of the mechanical generation of electricity would be facilitated.

4.7.2 Research Question 2

What are the perceived barriers that may limit the successful teaching and learning about fundamental electric and magnetic phenomena?

Reflecting on their K-6 school experience, respondents identified that they could not recall a great deal about any science activities they had experienced other than 'nature study'. Tradespersons acknowledged that their school experiences with electric and magnetic concepts had not or had only minimally contributed to a fundamental understanding that could be applied to their vocation or life experience. Further investigation of this lack of memorable experience revealed a perception that, in the experience of the participants, science was **boring** and **poorly taught**, using **transmissive 'write this down' techniques** requiring the recall of apparently **irrelevant** material.

K-6 teachers interviewed identified the NSW **syllabus** (and its support documents) as contributing negatively to practicing teachers' attitudes toward the teaching of science. A significant lack of easy to use and readily available **hands-on activity promoting resources** was also identified as a barrier to the successful teaching of science in K-6 classrooms. It was also identified that the **equipment** necessary for recommended activities (as defined by syllabus support documents and popular texts) is too expensive or not readily available and, in any case, the manipulation of the equipment takes too much time and practice if it is to work well. **Texts** were described as prescriptive, and audiovisual resources were preferred, as they tended to occupy the class and required minimal preparation prior to incorporation into classroom situations. A concern that most K-6 **learning spaces** are set up as normal classrooms making it difficult to conduct inquiry type investigations was expressed by most (80%) teacher respondents.

These identified barriers were considered when developing and refining the sequence undertaken by pre-service K-6 teachers in subsequent phases of the project.

4.7.3 Carried Forward

Exhaustive descriptions constructed during the analysis of the data collected during this phase identified four themes that were carried forward to provide guidance and a foundation for the development of the instrument components constructed for implementation during Phase II (Initial Instrument). The identified barriers to the successful teaching of electric and magnetic concepts to K-6 students formed a foundation for the development of teaching and assessment strategies explored during Phase II.

CHAPTER 5

PHASE II – ASSESSING AND ENHANCING UNDERSTANDING AND CONFIDENCE – INITIAL INSTRUMENT

5.1 INTRODUCTION

This chapter describes and reports on the development and application of the Phase II instrument designed to guide and inform the construction of answers to Research Questions 3 and 4.

Research Question 3 asks:

> *Within the context of pre-service K-6 teachers, what are the variations in the understanding of the identified fundamental concepts?*

Research Question 4 asks:

> *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 chapter concludes with a discussion of the results of this phase that led to the refinement of the instrument applied during Phase III.

5.2 INSTRUMENT DESIGN CONSIDERATIONS

The conduct of Phase I revealed three main aspects that guided the design of the instrument to address the Research Questions for this Phase.

1. Key set of Ideas
   During Phase I, Expert Interviews and collegial discussions identified a large list of what may be considered fundamental electric and magnetic concepts.

2. The Modelling of Effective Strategies
   During an open forum with the whole cohort of pre-service teachers wishing to learn how to teach, a general opinion was expressed that to require them to learn all the content they 'should' know in the short time available during the timetabled course was an unrealistic expectation. The view was also strongly expressed that it would be more valuable to them to undertake an exploration of selected concepts in a manner that would facilitate the observation of and participation in modelled teaching strategies.

3. Limit and Focus

   Consideration of the time available within the structure of the EDSE213 unit highlighted the need to limit the number of concepts to be explored and to focus on the overt modelling of a few teaching strategies able to be applied by early career teachers. Of the fundamental concepts identified, four were unpacked and specific explorations were compiled that would, it is postulated, establish a desirable foundation for beginning teachers to build upon when designing and teaching K-6 lessons in electricity and magnetism. The four concepts were:

   - safety with electricity — at home and in the work-place;
   - efficient use of electricity;
   - efficient generation of electricity; and
   - the motor effect.

5.2.1 Research Setting

The voluntary participants (n = 84) in this phase of the study were second-year students enrolled in the *Primary Science and Technology Curriculum Studies* EDSE213 course during Semester 1 2009 at the UNE. This one semester, six credit-point course of six hours each week is a component of the B.Ed. (Primary) teacher training degree (see Appendix B for course details). The philosophical basis of this course is to equip pre-service teachers with a foundation of science knowledge deemed necessary to enable them to prepare and deliver effective lessons for K-6 students and hence achieve the outcomes defined by the K-6 Science and Technology Syllabus (Board of Studies NSW 1993).

5.2.2 Instrument Alignment

The design of the Phase II instrument was guided by the literature and discussions with members of the research team, the UNE Science Education team and practising teachers. These led to the recommendation that the request of the participating preservice teachers be accepted to ensure that the research environment reflect a realistic classroom situation. With this in mind, it was determined to align the instrument with:

The 5Es

The overarching framework for the construction of the sequence was small group, inquiry-based learning activities incorporating the 5Es learning cycle as adopted by the *Primary Connections* project (see Chapter 3.5.3), a widely used resource in Australian schools designed to enhance the scientific literacy of K-6 students.

Inquiry-based Activities

Rennie, Goodrum and Hackling (2001) are among many researchers who have proposed that the teaching and learning of science should be inquiry-based, and that students should be encouraged to investigate their own ideas by constructing explanations about the real world from their personal experience. This proposition should also be reflected in the preparation of pre-service teachers. It was therefore deemed necessary that the developed sequence provide authentic inquiry-based practices, experiences and reflective opportunities where 'student-centred instructional strategies that address the dimensions of meaningful learning, and motivation and affect can change pre-service teachers' beliefs about their ability to teach science' (Watters & Ginns 2000:317).

Predict-Observe-Explain-Share (P-O-E-S)

The Predict-Observe-Explain strategy described by Palmer (1995) is incorporated into the 5Es approach as espoused by the *Primary Connections* project. The 'Share' component was added to incorporate a collaborative-learning approach supported by Mazur (1997) and Nelson (1994). This Vygotskian (1978) social constructivist model supports the notion that existing learner ideas (concepts) can be extended to more complex ones — by refining what is already known by the learner, or by modifying previous experiences and ideas with new observations and knowledge with the guidance of peers and/or more able persons.

Embedded Formative Assessment

To exemplify the need to identify evidence-based learning indicators that teachers may seek to observe in their students as demonstrations of a particular level of understanding, it was agreed that the participants should be encouraged to reflect on formative, diagnostic assessment strategies and observations as part of their own learning of the defined concepts. This practice would also serve as an evaluation mechanism in terms of the effectiveness of the teaching strategies being modelled. The format and situation of the assessments would be informed by the application of a phenomenographic approach to the analysis of the collected data.

An Iterative Cycle

Variation in learner understanding identified by formative assessment during the application of the teaching sequence informed the researcher (teacher) about the design of other iterations of the desired experientially built understanding. This facilitated the development of supplementary extension and remediation experiences in the form of an iterative cycle, to generate a specific and more scientifically literate understanding, able to be described by the learner.

Feedback to Participants

To encourage a metacognitive awareness of processes that focus the learning of content and pedagogy facilitating its application in another context — that of the learner becoming the teacher, evaluating the effectiveness of the teaching strategy as a method of facilitating learning by others — the results of the preliminary analyses were discussed with the participants during the subsequent lecture and workshop (see Appendix D.5). Sharing the findings of the analysis with the participating cohort, particularly the identified variation in understanding, served to inform them about what they may experience as facilitators of learning in real classrooms – that is, as teachers.

5.2.3 Instrument Delivery

Discussions with the lecturer of the EDSE213 unit were held to negotiate a timeframe for delivery of the Phase II instrument to volunteer participants enrolled in this second-year unit. This resulted in the allocation of a workshop, followed by a lecture then another workshop as successive sessions, each of 2 hours duration. The same workshop elements were presented to three approximately equal groups of participants and were conducted in a classroom environment with a similar spatial arrangement to a typical K-6 classroom. The lecture was conducted with the whole cohort in a tiered lecture theatre.

5.3 DEVELOPMENT OF THE PHASE II INSTRUMENT

This phase aimed to design, implement and evaluate specific strategies and tools proffered by the current literature, and acknowledged as effective by experienced teachers and colleagues alike. The development of the research tools and sequential teaching strategies are detailed below.

5.3.1 Development Team

A three-member team of myself, my co-supervisor and a practising K-6 teacher comprised the primary development team. In consultation with the EDSE213 lecturer, a series of eight two-hour sessions were conducted over a two-month period to assist in the development of the Phase II research instrument.

5.3.2 Clarification of Boundaries

Considering the instrument design parameters, the development team highlighted the need to focus the delivery of the sequence and the data collection process. Consequently, four specific boundaries within the context of the aims of the project were identified. Specifically, that:

1. the sequence presentation and data collection be conducted as part of a normal unit of study contributing to the award of a teaching qualification;
2. the experiential knowledge gained and pedagogical skills rehearsed be transferable to a real classroom environment;
3. the sequence be constructed and deliberately aligned with the availability of existing and familiar resources; and
4. the teaching strategies modelled reflect modern research including:
    - *Primary Connections* and the 5Es
    - Formative Assessments
    - Inquiry-based Pedagogies

The drafting of the Phase II instrument was conducted with these defined boundaries guiding the development of the teaching sequence.

5.3.3 Key Ideas Linked to Possible Activities

The key ideas and concepts identified during Phase I were examined individually by the development team members, and a series of experiences and activities were put forward for consideration. This provided a list with some 83 elements identified. These were ultimately distilled to a list of 21 that fitted into the areas of the four fundamental concepts identified by the Phase I Expert Interviews (see Table 5.1).

Key list of identified fundamental themes/ideas	**Tools to collect data**	**Learning elements to explore using sequence**
1. *Safety* • Safety with power-points • Safety with power-lines • Electricity and water • Safety with power-cords • Safe use of appliances • How to treat electrocution	Survey questions. Lists. Likert-type scales. P-O-E-S. Diagrams. Collaborative explanations. Small group Interviews.	Insulation – fundamental to safety *a) Electricity is a flow along a conductor* *b) Testing for conductivity* *c) Everything (including people) conducts electricity if it is energetic (volts) enough* *d) The skill of, and reasons for, stripping insulation for electrical circuit continuity* *e) List electrical devices* *f) List magnetic devices*

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2. ***Efficient Electricity Use*** • Making electricity has an impact on the environment • More watts written on appliance, the more power it uses (costs more to run) • Most appliances use power until turned off at the power-point • What do the energy star ratings on appliances mean? • What information can read from a power bill?	Survey questions. Lists. Open written-response questions. P-O-E-S. Hands on activities. Collaborative explanations. Small group Interviews.	Costs of electricity (environmental and economic considerations) *a) Completing a circuit – electricity will not flow unless it can go somewhere.* *b) Variables in light brightness – energy of electricity (volts) versus amount of electricity (amps)* *c) Mathematical manipulation of units of electricity - Power* *d) Units named after scientists*
3. ***Generation of Electricity*** • Electricity is not a never-ending resource • Making electricity requires energy • Ways of making electricity • Making electricity has an effect on the environment • Is solar electricity better than power station electricity? • How else can we make electricity? • How do batteries work?	Survey questions. Lists. Open written-response questions. P-O-E-S. Hands on activities. Collaborative explanations. Small group Interviews.	Mechanisms and consequences of electricity generation: *a) Moving magnet in coil – variables* *b) Moving electricity in a coil – magnetism – electromagnets* *c) Electricity and magnetism are closely related* *d) Mechanical to electrical energy* *e) Light to electrical energy*
4. ***The Motor Effect*** • moving a magnetic field can make an electric current • moving electric current can make a magnetic field • magnetic fields interact to cause rotation.	Survey questions. Lists. Open written-response questions. P-O-E-S. Hands on activities. Collaborative explanations. Small group Interviews.	Conversion of electrical energy to mechanical energy *a) Magnetic interactions – magnetic/non-magnetic materials* *b) Magnet/magnet interactions – attraction/repulsion* *c) Making an electromagnet – variables regarding strength* *d) Making a simple electric motor – how does it work?*

Table 5.1: Linking the Fundamental Concepts/Themes identified during Phase I with the research tools used to investigate the student understanding, and the Learning Elements explored during this Phase.

5.3.4 Instrument Design

Given the constraints of the workshop–lecture–workshop sequence, the development team decided that a tangible workbook would best serve the participant and researcher requirements. This format served the dual purposes of:

- The participants would have a personally constructed resource that reflected the development of knowledge and pedagogical skills that they could use as a reference at the start of and throughout their teaching career.
- The research team was able to collect the workbooks at the completion of each component, copy them and ensure their return prior to engagement with any subsequent component. This meant that the research team was able to conduct analyses of the participant responses in a timely and considered manner.

Initially, each team member individually drafted a learning sequence within the scope and constraints of the workshop–lecture–workshop opportunity. The sequences were then discussed with the pros and cons identified and debated. This resulted in the development of a draft sequence that outlined the sequencing of the key ideas, appropriate activities and embedded assessment strategies.

The collaborative nature of many of the activities also meant that the research participants were given the opportunity to reflect on the formative assessments necessary to evaluate learning and to guide the construction of additional complementary learning experiences.

5.3.5 Instrument Mapping

Table 5.2 below illustrates how the concepts, data collection methods and sequence elements were mapped. The activities undertaken in each part of the sequence contributing to this phase of the project are matched to the pre-determined fundamental concepts and component themes designed to explore the effectiveness of the learning elements using the derived sequence. The specific research tools used as data collection methods as well as teaching and formative assessment strategies being modelled are justified and mapped against Research Questions being addressed by this phase of the project.

Workshop Sequence Elements

These describe the specific strategies employed to collect data for analysis to answer specified research questions.

The Learning Element – Sequence Components

Derived from the themes identified during Phase I: Expert Interviews, the learning elements, *Safety, Efficient Energy Use, Efficient Energy Generation* and the *Motor Effect* (numbered **1 to 4** in Table 5.2) were deconstructed and elements suggested to explore the themes were then built into the sequence. The **Learning Elements** annotated **a** to **f** are described in Table 5.1 above.

The Research Tools – Formative Assessment Strategies

To facilitate the identification of conceptual growth, and stimulate reflection on the nature of how the learning is being manifested in the models being constructed by the learner, formative assessment strategies were designed and mapped against the Learning Elements described in Table 5.1. These were incorporated to enhance pedagogical awareness and participant (teacher) confidence in adopting formative assessments as a classroom tool. The strategies (numbered **A to H** in Tables 5.2 – 5.10) are:

- **A. Survey questions** – included as part of the activity workbooks.
- **B. Likert-type scales** – seeking a value response describing a personal perception.
- **C. Open written response** – associated with survey questions and Likert-type scales to offer participants the opportunity to provide comment on the value to them of the sequence elements or more information about particular components.
- **D. Predict-Observe-Explain-Share**
  - a. Individual written predictions and explanation of observable phenomena.
  - b. Shared verbal (some recorded during workshops, transcribed and analysed) and written explanation.
  - c. Hands-on manipulation, shared explanation, personal defence of explanation and written report.
- **E. Diagram construction –** while it is acknowledged that some of the diagrams resemble concept maps, the analysis of these as entities that describe conceptual understanding was deemed invalid as not all of the participants had exposure to concept map construction techniques and were not advised to construct diagrams in any particular way as part of the pre-intervention survey data collection process.
- **F. Models and analogies –** constructed as explanations recorded individually and shared with peers.
- **G. Student collaboration –** negotiation of shared understanding.
- **H. Small group interviews –** conducted when possible on the day after the workshops and lecture to provide the students with time to internalise the experiences and to reflect on their effectiveness as teaching strategies.

Rationale

To justify the reason for inclusion of the strategies in the sequential research instrument, a rationale was proposed and agreed to by the development team for each component. The rationale statements are included in Table 5.1.

RQ (Research Question)

The final column in Table 5.2 makes reference to the particular research question being addressed by each Research Tool, identified and defended in the previous columns.

													Rationale	RQ
					Introductory discussion								Put students at ease; outline structure and purpose of research project; describe the desired outcomes of the next 3 sessions. Discuss Pedagogical Content Knowledge (PCK).	All
Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**									**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
Pre-intervention survey	All				A	B	C		E	F			Establish and explore level of student knowledge; identify misconceptions.	3,4
	1e				A								Situate the study of electrical phenomena in a real world context. Provide relative quantitative measure of conceptual knowledge about everyday electrical devices.	3
	1f				A								Situate the study of magnetic phenomena in a real world context. Provide relative quantitative measure of conceptual knowledge about everyday devices that utilise magnetic phenomena. Assess awareness about the relationship between electricity and magnetism.	3
	1a	2a						Dc	E	F			Build on existing student held models of electricity; identify misconceptions.	4,5

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	1b	2a						Dc					Build on existing models of electricity. Identify misconceptions.	4,5
	1d	2a						Dc		F			Develop confidence in simple physical skill applicable to most elementary electricity experiments. Identify as a source of many experimental failures.	2,4
			3b		A			Da					Explore the relationship between moving electricity and the production of magnetism.	4,5
			3e					Dc	E				Establish and acknowledge the existence of a relationship between electricity and magnetism.	4
				4a	A			Dc			G		Build a fundamental understanding of the existence of magnetic effects on magnetic materials.	3
				4b	A			Dc			G		Build an understanding of the existence of magnetic effects.	3

Table 5.2: The rationale for linking the pre-intervention survey to specific research tools.

Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**								**Rationale**	**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
Small group Interviews	Discussion of effectiveness of strategies used											H	Collect considered feedback from participants as learners and teachers on the effectiveness of the sequence elements presented and suggestions for improvements.	4

Table 5.3: The linking of the small group interviews component of the Phase II research instrument to the specific research tools.

Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**								**Rationale**	**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
Lecture sequence elements	Review of Workshop				Provide feedback to students.								Inform students of initial analysis of Workshop 1 workbooks. Level and variation of understanding of identified concepts. Level of confidence to teach concepts of Year 4 discussed and requests for modelling of effective pedagogies and learning activities noted and acknowledged.	3,4
	1a	2a							E	F	G		Build on/Correct identified misconception regarding complete circuit. Students informed of effectiveness of peer interaction/learning.	3
		2a	3a 3c		A				E		G		First-hand experience of individual and small group constructions of understanding.	3,4
	1d	2b							E	F			Sharing variation of understanding in terms of different models for electricity flow – challenge to the teacher is to decipher student models and plan ways to change student conceptions (work of Skamp (2008) and Cosgrove (1998) discussed).	3,4
		2c								F	G		Overcome trepidation regarding units associated with electricity.	4
			3b 3c		A		C	Db			G		Review of electromagnetism workshop activities – discussion of value of reflection of previous activities, comparison of growth of models as they change and what caused the change.	3,4
		2c			A			Da					Identification of change in student conception and the reason for it.	4

Table 5.4: The rationale for the Lecture sequence elements of the Phase II research instrument linked to the specific research tools.

Workshop Sequence Elements	Learning Element - Sequence Component				Research Tool - Formative Assessment Strategy								Rationale	RQ
	1	2	3	4	A	B	C	D	E	F	G	H		
Availability of equipment	Discussion with all participants involving other members of the research team.											H	Remove stigma associated with availability of equipment to conduct activities that demonstrate phenomena. Student led collaborative discussion about sources of equipment and collegial relationships with other schools and businesses - identified by Phase I participants as a significant contributor to the unwillingness of K-6 teachers to offer science-based experiences to their students.	2,4

Table 5 5: The linking of the sequence elements of the Phase II research instrument to the rationale for employing the specific research tools.

Workshop Sequence Elements	Learning Element - Sequence Component				Research Tool - Formative Assessment Strategy								Rationale	RQ
	1	2	3	4	A	B	C	D	E	F	G	H		
Small group interviews	Discussion of change in conceptual understanding				Discussion of effectiveness of pedagogies used to change conceptual understanding								Review of Lecture – engaging? Incited discussion of transmissive versus experiential learning.	

Table 5.6: The linking of the sequence elements of the Phase II research instrument to the rationale for employing the specific research tools.

Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**								**Rationale**	**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
	Review of Lecture				Provide feedback to students								Describe to students findings relating to effectiveness of sequence elements – small group collaboration; hands-on activities.	2,3
	1a	2b	3c	4c	A		C	Dc	E				Shared explanations of how shaky torch works to exemplify consolidation of conceptual understanding of magnetic/electric interactions.	
	1d		3c	4b		B	C			F	G		Demonstration of construction of simple electric motor without explanation of steps to facilitate opportunity for learners to apply accumulated skill and knowledge to make their own.	
	1e	2c	3a					Da Db Dc	E		G		Student attempts to improve design/efficiency of their electric motor involves application of knowledge gained during sequence to consolidate personal model.	
		2a	3e	4b	A	B				F	G		Consolidation of relationship between electric motor and electric generator – linked models.	

Table 5.7: The linking of the sequence elements of the Phase II research instrument to the rationale for employing the specific research tools.

Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**								**Rationale**	**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
Review of Sequence with participants	Effectiveness of workshop sequence to consolidate and extend student knowledge.				In depth discussion with each of three groups as to the effectiveness of the teaching strategies modelled during the sequence. Consideration of improved confidence level.								Participants shared opportunity to consider what elements need to be 'understood' and hence 'taught' to enable students to build personal model of how the object under consideration 'works'. This strategy designed to help students identify their personal model, to change the model when it doesn't work, to share the model and to modify it again if necessary.	

Table 5.8: The linking of the sequence elements of the Phase II research instrument to the rationale for employing the specific research tools.

Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**								**Rationale**	**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
Small group Interviews	Review of workshop activities											H	Working with electric motor identified as fun and effective at identifying student problems with understanding of defined concepts.	

Table 5.9: The linking of the sequence elements of the Phase II research instrument to the rationale for employing the specific research tools.

Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**								**Rationale**	**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
Post-intervention survey	All				A	B	C		E	F		H	Provides qualitative evaluation of learning - led to mapping of sequence elements with effectiveness of strategies employed.	3,4, 6

Table 5.10: The linking of the sequence elements of the Phase II research instrument to the rationale for employing the specific research tools.

Workshop Sequence Elements	**Learning Element - Sequence Component**				**Research Tool - Formative Assessment Strategy**								**Rationale**	**RQ**
	1	**2**	**3**	**4**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		
Research Team Collaboration	Review of Learning Elements.				Consideration of effectiveness of Teaching Strategies as part of sequence. Discussion of improvements.								Step back and consider the data collection exercise as a whole in light of its effectiveness as a research instrument. Identification of components of Phase II Instrument to be taken into Phase III with EDSE213 2010.	

Table 5.11: The linking of the sequence elements of the Phase II research instrument to the rationale for employing the specific research tools.

5.4 THE INSTRUMENT

The research instrument incorporated a range of tools. These were applied to identify the participant's current level of knowledge of the particular concepts of electricity and magnetism, and personal perception of their preparedness and confidence to teach the concepts. They also provided a qualitative measure of the change in conceptual understanding and confidence after having participated in the Phase II research instrument sequence.

The tools were integrated into three workbooks, one for each scheduled session (Workshop 1, Lecture, Workshop 2). This facilitated the expeditious collection and copying of the booklets for preliminary analysis, and their return at the beginning of the next sequence component. Each of the work booklets elicited written responses from the participants to:

a. survey type questions;
b. Likert-type scales with invitations for the provision of written open responses to qualify answers;
c. requests to record Predict-Observe-Explain-Share including individual and small group activities;
d. the drawing and labelling of diagrams; and
e. the construction of lists.

5.4.1 Workbook I – Workshop 1

An overview of the project as well as information about learning and teaching cycles and formative assessment strategies for consideration at different times during the remainder of the project was provided in the beginning pages of Workbook I. This was followed by the specific questions and activities, responses to which would inform subsequent phases of the project. The booklet contained 38 pages, and acted as a resource for the participant and a data collection tool for the researcher.

The contents of Workbook I included:

1. What is Science Teaching about?
2. Methods to Probe Understanding.
3. Pre-intervention survey containing:
    a. survey-type questions;
    b. Likert-type scales with invitations for the provision of written open responses to qualify answers; and
    c. requests for the construction of lists.
4. Tools for the Teacher — identifying 'misconceptions'.
5. Predict-Observe-Explain-Share – making simple circuits, making electromagnets.
6. Teaching Models — 5Es (and others).
7. Exploring the Shaky Torch.
8. Magic with Magnets.

5.4.2 Workbook II - Lecture

This booklet consisted of 10 blank pages to facilitate free response to the questions and activities posed for individual and small group consideration.

The elements addressed by Booklet II included:

1. Feedback to the participants from the preliminary analysis of Workbook I.
2. Recording Predict-Observe-Explain-Share details.
3. Reporting on the making of a simple light-globe circuit.
4. Moving magnets in the proximity of coils.
5. Explanations of how the Shaky Torch works.

5.4.3 Workbook III – Workshop 2

This 18-page booklet provided details about the activities to be conducted. This was a deliberate attempt to free the researcher and observers to assist and observe the collaborative nature of the interactions.

Specifically, the contents of Workbook III were:

1. Discussions — explorations and collaboration.
2. Explanations of how the Shaky Torch works.
3. More about electromagnets.
4. Making an electric motor.

5. Post-intervention survey, the same as the pre-intervention survey, was completed in the final minutes of the last workshop.

Appendix D contains the data and detailed analysis for this phase of the project. A condensed copy (large spaces and blank pages removed) of the final iteration of the Phase II instrument is provided in Appendix A. A complete electronic copy of the Phase II booklets is available by contacting the author.

5.5 CONDUCT OF THE PHASE II RESEARCH INSTRUMENT

The EDSE213 *Primary Science and Technology Curriculum Studies* coursework students were informed that their participation in the data collection process was voluntary, and each was provided with a copy of the project information sheet, consent form and the initial workbook. Students who elected to participate were invited to sign a consent form and identify themselves with a unique group name that they would use for each entity of the data collection process.

5.5.1 Interactive Workshop

The 2009 EDSE213 cohort was divided into three groups for the workshops at different times (n = 29; 29; 26). The workshop environment was a room set up to resemble a K-6 classroom — tables and chairs arranged centrally with workbenches at the sides of the room. Most of the individual and collaborative group activities were conducted at the large student tables.

Attending the initial workshops were the course presenter (an experienced tertiary pre-service teacher educator with significant science teaching experience), and the three members of the primary research team (my two supervisors and myself). Following introductions, the group was asked to complete the pre-intervention survey — described as a way of establishing their current understanding, individually and collectively, of fundamental electric and magnetic concepts, and of their attitudes toward the teaching of science. This led to an open discussion regarding the participants' perceptions of what teaching strategies may effectively teach science concepts to K-6 students. The participants were encouraged to reflect upon their own experiences as learners of science at school and record in their workbooks those experiences that they believe contributed to an effective learning environment, as well as factors that may have hindered or limited their understanding.

Participants then undertook a series of individual and small group activities designed to develop their level of conceptual understanding. An outline of the sequence elements is provided in Appendix A. An example of an activity that involved the drawing of a simple circuit is presented in Figures 5.1 and 5.2 below. The analysis of these drawings is detailed in Appendix D.2.4.

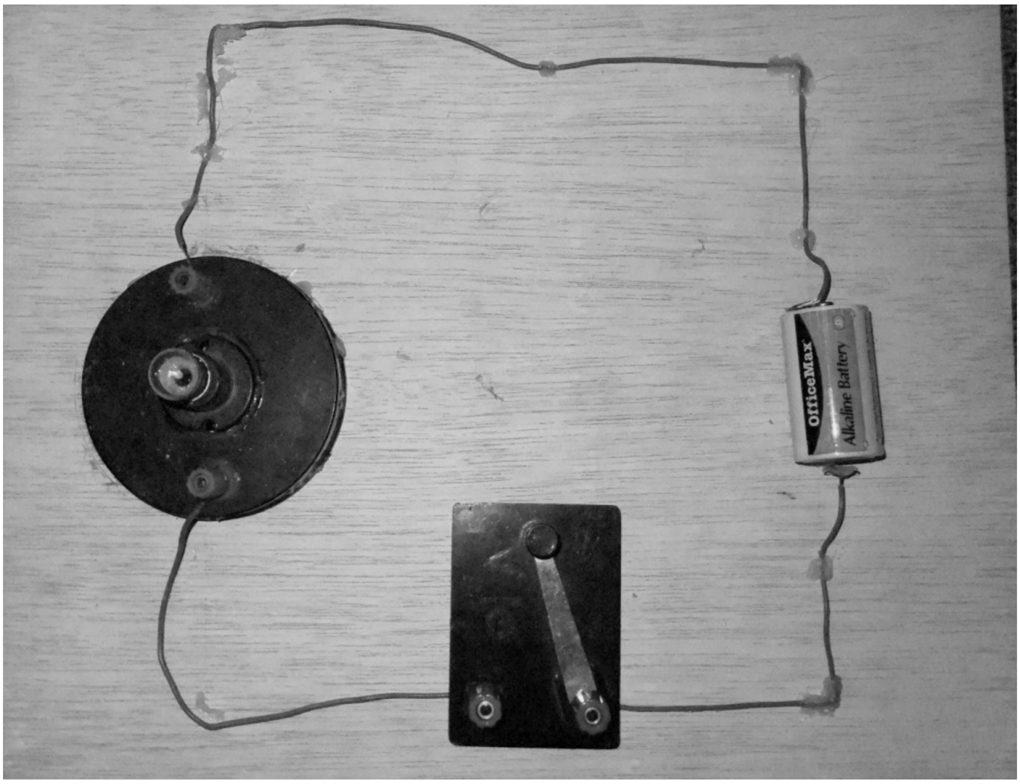
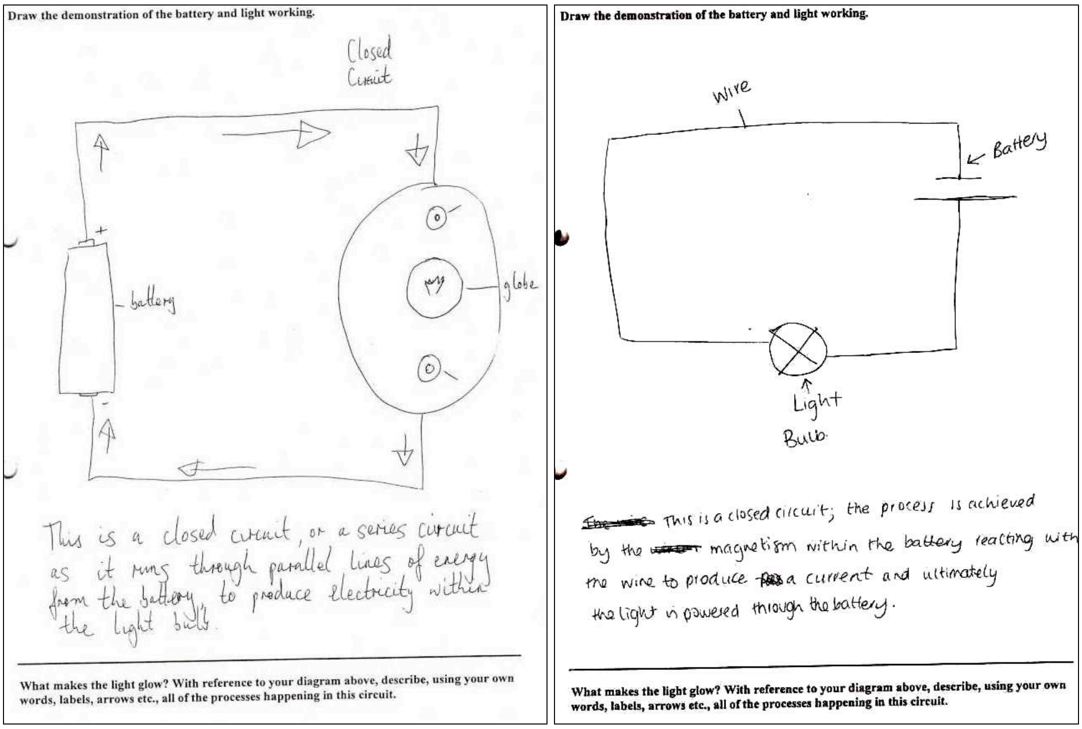


Figure 5.1: Photograph of the simple circuit used in the first workshop and referred to in the interactive lecture.



Draw the demonstration of the battery and light working.

This is a closed circuit, or a series circuit as it runs through parallel lines of energy from the battery, to produce electricity within the light bulb.

What makes the light glow? With reference to your diagram above, describe, using your own words, labels, arrows etc., all of the processes happening in this circuit.

Draw the demonstration of the battery and light working.

This is a closed circuit; the process is achieved by the magnetism within the battery reacting with the wire to produce a current and ultimately the light is powered through the battery.

What makes the light glow? With reference to your diagram above, describe, using your own words, labels, arrows etc., all of the processes happening in this circuit.

3-dimensional drawing (SID P2P1W1Gb103)

2-dimensional schematic drawing (SID P2P1W1Gb154)

Figure 5.2: Examples of student diagrams.

During the initial discussions with the workshop group participants, a limited understanding of teaching strategies to promote the learning of science concepts was identified and acknowledged by the majority of the cohort. Consequently, it was requested that the teaching of the prescribed coursework concepts model modern teaching practice, reflecting current research into the learning processes at a K-6 level. It was also agreed that activities presented would reflect those able to be undertaken by Year 4 students that combine individual and small group tasks. This elicited a comparison by the participants of the effectiveness of their learning as individuals, with that derived from engaging in collaborative, co-operative learning tasks.

Analysis (Colaizzi 1978), with a phenomenographic approach (Marton 1989), (see Section 3.3.5) of the pre-intervention survey responses, the completed components of the interactive workbooks and the observations made by members of the research team during the workshop, informed the refinement of the design of the subsequent lecture. The observations related to the:

- participants' ability to manipulate the equipment;
- enthusiasm exhibited by participants to share observations; and
- change in confidence to present, consider and negotiate explanations as part of the process of building understanding.

Following the workshop, informal interviews were held with participants focusing on their opinions about the effectiveness of the workshop and what concepts needed to be further explored using different strategies during later learning opportunities.

During these interviews, a strongly supported collective notion was proposed that these hands-on, activity based peer interaction experiences encouraged internalisation and ownership of the learning:

> *"...I really responded to not being told what to learn, but to me doing the learning."*
>
> (SID P2P1w1Gb177)

In acknowledging components that did not contribute to an improved knowledge or understanding, the opinion was expressed that the sequence elements would be of greater value to the learner if they were developed in terms of how the phenomena being explored could be fitted into the everyday experience of the learner.

The 'hands-on' nature of the activities was acclaimed as positively contributing to the enjoyment and hence engagement with the phenomenon being explored.

> *"…we've had these things – or some of them – shown to us before, but we never got to play and this was really enjoyable."*
>
> (SID P2P1w1Gb154)

Identifying pedagogical elements of the sequence, a concern was expressed about classroom management issues.

> *"I am still worried about letting kids loose with all this stuff. They're not like us and would need a lot of help and we can't get to all of them with so many things happening at once."*
>
> (SID P2P1w1Gb156)

This affirmed the need to discuss how the 5Es with the embedded Predict-Observe-Explain-Share may contribute to an active, yet controlled, learning environment.

Tables D.23-D.26 in Appendix D exemplify other participant responses during the small group informal interviews, the analysis of which contributed to the development of the final instrument.

5.5.2 Interactive Lecture

Following the three Workshop I sessions, a single interactive lecture was conducted with the complete cohort (n = 84). The course presenter and members of the research team were involved in the group activities and discussions during the lecture. The lecture theatre environment was used to:

- review the format of the workshops and the effectiveness of the activities conducted and the strategies modelled;
- provide additional experiences for the participants to build on the conceptual understanding achieved during the initial workshop;
- address shortcomings in fundamental conceptual understanding identified by the analysis of the pre-intervention survey and initial workshop responses;
- demonstrate modern and effective approaches to teaching science in the K-6 classroom environment;
- enhance the confidence to teach science to K-6 students by arming the participants with background knowledge, reinforced by first-hand experience of effective teaching strategies and formative assessment methods;
- introduce Predict-Observe-Explain-Share activities as an effective, research supported teaching strategy; and
- introduce the 5Es (Australian Academy of Science 2005) as a learning cycle supported by recent innovations in Australian curriculum development.

The lecture was presented in an environment where small group peer interaction was encouraged as an essential element. The lecture began with an open discussion about the results of the initial analysis of their workbook responses (see Appendix D.5). The inquiry-based activities, built on a Predict-Observe-Explain-Share framework, invited each participant to predict what may happen during an activity, make observations, and develop an explanation for their observations as they constructed an overall understanding of a core or fundamental concept. The participants were then invited to share their explanation with other members of their group, eventually arriving at an evidence-based consensual explanation for the phenomenon being observed. An integral part of this process was the observation of the negotiation of the explanation, providing a means to identify change in the depth of understanding demonstrated by the protagonists. As detailed in the specific workbook activities, the 'shaky' (Faraday) torch (see Figure 5.3) was used to stimulate engagement and interest and rehearse the negotiation of collaborative understanding. See Figure D.8 for examples of labelled diagrams of the Faraday torch.

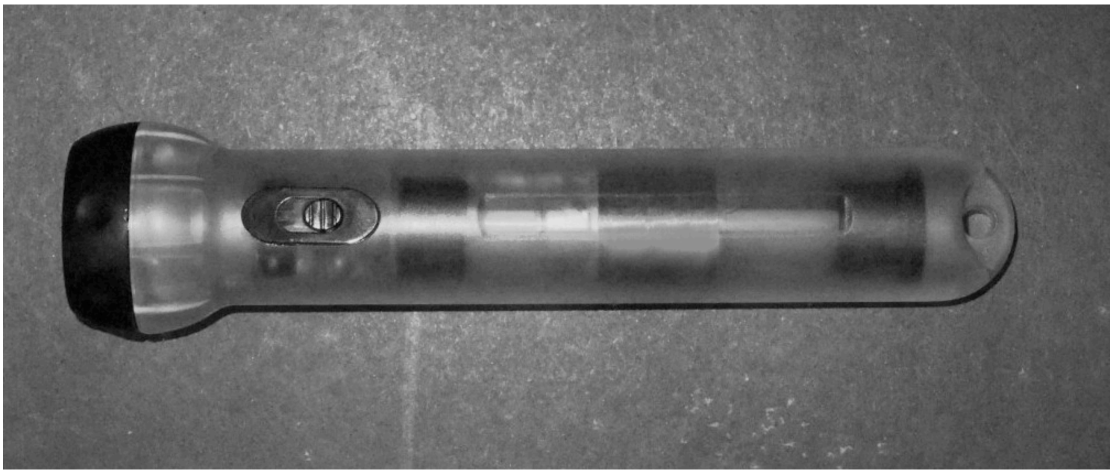


Figure 5.3: The 'Shaky Torch' the participants were asked to draw and label.

Informal interviews were conducted the day after the lecture to explore the perceived effectiveness of the learning and teaching strategies. This information guided the refinement of the sequence for presentation during later stages of this Phase, and during Phase III with another cohort of EDSE213 in 2010.

The Predict-Observe-Explain-Share and peer interaction strategies were particularly acknowledged as effective and this contributed to the decision to further develop these strategies as integral components of the final instrument.

> *"I reckon the Predict/Observe/Explain is a great way to learn. I really learned a lot from the others in the group when we tried to convince each other about our explanations."*
>
> (SID P2P1W1Gb128)

Hands-on activities were once more identified as effective strategies and statements referring to their application in the classroom indicated participant consideration of teaching strategies being modelled.

> *"...seeing such simple equipment that anyone can make, made me enthusiastic to try it myself."*
>
> (SID P2P1W1Gb177)

Again, peer interaction was endorsed as an effective means to promote learning. This is ably summed up by the following participant response:

> *"After you explained it to us, the most amazing thing was being able to explain to each other what we saw. I mean, we tried to convince others in our group that we were right. When I could see that "Greg's" explanation was better than mine, I thought about why and that really helped me to understand what was going on – not that Greg knows more, he just saw things that I missed."*
>
> (SID P2P1W1Gb133)

The feedback also helped develop formative assessment strategies to be utilised as a tool to evaluate the effectiveness of the learning during the application of the employed strategies.

Table 5.4 above describes the rationale that guided the construction of the interactive lecture. The design provided a model of how knowledge can be constructed collaboratively — from existing ideas (concepts) to more complex models — all by refining and sharing what was already known, or by modifying previous experience and ideas with new observations and knowledge. The 5Es were mapped over the lecture components (see Appendix D, Table D.21) and exemplified to the participants as an effective means of presenting course material.

5.5.3 Interactive Workshop

Following consideration of the feedback derived from the informal interviews conducted after the interactive lecture, it was negotiated with the research team that the final workshop should amalgamate the initial workshop and subsequent lecture experiences. To exemplify the importance of an understanding of the relationship between electrical and magnetic interactions, the activities presented during this final workshop were focused on measuring electrical conductivity of different substances, and on making a simple homopolar electric motor (Figure 5.5). The process was presented in a reproducible sequential manner designed to establish and strengthen the pedagogical link between the enhancement of knowledge, and reflection on the previous experiences of the participants.

Part of the process required participants to write explanations for each of the steps they took and identify the pedagogical considerations they needed to take into account if they were to present a similar activity to a class of Year 4 students. The participants were also asked to indicate specific behaviours (formative assessments) they would be looking to observe as a demonstration of the desired conceptual understanding requisite in their students. Details of the sequence elements provided to the participants to construct their motor are found in Appendix D6.3.

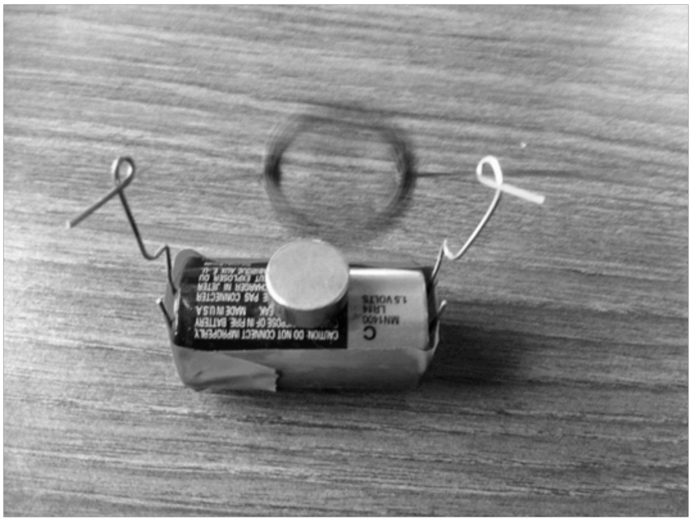


Figure 5.4: Simple homopolar motor constructed during final workshop.

To facilitate a comparison between the level of understanding demonstrable by the participants before and after the interventions prescribed by the Phase II research instrument, a post-intervention survey was conducted during the final minutes of the workshop. This survey was the same as the one administered at the beginning of the first workshop. The survey also assessed the effectiveness of the strategies used to minimise the variation in understanding as participants built their own understanding and explanations of electric and magnetic phenomena. The post-intervention survey analysis provided a qualitative measurement of the change in confidence of the participating preservice K-6 teachers as a consequence of involvement in the sequential interventions of the Phase II research instrument. The informal interviews provided additional feedback that led to minor modification of the sequence elements toward its adoption as the Phase III research instrument to be applied with the EDSE213 cohort of 2010. The modified activities and additional ones incorporated in the final instrument are detailed in Section 5.5.6.

5.5.4 Small-group Interactive Informal Interviews and Formative Assessment

As noted previously, informal, conversational interviews (Cohen, Morrison and Manion 2007:353), of approximately one-hour duration, were conducted with small groups of volunteer participants at the conclusion of each of the three teaching sessions. During these exchanges, participants were invited to identify evidence based learning indicators they may observe in their students that demonstrate the desired level of understanding or indicate the need for remedial intervention(s). The participants subsequently reflected on formative, diagnostic assessment strategies and observations that provided information about the levels of student understanding, and how they may identify possible student difficulties to the teacher. This reflective practice was also evaluative in terms of the effectiveness of the teaching strategies being modelled. The comments made reflected a change in participant thinking, in that they demonstrated that they were beginning to consider their own classroom practices. This was in terms of how they may identify the engagement of their students in the learning process, and how the students may be assessed along the way to evaluate their progress to guide for future learning activities.

> *"I'd have to find out if Year 4 kids knew anything about magnets before I gave them activities to explore. Magnetic toys are fairly common these days and the kids might already know about poles and attraction and repulsion."*
>
> (SID P2P1W1Gb133)

5.5.5 Constraints

While it is acknowledged that an ideal K-6 classroom situation could not be emulated, informing the participants of the intention to model the inquiry-based strategies created a situation where the participants played the dual role of learner (of the electric and magnetic concepts being presented) and teacher (in terms of their reflections on the effectiveness of the strategies). The incorporation of small group, peer learning situations provided a strategy for the participants to experience the constructivist nature of the activities and to share their appraisal of the effectiveness of the sequence.

The participants were also asked to make subjective and personal judgements about their confidence levels to teach the identified topics without the opportunity to personally appraise the skills demonstrated during the sequence. This led to the incorporation of small group peer-teaching opportunities as part of Phase III to facilitate the practice of skills being modelled during application of the final instrument.

5.6 RESULTS OF APPLICATION OF PHASE II RESEARCH INSTRUMENT

As outlined in Table 5.2, a collaborative review of the effectiveness of the data collection process using the Phase II research instrument was held immediately following the final small group informal interviews. An overview of the collected responses and comments expressed by the participants indicated a need to step back from the data and analyse it as a whole. This involved making observations about overall themes emerging from the data in terms of frequency of occurrence within the written workbooks across the whole cohort and multiple references to the same themes within the comments expressed during the informal interviews. This analysis provided additional guidance to the subsequent development of the final data collection instrument in terms of:

- the effectiveness of the sequence defined strategies as perceived by the participants; and
- the building of confidence expressed as a consequence of participating in the modelled strategies in a close-to–real classroom environment.

5.6.1 Reporting on the Themes

In reporting on the demonstrated level of understanding of the identified themes, the initial variation in understanding among the cohort was defined by a simple count of the responses deemed correct[1] and expressing this as a percentage of the total responses by the whole cohort.

Table 5.12 illustrates the changes in the mean student score for the various components of the survey elements explored, enabling a comparison to be made between the level of student understanding before and after the application of the initial sequence.

Table 5.12 also reveals that the application of the sequence has increased the level of conceptual understanding of the participants. The standard deviations (SD) of those items with a percentage score indicate a reduction of the variation in understanding. This trend is repeated when considering the reduced variation in those responses requiring lists, or specific identification of items (for example, the number of appliances listed that use electricity). Points 11 and 12 demonstrate an overall increase in personal assessment of confidence to teach the concepts using the strategies, although some recognised that a lack of understanding could continue to impact negatively on confidence to teach the concepts. Point 12 particularly demonstrates that, although perceived confidence after the sequence increased from 4.2 to 5.8 (out of 10), the change in standard deviation reflects the reported perception that the activities in the sequence made the participants more aware of their limited knowledge and this awareness negatively impacted on their confidence. Point 13 demonstrates that the applied sequence has encouraged participants to consider what

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[1] The participant responses were mapped against an assessment rubric (see Appendix A.2) by two members of the research team to ensure iterator reliability.

may be construed as barriers to effective learning and impede their effectiveness as facilitators of learning.

Pre- and Post-intervention Survey Element	**Mean pre-intervention survey Student Score**	**Mean post-intervention survey Student Score**
1. Listed electrical devices	$\bar{x} = 11$ Range: 1-22 listed devices	$\bar{x} = 14$ Range 7-17
2. Listed magnetic applications	$\bar{x} = 4$ Range 3-12	$\bar{x} = 11$ Range 6-9
3. Diagrammatic representation of circuits	$\bar{x} = 44\%$ SD = 14.7	$\bar{x} = 64\%$ SD = 9.6
4. Explanation of light globe working	$\bar{x} = 11\%$ SD = 31.5	$\bar{x} = 23\%$ SD = 23.3
5. Meaning of the term: Magnetism	$\bar{x} = 38\%$ SD = 15.1	$\bar{x} = 48\%$ SD = 9.2
6. Meaning of the term: Electricity	$\bar{x} = 34\%$ SD = 14.9	$\bar{x} = 59\%$ SD = 12.2
7. Meaning of the term: AC	$\bar{x} = 9\%$ SD = 21.1	$\bar{x} = 19\%$ SD = 16.1
8. Meaning of the term: DC	$\bar{x} = 11\%$ SD = 19.4	$\bar{x} = 29\%$ SD = 13.4
9. Identification of ways electricity may be generated	$\bar{x} = 2$ Range 1-6	$\bar{x} = 4$ Range 3-6
10. Self-perceived reported Confidence Level as identified by Likert-type scales	$\bar{x} = 4.2$ Range = 0 – 8.5 SD = 1.3	$\bar{x} = 5.8$ Range = 0 – 8.5 SD = 1.7
11. Identified areas confident to teach	$\bar{x} = 2$ Range 1-5	$\bar{x} = 3$ Range 2-7
12. Identified areas not-confident to teach	Most Range "All-Most"	Less Range 3-7
13. Identified teaching difficulties or barriers to learning students may face – written collaborative response	$\bar{x} = 1$ Range 1-5	$\bar{x} = 3$ Range 2-8

Table 5.12: Changes in the mean student score for each of the identified fundamental concepts explored during the sequence. It should be noted that the percentages expressed offer a degree of 'correctness' as identified by the research team.

5.6.2 Results for Research Question 3.

Research Question 3 asks:

> *Within the context of pre-service K-6 teachers, what are the variations in the understanding of the identified fundamental concepts?*

To answer this question, the analysis of a number of components of the sequential experience needed to be considered. Using Colaizzi's 7-step phenomenology process, analysis of the participant responses led to the construction of Exhaustive Descriptions for each of the categories under investigation identified from Phase I. From these, a Fundamental Structure for each of the categories was built and this was then relayed back to the participants during the lecture and workshop opportunities as a Member Check. Acknowledging the significant variation in the levels of understanding determined, the participants affirmed the Fundamental Structures for each of the categories as representative of the knowledge about the fundamental concepts of the cohort. As part of an open discussion, an evaluation of the sequence was conducted by identifying those components considered to be valuable as means of building understanding, and those that should be omitted or required revision and amendment.

It was pointed out during the whole cohort lecture that the elements of the pre-intervention survey were specifically designed to ascertain what the participants understood about how electricity and magnetism impacted on their daily lives, and their depth of knowledge about the relationship between electricity and magnetism. Consideration of Table 5.11 above reveals that the variation in participant understanding has decreased. This implies that, while those with a good understanding have had their understanding enhanced, those with a limited knowledge have had theirs enhanced to a greater extent, bringing them closer to the desired level of knowledge and understanding for K-6 teachers.

Safety

Pre-intervention survey Exhaustive Description:

> *Electricity provides power to make many things work. It comes from batteries and power stations. Moving a magnet in a coil can create electricity. Electricity can be dangerous and care should be taken using power-points and around power-lines as sparks can jump to you. Electrical power comes from positive and negative charges moving through wires. The wires must all be connected to have a circuit for appliances to work. Charge then passes through the appliance to make it work. Breaking the circuit is like turning off the switch. Electricity can make heat, cold, light, sound and movement. To help students (K-6) learn about electricity, they can make and play with simple circuits (e.g. a torch, a 'skill tester'), visit a power station, talk to an electrician and play role play games (such as 'pass the pulse'). An ambulance officer could talk to the class to talk about safety with electricity.*

Concepts notably absent from the above description include conductivity of different materials, insulation to prevent current flowing to a person, how to identify possible electrical dangers (such as *damaged power-cords*) and natural sources of electricity that can be dangerous (*lightning*).

Responses to the circuit drawing task in the pre-intervention survey and the integrated hands-on activities in the first workshop, indicated significant variation in understanding of the need for a pathway to enable electric current to move. For example, of the 16 small groups (74 participants in total), 10 groups took more than 10 minutes to construct a simple circuit comprising a light bulb, cell and one piece of insulated (plastic coated) wire. In another activity in the same workshop, 13 of the groups were unable to complete the task of making and using an electromagnet. The main reason in both instances, as identified by observers initially and eventually by the participants, was a failure to remove the insulation from the wire to complete the circuit. During the informal post-workshop interview with participants (n = 4), a level of frustration with either the activity ("the equipment must have been faulty" (n = 4), themselves (n = 3) (in terms of their lack of ability to complete the task ("how stupid am I?": SID P2P1W1Gb179)), or their peers (for not seeing how simple it was (n = 2)). This, coupled with the oft-asked participant question "will I get a shock?" revealed a limited understanding of insulation as a property integral to the safe use of electrical appliances in terms of the prevention of electric shock to the user, and the nature of the relationship between insulation and the potential difference needed to overcome the insulation and cause an "electric shock". Whilst the participants indicated a basic knowledge of the need to avoid downed powerlines and flying kites near powerlines, two of the groups were unable to explain how to remove an electrocution victim from the source of the electricity without exposing themselves to possible danger. Activities exploring the nature of conductivity and subsequently insulation were therefore incorporated as part of the teaching sequence during the final workshop.

Efficient Energy Use

Pre-intervention survey Exhaustive Description:

> *Electric motors are devices that are powered by electricity to do work and make things move. Switches turn electrical appliances on and off. Electrical appliances are important for our everyday lives but they cost money to run. The more powerful an appliance is, the more it costs to run. Batteries are an expensive source of electricity, and they must be put in the right way to work things. Good conductors use less electricity than bad conductors.*

For this category, it is most pertinent to note what has **not** been included in this description — that is, factors that were not mentioned by the participants. Less than half of the participants (n = 32) provided any response to survey questions relating to how to efficiently manage electrical energy consumption. Also missing from this description are any references to several elements of the fundamental concepts identified during Phase I. These include:

- Using electricity has an impact on the environment (through its generation).
- The higher the power rating of an appliance, the more it costs more to run.
- Most appliances use some power until turned off at the power-point.
- What do the energy star ratings on appliances mean?
- What information can we read from a power bill?

After revealing this to the participants during the interactive lecture, it was negotiated and agreed that such omissions were related to lack of recognition that these are relevant to their everyday lives within the context of informing (teaching) students about efficient energy use. The participants suggested that, as the strategies and activities being employed were more hands-on and reflective of true exploratory 'science' investigations, those concepts could be left to the realms of social science (the environment) and mathematics (reading bills). This perception again reinforced the need for an awareness of the cross-curriculum approach that could be adopted when exploring such concepts.

Participant-generated definitions of several terms associated with electricity and magnetism were elicited. Consideration of the variety of definitions provided, and the limited number that could be regarded as representing a fundamental understanding of the concept, demonstrated a significant limitation of knowledge of these concepts. For example:

> "*electricity is charge that flows through wires to power objects*" (34%);
> "*magnets attract metals*" (91%); and
> "*an electromagnet absorbs electricity to make magnetism*" (37%).

These, and the fact that more than half of the cohort failed to respond, suggests that knowledge of the basic terminology associated with efficient electricity use is limited. Thus, by association, the significant majority of students would not be able to identify how electricity use could be efficiently managed.

During the final workshop, in seeking to make the built electric motor 'better', only 13% (n = 11) of the participants identified any relationship between the power generated by the motor and the amount of electrical energy consumed. The majority of participants indicated that the motor could be made more efficient by having more turns of wire in the coil (%R = 65), and by having stronger magnets (%R = 76). Only 24% of the participants identified that efficiency was related to the amount of electrical energy consumed compared to the work the motor could do. Recognising that these were collaboratively generated responses, significant variation was identified in individual responses, as distinct from the group response. This led to the construction tasks that explored different aspects of electrical use including the amount of work that electric motors with different voltage ratings (1.5V and 9V) can do, and the relationship between the efficiency of electromagnets and the materials from which they were constructed.

Electricity Generation

Pre-intervention survey Exhaustive Description:

> *Electricity comes from power stations and travels to us in power-line wires. Electricity has to be made all the time because it is being used by appliances. Electricity is also made by batteries. Batteries go flat when they run out of electricity, but they can be recharged by putting electricity back in. Other ways to make electricity are solar, water and wind. Electricity flow from power stations is measured in volts. It costs money to make electricity.*

The participants were asked to list, in each of two columns, devices that use electricity and those that use magnetism. Of the 84 participant responses, the average number of items listed that used electricity was 11 and of these, the majority (n > 8) were electronic and entertainment or communication-oriented in nature. These were identified as appliances that may be for personal use (computers, mobile phones, iPods). The average number of items identified as using magnetism was significantly less (n = 4), the most common response listing 'fridge magnets'. Only 3% of the cohort made reference to magnets being a component of electrical generators and 42% to compasses being 'suspended magnets'. One participant made reference

> "*…compasses are magnets that are able to move to align themselves with the Earth's magnetic field.*"
>
> (SID P2P1W1Gb111).

Only 10% of participants identified any relationship between electricity and magnetism and all of these referred to electromagnets (specifically mentioning 'speakers').

A limited understanding of the nature of electricity itself — how it 'flows' through a circuit and the many ways it may be generated for everyday use — further complicates the picture. The range of understanding confirmed the need to construct a variety of teaching strategies to draw the understanding of the participants toward a single entity. Hands-on activities that facilitated a step-by-step building of the understanding of the relationship between electricity and magnetism were consequently chosen for testing as part of the Phase III sequence.

A pre-intervention survey item asked participants to describe how electricity is made. Only 29% provided any response, most stating that it

> *"…comes from power stations",*

without providing any detail of how the electricity is generated. This led to the construction of a hands-on activity that explored a combination of three motors (see Figure 6.7) as part of the Phase III research instrument. The participants were asked to explain the relationships between the electricity-driven motor that was connected physically to another motor that was, in turn, connected by wires to a third motor.

To further exemplify the principles of electricity generation, participants were reminded of the effect of passing a magnetic field through a coil connected to a meter. This simple activity was embellished by several of the groups (n = 7 of the 16 groups) that made qualitative statements referring to the speed with which the magnet was inserted and withdrawn, the strength of the magnet being moved, or the number of turns of wire making up the coil. Collaboratively generated explanations of the observed phenomena, once shared, negotiated and identified as 'more correct' than individual explanations, were reported as more readily remembered. This was demonstrated by responses to the post-intervention survey item, supporting the premise that collaborative learning (Couch & Mazur 2001; Nelson 1994) is an effective mechanism to establish and build a foundation of fundamental concepts, and can be effectively modelled to pre-service K-6 teachers.

Motor Effect

Pre- intervention survey Exhaustive Description:

> *Electric motors are devices that convert electricity to usable energy to do work. Electric motors make things move.*

No participants identified a magnet as a component of an electric motor. This indicates a significantly incomplete understanding of the motor effect by the majority of aspiring pre-service K-6 teachers, and of the interrelationship between electricity and magnetism in terms of the generation of either. To exemplify the importance of this relationship, the activities presented during the final workshop were focused on exploring electric and magnetic interrelationships with permanent and electromagnets culminating in the making a simple homopolar electric motor (Figure 5.1). This brought together some of the fundamental concepts explored during the initial workshop and subsequent lecture, and incorporated a combination of individual and group activities. The construction of the motor was demonstrated once and the participants were then invited to construct their own from the raw materials that were supplied in bulk: they had to cut their own length of wire to make a coil, shape the paper-clips for the commutators and balance the assembly for it to work. While some individuals (35%) chose to construct their own motor, most elected to work together in their designated groups and, as such, completed the task as a negotiated step-wise process.

While most of the participants (10 groups and 11 individuals) were able to successfully build the motor within a 30-minute time-frame, some (2 groups and 7 individuals) were observed to have difficulty with particular aspects of the construction related to the insulation on the wire forming the coil being used as commutators. This observation led to the identification of limitations in the desired level of conceptual understanding regarding the nature of insulation. A failure to correctly remove the insulation from the ends of the coil led to 55% of the unsuccessful initial attempts to make the motor. However, diagnosis of the faulty construction by peers rectified the situation with all of the motors. The need to revisit the concept of insulation coupled with magnetic field interactions by current-carrying coils and permanent magnets was identified as necessary in subsequent applications of the research instrument. Similarly, formative assessment questions such as "how would you reverse the direction of spin of the coil?" revealed a limited understanding of the concept of the relationship between current and the magnetic field formed as it moves through the coil of wire. This, when matched with the perception among some students (42%) that magnets have positive and negative ends led to the inclusion of additional activities with magnets (compasses, different shaped permanent magnets and electromagnets) to explore the direction of magnetic fields, and their interaction in terms of attraction and repulsion as a force capable of inducing movement.

5.6.3 Discussion of Results for Research Question 3

A significant variation was found in the depth of understanding demonstrated by the participating cohort of pre-service teachers from extremely limited (47%) to adequate for teaching about electricity and magnetism (29%). The middle 24% demonstrated what could be regarded as an elementary understanding of fundamental concepts of either electricity or magnetism, but not both. During the small group interviews, the participants acknowledged this limitation, most (67%) cited a dislike for science, exemplified by

> *"Although I don't like science, I'll have to learn it when I have to teach it"*

(SID P2P1W1Gb119)

Further analysis of the guided activity workbooks revealed that approximately half of the participants significantly changed, and built on, their personal models of the phenomena determined by Phase I during the intervention sequence in Phase II. It was also evident that the sequence of activities, when undertaken as individuals, was less effective at building a more acceptable conceptual understanding, than when the participants were invited to share their observations, deductions and explanations with their peers. This adds support to the advantages of a social constructivist approach (Vygotsky 1978), coupled with the peer learning processes espoused by Couch and Mazur (2001), Nelson (1994) and others, to pedagogical approaches that develop and enhance the learning of science concepts.

Considering the shared observations and negotiated explanations for each of the Predict-Observe-Explain-Share activities, a SOLO (Biggs and Collis 1982) categorisation of these revealed a change in complexity and organisational structure as the peer-negotiation process progressed. Individually, a full range of categorised explanations were constructed for each activity, an example of which is presented in Table 5.13 for a response to the "bar magnet being inserted into a large coil of wire" example conducted during Workshop 1. A similar categorisation of the overall Predict-Observe-Explain-Share activities undertaken during the final workshop revealed a shift toward the more abstract, identified by some participants as being due to them gaining confidence and feeling more at ease as their familiarity with the process grew, and as they got to know each other.

Level of Learning Category Demonstrated	**Examples of Student Response**
Pre-structural	"the force used to put the magnet into the coil is turned into electrical force that moves the pointer and when you take it out, the force is sucked back out of the pointer".
Unistructural	"if you push the magnet in, the needle goes left, and it goes right when you pull it out".
Multistructural	"the magnet pushed the pointer to the left while it is moving, but when stopped, the needle goes back to zero. Does this have anything to do with energy conversion? I mean, it everything is still, there is no energy to convert into another form, like electricity – I assume the meter is measuring electricity?"
Relational	"moving the magnet into the coil makes electricity as shown by the meter needle moving. When the magnet stops, no electricity is being made, and when you pull it out, the electricity goes the other way."
Extended abstract	"are we making AC?"

Table 5.13: Examples of SOLO (Biggs & Collis 1982) categorisation of individual explanations to the "bar magnet being inserted into a large coil of wire" example conducted during Workshop 1.

The range in accuracy and detail provided in the responses to the pre-intervention survey activities (see Table 5.4 above, and Appendix D) was also categorised using Bloom's Revised Taxonomy (Anderson & Krathwohl 2001) with most responses (56%) falling in the *Remembering* or *Understanding* categories. Only 7% of responses demonstrated an *Application* of their knowledge beyond recall of facts and events. This, coupled with the raw scores obtained from the pre-intervention survey questions, indicated a low level of conceptual understanding of electric, magnetic and electromagnetic phenomena. This is exemplified by such statements as:

> *"magnets have positive and negative charge"* (44%); and
> *"opposites (+ and -) attract and likes (- and – or + and +) repel"* (25%).

That personal knowledge and understanding of the fundamental concepts was perceived as inadequate to teach the identified concepts to Year 4 students was exemplified by such statements as:

> *"I don't understand most electric and magnetic things"* (44%); and
> *"I don't know what I don't know"* (35%).

Most (78%) attributed their lack of understanding to their "bad" school experience of science, citing it as boring, lacking relevance and delivered in a most uninteresting, transmissive fashion. This is in line with the findings of many science education researchers, notably Appleton (2003), Crouch and Mazur (2001), Duschl, Schweingruber and Shouse (2007), and Lyons and Quinn (2010) as outlined in Chapter 2. Whilst the participants expressed a desire to know more, they also recognised that their lack of knowledge may contribute directly to a limited confidence to teach about this and other science topics.

5.6.4 Results for Research Question 4.

Research Question 4 asks:

> *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?*

As detailed in Chapter 2, much of the literature about primary science education makes reference to the preparedness, and apparent reluctance, of many K-6 teachers to teach science (for example, Appleton 1977, 1995, 2003; Department of Employment, Education and Training [DEET] 1989; Goodrum, Hackling & Rennie 2001; Hackling 2007; Mellado, Blanco & Ruiz 1998; Smith & Neale 1991).

Masters (2009), in reviewing numeracy and science learning in Queensland K-5 schools, has identified highly effective teachers as having a deep understanding of the subjects they teach, 'having studied the content they teach in considerably greater depth than the level at which they currently teach' (p. 4). There is a direct correlation evident between the level of understanding as determined by the pre-intervention survey instrument, and the level of confidence expressed by the participants to teach about electricity and magnetism (see Figure 5.6 below). The post-intervention survey revealed that the application of the modelling process had not only increased the level of student understanding, but that there had been a significant increase in the confidence to teach the fundamental concepts (primary scale response increase from 4.3/10 to 5.7/10 — see Figure 5.7 below), citing the success of peer learning and hands-on activities as major contributors to this increase. Specifically, participants reported significant improvements in the enjoyment they felt during their involvement in the sequence, both as a student learning about the concepts of electricity and magnetism, and as a teacher as they reflected on the teaching strategies that contributed most to the improvement in their understanding.

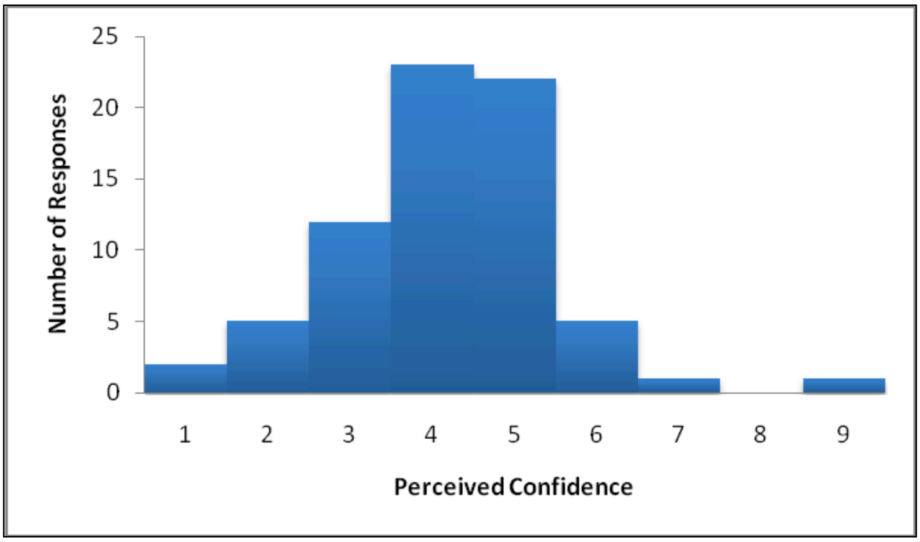

Figure 5.5: Pre-intervention survey histogram: confidence versus frequency – Mean = 4.2; SD = 1.3

Figure 5.6: *Post-intervention survey histogram: confidence versus frequency – Mean = 5.8; SD = 1.7. When compared to Figure 5. 6 above, note shift to right.*

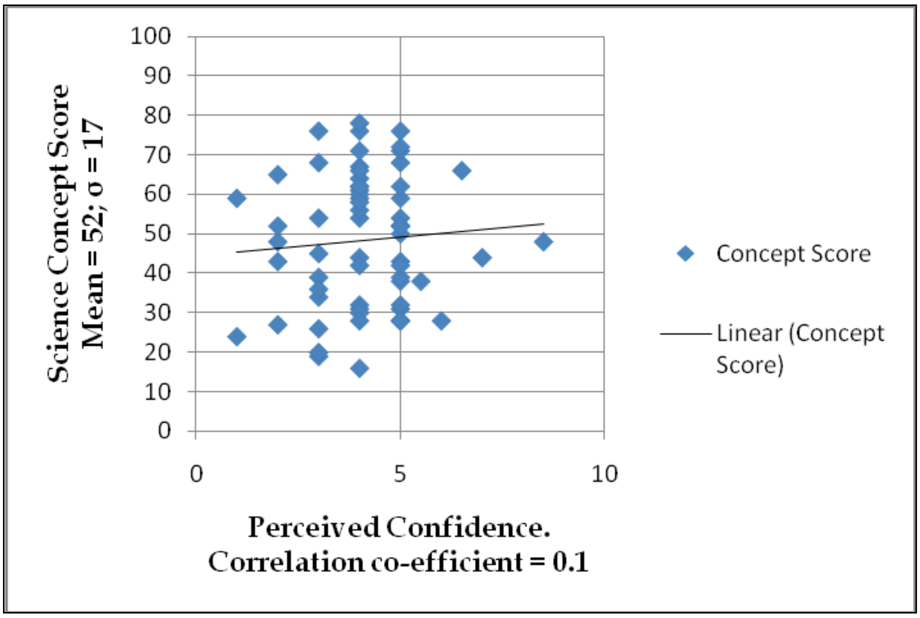

Figure 5.7: *Graphical representation of the relationship between Fundamental Science Concept Score – Electricity and Magnetism (Lyons 2008) and Perceived level of Confidence – Pre-intervention survey results.*

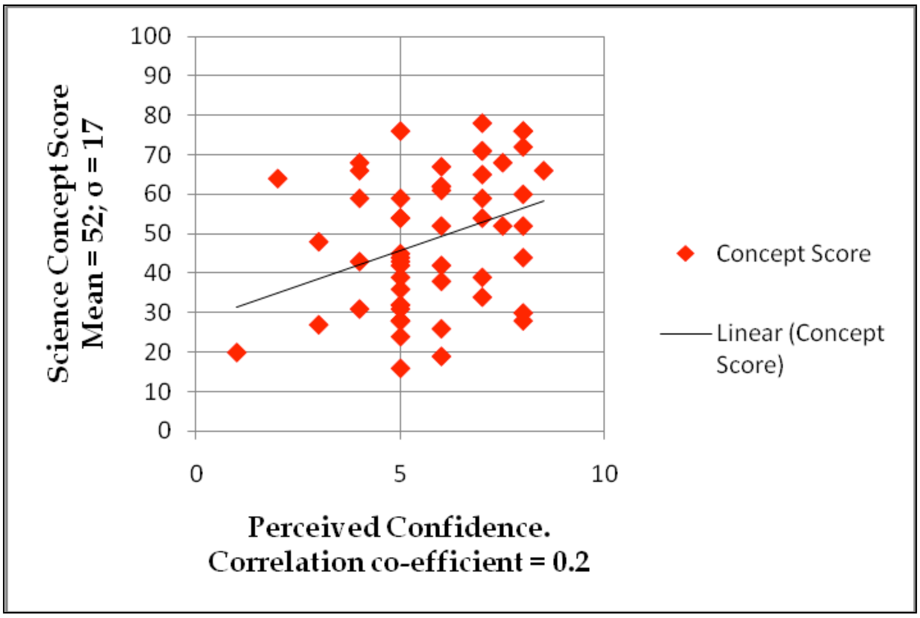

Figure 5.8: Graphical representation of the relationship between Fundamental Science Concept Score – Electricity and Magnetism (Lyons 2008) and Perceived level of Confidence – Post-intervention survey results.

'[T]eachers today are having to learn to teach in ways in which they have not been taught themselves' (Hargreaves *et al.* 2001:197). In line with this premise, and as a direct consequence of the variation identified in both understanding and confidence to teach the fundamental concepts, it was negotiated with, and agreed by the initial cohort, that the application of the Phase III research instrument should further model research supported, effective science learning strategies.

That the participants in this cohort of pre-service teachers expressed a low level of confidence to teach science is in keeping with the findings of the research outlined in Chapter 2. Similarly, participants stated that this lack of confidence is reflected in a lack of desire to teach science, particularly physical science concepts such as those identified in Phase I of this project. They cited the major reason for their lack of confidence as their lack of content knowledge, and their lack of interest in learning the requisite content, based on a perception of lack of relevance to their lives and experience. Some stated that they would avoid teaching those concepts in which they lacked a comfortable level of understanding. During the small group interviews, this 'comfortable level of understanding' was clarified as the level at which they, as teachers, would be able to

> *"field student questions without being made a fool of"*
>
> (SID P2P1W1Gb162)

The success of the instrument in building conceptual knowledge and teacher confidence was confirmed by the results of the analyses of the activity workbooks and the small group informal interviews, as well as anecdotal feedback from the research team and course presenter as presented in Table 5.11 above. Whilst most participants with low scores indicated a low level of confidence to teach the concepts, a similar number with high scores expressed the same low level of confidence. Also, some students with a low knowledge score stated that they were confident to teach the concepts, reporting that they would learn about 'it' (the fundamentals) when it came time to teach 'it'. Only a small percentage of participants with high knowledge scores stated that they were confident to teach 'it' to Year 4 students. Exploration of the level of school science experienced, revealed that those participants who had completed science studies in their post-compulsory school years were most confident, and they felt more familiar with most of the experiences provided to them for application in their own classrooms.

Observation of the manipulative skills demonstrated by the participants during the latter activities of the sequence also indicated a marked improvement in their confidence to participate, and to discuss with other group members, reasons for their actions, and possible explanations for their observations. This application of the Predict-Observe-Explain-Share learning cycle was reflected upon by one participant who stated that this was a

> *"...great way to engage all of the students at their own level"*
>
> (SID P2P1W1Gb177)

and another who reported a wish that had that technique been used during her schooling, she

> *"...might have enjoyed science, and learned something"*
>
> (SID P2P1W1Gb121).

These comments support the notion of Lyons (2005), Palmer (2008) and Rennie, Goodrum and Hackling (2001) whose recent research suggests that 'the way science is taught in schools is one factor that has been linked to declining interest and enrolments' (Palmer 2008:169).

5.6.5 Discussion of Results for Research Question 4

The variation in understanding of the fundamental concepts is not a direct reflection of the participants' perception of their level of confidence to teach the concepts. Requests from the cohort, supported by the findings of researchers, to model effective teaching strategies, led to the application of the Phase II research instrument and its evaluation as part of the post-intervention survey component and small group interview component.

Schoon & Boone 1998 (cited in Palmer 2008) propose that science content courses for pre-service K-6 teachers are comparatively unsuccessful in improving teacher attitudes to science. The effectiveness of this initial sequence, incorporating the 5Es and Predict-Observe-Explain-Share, as both a classroom-teaching tool, and pedagogical modelling tool for pre-service K-6 teachers, was acknowledged as high by the analyses and by participants. Participation in collaborative learning processes was confirmed as a major contributing factor to this effectiveness, as was the participant knowledge of, and enthusiasm for, the 5Es and Predict-Observe-Explain-Share enhanced.

5.6.6 Problems with the Instrument

The administration of the instrument over the two weeks of semester I in 2009 presented few problems, apart from continuity in terms of the attendance (and hence longitudinal participation) of a small proportion of the cohort (7%). Whilst the organisation and provision of the necessary equipment for active involvement by the whole cohort in the hands-on activities required attention to detail (magnets, wire, multimeters etc.), most of these issues were minimised by the application of a rotational sequence to the activities, the culmination of which was a single activity conducted during the final workshop — the building and testing of a simple homopolar motor. The number of participants (n > 40) who subsequently sought to borrow equipment or, indeed, procure their own resources to further 'play' with the motor they were building, was another measure of the success of the application of the instrument.

However, detailed analysis of the participant's written responses and the informal small group interviews with participants revealed that some of the activities were not achieving the desired level of conceptual understanding (viz. the ability to *apply* as described by Anderson and Krathwohl (2001)) by all of the participants. Some activities did not decrease the variation in understanding to any degree sufficient to be recognised as successful. This was reflected in the personally perceived level of confidence to teach particular concepts. Consequently, additional activities with an emphasis on observation and shared explanation of specific phenomena associated with the fundamental concepts were incorporated for administration during the Phase III application of the sequential instrument. Table 5.12 below details the additional elements of the sequence identified and built into a recursive loop as a modification of the peer-teaching process adopted during the final component of Phase III.

Fundamental Concept	**Initial Activity**	**Additional activity**	**Formative assessment prompting additional activity**
Safety	Insulation	Measuring conductivity of insulated materials before and after removal of insulation	Construction of circuit without removal of insulation.
Efficient Energy Use	Measuring power – voltage and current	Measuring the efficiency of different voltage-rated small electric motors.	Stating that energy consumption is a reflection of the power rating of an appliance.
Energy generation	Moving magnets inside coils of wire	Different magnets and different coils of wire	Not testing variables of coils, magnet strength and proximity for current generation.
Motor effect	Magnetic interactions – testing magnetic materials	Different shapes of magnets and the magnetic field generated	No explanation of magnetic fields interacting to cause rotation.

Table 5.14: Additional Sequence Components Identified from Formative Assessments

5.7 SUMMARY AND CONCLUSIONS

This chapter details the development and trial of an instrument designed to measure the variation in understanding of a cohort of pre-service K-6 teachers about fundamental aspects of electricity and magnetism, and subsequently enhance that knowledge. The instrument also explored the relationship between the self-perceived confidence of the participants to teach the prescribed syllabus, and their school science learning — cited by the majority as being boring, irrelevant and poorly taught to them.

5.7.1 Findings Taken Forward to Inform Phase III

Analysis of the post-intervention surveys revealed a significant gain in participant understanding. Application of the Bloom's Revised Taxonomy (Anderson & Krathwohl 2001) to categorise participant responses yielded a demonstrably significant shift toward the *higher order thinking skills*. It was also evident that the variation in understanding was diminished. However, the participants reported that some of the activities had not been as effective as was anticipated. For example, there was a demonstrable shortcoming in the understanding of the concept of insulation as it related to electrical safety in the home and the workplace. Although there was an increased grasp of the need to ensure the completeness of a circuit to enable electricity to 'flow' around a circuit, it was revealed that some students did not realise that the coating around wires provided an insulating property to prevent the flow of electricity. It was therefore decided to further explore the nature of insulation, particularly in terms of the need to remain insulated against possible current flow into the body.

Feedback provided by the research team, observers and the small group informal interviews, indicated that some activities needed modification in order to link the desired growth in conceptual understanding and the real life experience of the participants This led to the redesign of some of the activities to incorporate direct relevance to the participants and the introduction of others into the sequence. For example, the relationship between the electric motor and the generator was included in the Phase III sequence (see Figure. 6.6).

Knowledge of the existence and application of magnetic properties in many of the everyday appliances used by and phenomena experienced by the participants was limited. Understanding of the properties of magnets was identified as needing to be enhanced. The shape of permanent magnets and the materials used to make them were areas in which participants demonstrated limited understanding. The misconception that the 'poles' of magnets are positive and negative in nature highlighted the need to provide experiences that highlight the differences between electric fields and magnetic fields. Similarly, a limited knowledge of the uses of magnets in everyday life was also found as significant, with refrigerator magnets identified by 87% of participants and only 3% acknowledging the use of magnets to generate electricity. This is particularly relevant in terms of the need to understand the interaction of magnetic fields when generating electricity (other than by light, chemical and friction means), and its use in appliances that utilise electric motors. Phase III activities identified as needing to be incorporated included the provision of opportunities for the participants to explore different iterations of electromagnets, the shape of a magnetic field (small compasses located around the electromagnet (see Figure 6.7), and factors that affected the shape and magnitude of the field.

The participants did, however, clearly acknowledge the effectiveness of the hands-on activities they explored, and the value of the collaborative opportunities to share and further build their level of understanding with their peers. The success of this modelled strategy was further developed for volunteers to undertake peer-teaching episodes to rehearse and further evaluate the collaborative learning strategies.

5.7.2 The Confidence of the Participants to Teach the Concepts

In most cases, the increased understanding of the fundamental concepts explored was reflected in an increased level of confidence to teach those concepts to Year 4 students. Some participants, however, reported that although their knowledge and understanding of the concepts had increased, it had served to highlight the need to gain additional knowledge and understanding in order to meet the possible challenges of being able to answer student-generated questions. The excitement expressed to actively pursue an increased conceptual knowledge of science is exemplified by the diagram below — it was handed to me at the completion of the sequence with the question "would this help me explain the shaky torch to my students?"

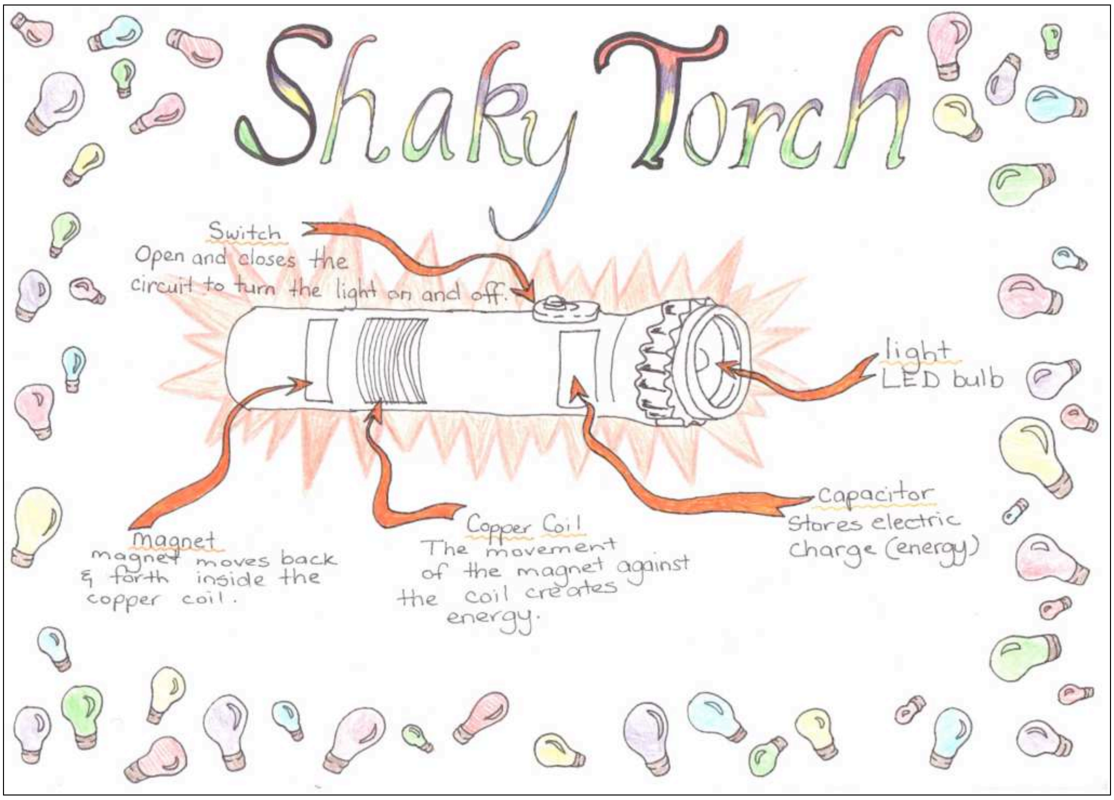

Figure 5.9: An example of an unsolicited participant working diagram of the shaky torch.

Reflecting on the modelled teaching strategies, it was acknowledged that these could be implemented by the pre-service teachers early in their career as practising teachers. It was also stated that the application of these strategies could be valuable to them as a means of engaging their students and ensuring relevance to the everyday experiences of their students. This is in-line with the constructivist approach to the generation of personal knowledge. Of particular note was the recognition of the value of peer-learning scenarios. These are more fully explored as a consequence of the application of the Phase III instrument, the results of which are presented in Chapter 6.