

Science and Mathematics Education Centre

**The Effect of Teaching and Learning Strategies on Conceptual
and Attitudinal Change of Gifted Primary Students**

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Doctor of Philosophy

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Declaration

This thesis contains no material which has been accepted for the award of any degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signature:

A handwritten signature in black ink, appearing to be 'S. J. Baker', written in a cursive style.

Date: 25th September 2017

Abstract

The purpose of this research was to determine the style of teaching and learning strategies that are most effective in bringing about conceptual growth and attitudinal change in gifted Year 6 students in the Primary Extension And Challenge (PEAC) program in Western Australian public schools. The research investigated the effectiveness of two types of three phase learning cycle; a descriptive learning cycle (DLC) and a hypothetical-deductive learning cycle (HDLC) as described by Lawson (1995). A quasi-experimental method was used with a 20 hour course in basic electronics as the intervention. Conceptual growth was determined using quantitative data from a concept mapping task and a two-tiered multiple choice instrument. Change in attitudes towards scientific inquiry and enjoyment of science lessons was investigated using the Test of Science Related Attitudes (TOSRA). All instruments were used in a pre-test and a post-test format. Additional qualitative data was obtained from teacher reflections on the administration of the learning cycles.

The research found that both the DLC and the HDLC produced statistically significant improvements in the students' understanding of basic electronics as measured by the concept mapping task and the two-tiered multiple choice test. However there was found to be no statistically significant difference between the two learning cycles. Data from the TOSRA indicated no change in attitude towards scientific inquiry and no change in the enjoyment of science lessons for either learning cycle. This result was partly due to the high pre-intervention positive attitudes which left little room for improvement. Analysis of the teacher reflections indicated that significant scaffolding was necessary in both learning cycles to enable students to understand difficult concepts.

It was concluded that both three phase learning cycles were an ideal teaching/learning model for use in the PEAC program due to their simplicity and effectiveness in bringing about conceptual growth. It was also concluded that although the learning cycles did not improve attitudes to scientific inquiry and enjoyment of science, it did maintain a high positive attitude in both aspects.

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Dedication

This research is dedicated to my late son Ian who was himself a PEAC student. A driving factor in this research has been the desire to better understand the difficulties that can be faced by gifted students and in particular the difficulties faced by my son Ian.

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CHAPTER 1 Introduction to the Thesis

1.1 Chapter Overview

In Chapter 1, I will provide a background to the events that led me to conduct this study. My initial reaction to teaching gifted primary students was one of amazement and I knew from the first lesson, I would need to adapt my strategies to suit their ability – to make my lessons more challenging. Many of my secondary school teaching colleagues constantly asked me: *Why are they so different?; How are you changing your lessons?* They were interested for two main reasons. Firstly the secondary school within which the gifted primary program was being conducted had many gifted students and the teachers wanted ideas; and secondly, the school wanted to retain these students when they graduated into secondary school. This school had a very sharing professional culture and I was eager to share my experiences with my teaching colleagues. I felt this was best done with some concrete evidence such as data from a formal research study.

1.2 A Personal Journey

As mentioned in the previous section I propose to share relevant aspects of my teaching career and how it led to the desire to conduct this study. The story demonstrates how my experiences and my need to adapt to changing curricula culminated in this study. This study will also consider my reflections as the teacher administering the two different teaching strategies used in this research. For example how practical is each strategy in a classroom situation? This study not only presented a learning situation for the students, it also presented a learning situation for me, the teacher. The account of my experiences in implementing this research are given in Chapter 5.

My science teaching career led me to teaching science to Australian Aboriginal students in the remote North West region of Western Australia. I had to change my teaching strategies dramatically to suit the learning style of Aboriginal students. Their learning styles included spatial and visual aspects. Concepts presented to these students needed to directly relate to their environmental experiences. For example the literacy program for the whole school (Kindergarten to Year 10) was based on experience readers. In this program teachers created an experience for the students which may have been a classroom experience or an excursion; the students write

sentences or a story about the experience and draw pictures to illustrate it. The artistic ability of the Australian Aborigine is phenomenal and using this ability was an effective strategy in engaging Aboriginal students. The stories and illustrations were then printed into booklets in the school's print shop. These books became experience readers, of which the students were very proud. Literacy was a high priority in this school. I now realize, after preparing for this study, that the experience reader program was a form of a three phase learning cycle. The experience generated by the teacher was an *exploration of a concept*; the writing about the experience was a *concept development*; and the later reading of the experience reader and discussion was a *concept application*. I had used this strategy very successfully for teaching science in the North West

During my time in the north west region, I commenced, as an external student, a Post Graduate Diploma in Science Education at the Western Australian Institute of Technology (WAIT). This was my introduction to postgraduate study with my major interest being teaching science to Aboriginal students. My final project for this diploma was a learning package tailored specifically for Aboriginal students in remote communities of the Pilbara region of Western Australia. Such a package needed to be mindful of the learning styles of Aboriginal students which were quite different to students with a European background. This experience was valuable to me when faced with the task of teaching gifted students at a later time because I had developed greater awareness, when planning curricula, of the need to consider the special learning needs of particular types of students.

In 2005 I took up a part-time position teaching science to gifted upper primary students in the Primary Extension and Challenge gifted education program (PEAC). In this teaching role I was employed as a science specialist and I had to design my own 20 hour courses (two hours per week for ten weeks) that would enrich and extend the PEAC students. I was now mindful of my North West experience with Aboriginal students in that I was dealing with students who were different to the mainstream and required different teaching and learning strategies. As mentioned previously, when teaching Aboriginal students I had to adapt my lessons to include spatial and visual experiences in meaningful contexts. Standard science lessons using European based concepts were not appropriate for Aboriginal students. The first characteristic I noted about gifted students was that they only needed to have a concept explained once or at

the most twice and they did not need to consolidate the concept with a multitude of practice examples. The students wanted to move onto the next concept.

The PEAC program is a withdrawal extension program, that is, students leave their normal schools and attend a variety of centres for extension studies. The program consists of series of 20 hour courses in which a broad range of learning experiences is offered to the students. Each course specializes in a specific knowledge domain such as creative writing, mathematics, drama, visual arts, contextual problem solving, and flight. Students are able to choose courses to suit their interests and abilities. Courses in the PEAC program could not be extensions of existing primary curricula and they had to be both challenging and motivating to the students. Courses I developed included *Rocket Science* (students were introduced to rocket stability, equations of motion and trigonometry), *Lost* (students were introduced to the basics of navigation, global grid systems, and map making), and *Electronics* (introduction to the concepts of voltage, current and resistance in circuits). In addition to these courses, I developed a series of courses introducing students to the three major science disciplines – biology, physics and chemistry. These courses were designed to be motivating with the aim of creating a desire in the students to study science in secondary school. All the PEAC courses I designed contained a high practical component. For example in *Rocket Science* students made their own rockets and in *Electronics* they constructed their own electronic gadgets. I had a suspicion in my early days of teaching gifted students that they liked using their hands and physically exploring devices and equipment. *Electronics* was chosen for this research because I considered that the students were unlikely to have been exposed to electrical concepts in their primary education, therefore prior knowledge would most likely be low.

An incident occurred in a *Rocket Science* lesson that illustrates how astute some of the PEAC students were. Students had just completed their rocket launches and calculated their maximum velocities using impulse and change in momentum:

$$\text{i.e. } Ft = mv - mu$$

The rocket started from rest therefore $mu = 0$; the students measured the mass (m) of the rocket; and impulse (Ft) for the rocket engine was supplied by the manufacturer. All the students needed to do was solve the above equation for final velocity (v). This incidentally is a Year 11 physics problem in the Western Australian physics syllabus.

PEAC students had no problems determining 'v'. At the conclusion of the lesson, I told the class that next week we will launch another rocket to measure its average velocity using height (measured using trigonometry) divided by time of flight. A year 6 student pointed out to me that that was not necessary because average velocity was half the final velocity if the rocket started from rest. The student was not strictly correct because a model rocket has a coasting phase before reached maximum height but he was not aware of that at the time. He had however correctly assumed constant acceleration during the rocket flight and without being asked, had intuitively applied his knowledge of the averaging equation and applied it to the rocket situation:

$$\text{Average velocity} = \frac{\text{Initial velocity} + \text{Final velocity}}{2}$$

I knew from this incident that I was dealing with students who were capable of high levels of thinking. I then asked myself - am I adequately challenging their ability?

A motivating factor in my decision to undertake this research was the fact I had no formal training in teaching gifted students. Although the DoE produced a publication (eTags, 2010) that outlined the characteristics of, the identification of, and the general modes of provision of a differentiated curriculum for gifted students, it did not provide specific teaching models for use by secondary teachers like me who were not specifically trained in gifted education. In fact, my primary trained PEAC colleagues were also not specifically trained in gifted education prior to entering the PEAC program. We were encouraged to complete the six modules of the 'Gifted and Talented Education Professional Development Package for Teachers' (2004) produced by the Gifted Education Research, Resource and Information Centre (GERRIC) of the University of New South Wales. I wanted to learn the best way to teach a gifted child by using their natural talents. It was already apparent to me that the methods I used with a mainstream class would quickly lead to boredom and not challenge their thinking skills. These modules and references and links in eTags, although valuable, did not refer to any research specific to Western Australia. Consequently I set myself the challenge to find and investigate a suitable model for teaching science to gifted primary students in Western Australia. I had a strong desire to not only improve my own teaching skills, but to provide a teaching model that I could share with my colleagues. To do this I would need to demonstrate that such a model was both effective and efficient to implement. At the time this study was commenced, teachers

in Western Australia had undergone many changes to the delivery of the science curriculum and to put it quite bluntly, teachers like myself were tired of the continual changes. Mindful of the need to keep changes to minimum, if I was to present a teaching model acceptable to my colleagues, the model would need to build on what they were already doing. I considered I chose a model to investigate that would suit this basic criterion.

In my quest to find a practical teaching/learning model, I came across a book titled *Science Teaching and the Development of Thinking* (Lawson, 1995). This book introduced me to the concept of learning cycles. On further investigation, I found another book titled '*The Learning Cycle*' (Marek & Cavallo, 1997) which was concerned with elementary school science. These two books complemented each other and gave me the basis for adapting the learning cycle for use in PEAC program. Learning cycles as described by Lawson (1995) seemed ideal for my purpose. I could compare a descriptive learning cycle (DLC), which was very similar to my normal style of teaching and that of many of my colleagues, with a hypothetical-deductive learning cycle (HDLC), which was more student-centred and inquiry-based. Science lessons in both the Achievement Certificate and Unit Curriculum were activity based with a component of inquiry embedded. The main difference being the sequence of the lessons. The activities within a typical science lesson were often used to demonstrate a concept introduced by the teacher rather than used as an exploration. The HDLC seemed an ideal strategy to compare with the DLC as it gave students the opportunity to formulate hypotheses and design experiments to test these hypotheses. This was the process I had always considered the inquiry process to be. All aspects of the two learning cycles are used by science teachers at some time or other and this research will give them a better understanding of how to use these aspects more effectively. It was at this early stage that I realized that the experience reader program I used with my Aboriginal students had a learning cycle structure and I knew that program was very successful.

During the development of the DLC lessons, I quickly realized that a three phase learning cycle as described by Lawson was a very logical way to teach. Learning cycles were never presented at our professional development sessions and on reflection I would not have hesitated to use learning cycles in my secondary science teaching had I known about them. During trials of the electronics course used in this study it was

obvious that the interest of the students was very high and they adapted to the process very quickly. Adjustments to my teaching style with regard to the DLC, were quite minor and preparation was no different. The HDLC however was not so straight forward. Not only were lessons longer to prepare, the lessons took much longer to conduct. This was due partly to the need to train the students to formulate hypotheses and design experiments, a process that was largely teacher-centred in the DLC, and partly due to the need for considerable scaffolding because of the student's lack of prior knowledge concerning electrical concepts and procedural knowledge related to the scientific method.

1.3 Purpose of the study and research questions

This research was designed to determine whether or not a three phase learning is a suitable model for teaching PEAC science courses and to compare two different types of learning cycle to determine the most effective. I used different groups with equivalent competencies to determine which is the most effective in enabling PEAC students to acquire concepts and develop a sound understanding of concepts in basic electronics. I also investigated any changes relating to the students' attitudes towards scientific inquiry and enjoyment of science. The two learning cycles that were compared were based on two learning cycles described by Lawson (1995): a descriptive learning cycle which has a high degree of teacher-directed instruction; and a hypothetical–deductive learning cycle, which is more inquiry-based and student-centred instruction. My research was conducted using six research questions which are stated below. The research questions fall into two groups: Research Questions 1, 3, and 5 are concerned with the general effectiveness of a three phase learning cycle; whereas Research Questions 2, 4 and 6 are concerned with the difference in effectiveness between two types of specific learning cycle.

Research Question 1:

Is a three phase learning cycle an effective teaching model for bringing about conceptual growth in PEAC students studying basic electronics?

Research Question 2:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical–deductive learning cycle, is the most effective in bringing about conceptual growth in PEAC students studying basic electronics?

Research Question 3:

Does a three phase learning cycle change a PEAC student's attitude toward scientific inquiry?

Research Question 4:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing a PEAC student's attitude toward scientific inquiry?

Research Question 5:

Does a three phase learning cycle change a PEAC student's enjoyment of science lessons?

Research Question 6:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing a PEAC student's enjoyment of science lessons?

1.4 Context and Limitations of the Study

In this research I examined two different teaching and learning strategies for gifted primary students. The research was centred on an extension program for gifted primary students in Western Australian State primary schools. The extension program is called *Primary Extension And Challenge* and is commonly known by its acronym PEAC. PEAC students are taken out of their normal classes to attend extension courses of study and this may involve travelling away from their normal school. To enter the PEAC program students are tested at the end of their Year 4 school year. They must achieve a percentile rank of 98% or higher on the ACER Test Of Learning Ability (TOLA) or the Standard Progressive Matrices (SPM) non-verbal intelligence test of general intellectual ability. This ranking places the students in the top 2% of their peer age group. When I started this research in 2011, the selection percentile rank was 97%, but in 2013 the percentile rank selection score was changed to 98%. This change and the move of Year 7 students to secondary school, reduced the number of students available for my research.

This study had to be conducted within the normal PEAC framework of the Education Department of Western Australia. This framework imposed significant constraints on the study. The constraints included limited student contact time, no access to students outside of lesson time, a large age range of the students, and the small number of students available. As a result of these limitations care must be taken in making generalizations from the results of this study.

The total student contact time for a PEAC course is 20 hours. The most common format of this time allocation was 10 weekly lessons of 2 hours. The lesson time of two hours had to be strictly adhered to due to transport of students to and from the various venues. No access to students was possible outside the lesson time for such strategies as interviews. Students returned to their respective schools on completion of each lesson.

The PEAC program consists of 3 cycles of 10 weeks. This meant that a particular course such as electronics normally was conducted only three times a year and each class consisted of a maximum of 20 students. Consequently, the study was limited by the number of students available. This limitation was further compounded by the age range of PEAC students. A PEAC class typically consisted of Years 5, 6, and 7 students (ages 10, 11, and 12 respectively). This age range meant a large developmental level range amongst the students. To eliminate this variable, only Year 6 students were chosen for the study because this was the largest number of research subjects available. Another factor in this decision was the fact that in 2015 all Year 7 students entered secondary school in Western Australia. Previously primary students entered secondary school in Year 8. Consequently only 51 students were available for the study.

1.5 Rationale

The Department of Education (DoE) recognises the need for a differentiated curriculum for gifted students. A document called *eTags for Talented and Gifted Students* (Department of Education, 2010) was produced by the Gifted and Talented Branch of the DoE and was issued to all public schools in 2010. This document defines the policies and practices with respect to gifted and talented education adopted for use in Western Australian public schools. It also gives some suggestions for teaching strategies in a gifted child differentiated curriculum. The suggestions

however are very general and are mostly concerned with differentiated curriculum design. The suggestions do not provide specific models suitable for teaching science to gifted students; hence I felt there was a need for introducing and evaluating a simple, effective and specific model for use by PEAC teachers when teaching science-related courses. It is important that the learning strategies in a teaching model adequately challenge the students and assist the development of their thinking skills. It was evident to me before I started this research that there was a large cognitive development range within PEAC classes. In order to determine the degree of this range I administered *Lawson's Classroom Test of Scientific Reasoning* (Lawson, 1995). The results of this test indicated the largest number of students fell in the transitional level between empirical-inductive and hypothetical-deductive thinking. I reasoned that if most PEAC students were in the transitional group it would be important to investigate a model that included hypothetical-deductive thinking strategies. This would help their progress to the hypothetical-deductive level. Lawson's Hypothetical-Deductive Learning Cycle seemed an ideal model to investigate. The Descriptive Learning Cycle, which was similar to common science teaching practice in Western Australia, would be an ideal model for comparison.

In addition to developing student thinking skills, all lessons need to be very efficient as PEAC courses provide only 20 hours of student contact time. The lessons I designed for use in this study, as mentioned previously, are based on learning cycles as proposed by Lawson and provide an efficient, three phase format for lessons. There are other types of learning cycles such as the 5 E's model (Bybee et al., 2006; Hackling, Peers, & Prain, 2007) and the IMSTRA model (Singer et al., 2008) which would be ideal for teaching science in a primary school situation; however I decided that the simplicity of a three phase cycle would be more suitable for the time constraints of a PEAC course.

Maintaining motivation in students in an extension program is a key factor when teaching science. Therefore I decided to also determine whether learning cycles change student's attitude towards science. I chose two affective domain aspects for this research. Firstly, did learning cycles affect a student's enjoyment of science lessons and secondly did learning cycles change a student's attitude towards scientific inquiry?

These aspects were investigated using the Test of Science Related Attitudes (TOSRA) a robust test often used in Australian studies (Fraser, 1981; Blalock et al., 2008).

I chose basic electronics for the course topic of this research because primary students would be unlikely to have done any formal study in electronics at their stage of education making the concepts largely new to them. I decided to design the course with a high practical component. The practical or project aspect of the course was chosen to ensure students had a high degree of individual engagement during lessons and were able to see a practical application to the concepts being studied. I reasoned that a practical aspect would increase student's enjoyment of the science learning experience and their attitude toward science. This reasoning turned out to be correct. Students became so absorbed in their projects I had to commence each session with the formal learning cycle before letting them work on their projects!

1.6 Significance of the Study

Teachers within the PEAC program in Western Australian public schools are largely free to design their own learning experiences for their students as there is no fixed curriculum for the PEAC program except for a ten week introductory course. This introductory course was developed by my colleagues and is called High Fives. High Fives is given to Year 5 students as an introduction to the PEAC program and introduces them to various learning strategies and concepts such as de Bonos' thinking hats (de Bono, 1985) and Gardner's multiple intelligences (Gardner, 1999). The High Fives course aims to develop thinking skills, communication and collaboration amongst the students with the intention that these skills will be used by them in later courses. After the High Fives course students are offered a variety of courses which are in many cases multidisciplinary. Teachers designing PEAC science courses need to maximize the opportunity to develop scientific thinking skills within the students. This is important because many PEAC students will choose to study science in upper secondary school and/or make a science career choice. Kelly (1991) states that gifted students make career choices at an earlier age than most and Watters (2004) maintains that an education in science for gifted children is in the national interest.

Quite often the PEAC science teacher is a secondary science teacher, like myself, who is asked to teach a PEAC course, or a primary teacher with little science background. These teachers will most likely have little or no specific training in gifted education or

science education. Such teachers need to develop two important skills; firstly the ability to prepare lessons that develop thinking skills, and secondly the ability to structure lessons into a sequence that meaningfully relate a number of concepts. Consequently, a major aim of this study is to support PEAC teachers by providing an effective framework for their planning and preparation.

The learning cycle enables the student to develop thinking skills by exploration of scientific phenomenon, developing explanations, and applying the concepts acquired that are related to that phenomenon. Also a spiral sequence of learning cycles enables a series of concepts to be placed into a meaningful sequence. The application of learning cycles however extends beyond PEAC courses. Many PEAC students will enter some form of Gifted and Talented Education (GATE) program when they enter secondary school. Findings from this study should be valuable for developing effective secondary school GATE curricula.

When I faced my first class of Aboriginal students I found the experience quite daunting and stressful due to the fact that I had no training in that kind of teaching. I had no idea of each student's background or ability. Some students had come directly from remote cattle stations of the Kimberley into a school situation. Where was I to start? Fortunately experienced colleagues were able to guide me. I had a similar experience with gifted students. What were the students capable of and where do I start? This I determined largely by trial and error. The teaching model investigated in this study should help alleviate this dilemma for teachers new to gifted education by providing a framework for them to plan and prepare their lessons – a framework that will develop student thinking skills and procedural knowledge, rather than just developing just their declarative knowledge.

1.7 Methodology

The research strategies I have chosen are consistent with a post-positive world view as defined by Creswell (2014) in that it attempts to determine the effectiveness of specific teaching strategies (causes) on conceptual and attitudinal change in students (outcomes). A post-positive approach to research requires systematic observation and numeric measurement to support or refute a hypothesis. My research collected quantitative data using three instruments in a pre-intervention/post-intervention method to determine the more effective of two teaching strategies. Specifically the

research compares the effectiveness of two types of learning cycles in a quasi-experimental design. The design method is quasi-experimental because the comparison groups were not chosen randomly but rather determined by the school timetable. The groups however were equivalent in all aspects.

To determine the conceptual growth and attitudinal changes in the students as a result of the intervention, three instruments were used in a pre-intervention and post-intervention procedure. To determine conceptual growth a two-tiered multiple choice test of ten items and a constrained concept mapping task were used. These instruments were developed by the researcher. Attitudinal change was determined by the Test of Science Related Attitudes (Fraser, 1981; Blalock, Lichtenstein, Owen, Pruski, Marshal, & Toepperwein, 2008).

The research was conducted using my own PEAC classes in an attempt to determine the best teaching strategies for gifted science students. Consequently, I considered that my own experiences as the teacher-researcher would be valuable when interpreting the results. On the completion of a task during the research, whether it be actual teaching or preparation of lessons and research instruments, I recorded my reflections on the process. On two occasions I audio-recorded sample lessons. These reflections and lesson recordings constituted qualitative data and proved to be very useful when interpreting results. Because I used this qualitative data to help interpret my quantitative data the research had a pragmatic worldview aspect (Creswell, 2014).

Being the teacher and the researcher was both advantageous and disadvantageous. It was advantageous in that the variable of using different teachers was controlled, and I had was able to record accurate impressions of the two strategies without interviewing a third party. It was disadvantageous in that I may have placed personal bias on a particular teaching style. This bias however was controlled by carefully scripting each lesson to ensure it truly reflected the desired teaching strategy where ever possible.

1.8 Organisation of the Thesis

This thesis consists of six chapters: Chapter 1 – Introduction; Chapter 2 – Literature Review; Chapter 3 – Methodology; Chapter 4 – Results; Chapter 5 – Teacher Reflections; Chapter 6 – Discussion and Conclusions.

CHAPTER 2 Literature Review

2.1 Introduction

This chapter is structured in two parts. Sections 2.2 to 2.4 review the literature relevant to the theoretical base of the pedagogical strategies used in the study. These sections also include relevant aspects of giftedness, inquiry learning, and learning cycles. These three aspects are critical to the study. If the special learning needs of the gifted student is not met, the student risks not reaching his or her full potential or at worst failing to achieve satisfactory educational goals. Gifted students require learning experiences and teaching strategies that utilize their special characteristics to maximize their conceptual growth. For these reasons, a section of this review will address the nature of giftedness. Researching the effectiveness of learning cycles as a teaching strategy for gifted primary students is the key objective of this study. Learning cycles are a structured form of inquiry learning; therefore it was considered essential to also consider the literature regarding inquiry learning.

How each of these aspects relate to the affective domain of gifted primary students is also considered. The overall themes of Sections 2.2 to 2.4 are illustrated in the concept map in Figure 2.1. It can be seen from Figure 2.1 that there is a large degree of interrelation between the major aspects of the study. Each major aspect however will be dealt with separately and a more detailed concept map for each will be provided.

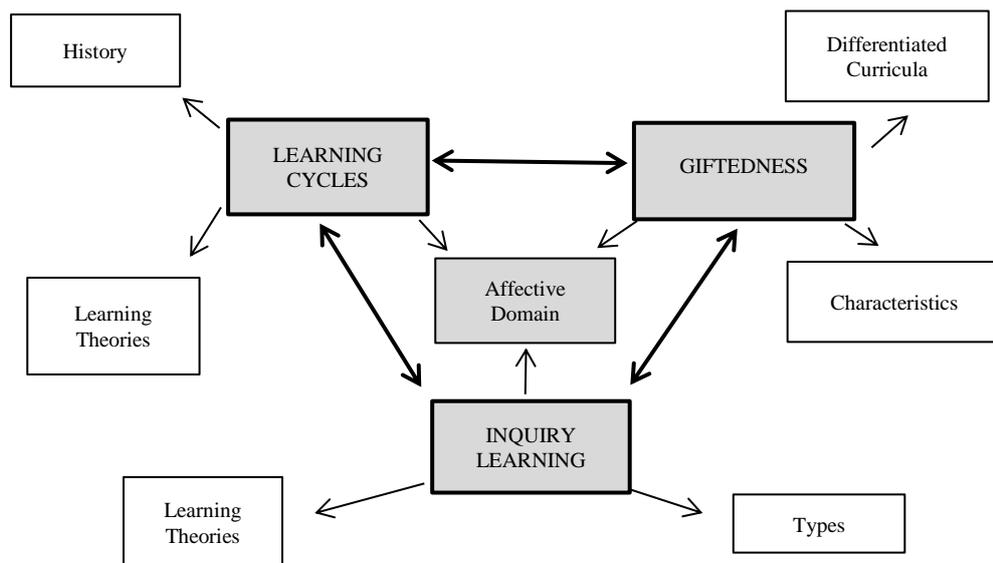


Figure 2.1 Overview of research literature review relevant to the general aims of the study.

The literature relevant to the research instruments used and the reasons behind their choice for this study are discussed in Sections 2.5 to 2.8. An overview of these sections is shown in Figure 2.2.

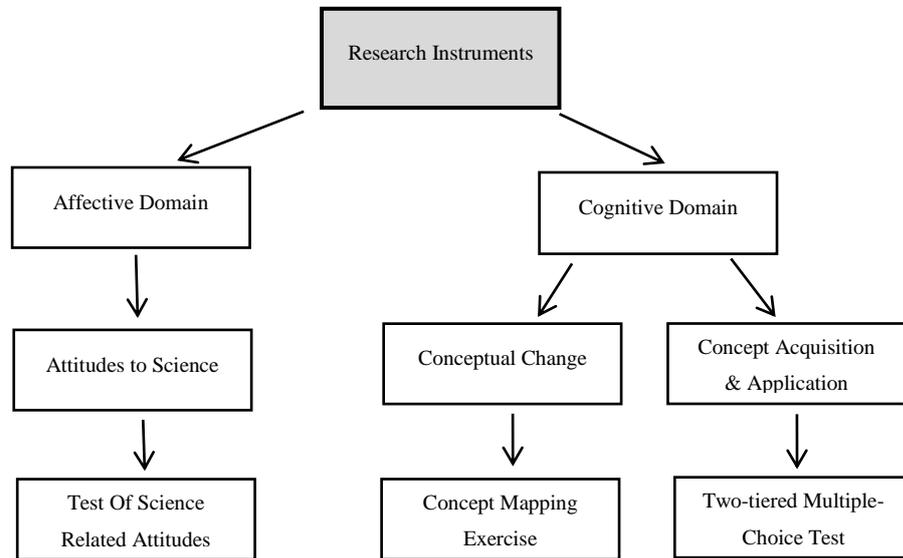


Figure 2.2 Overview of the research instruments to be used in this study.

2.2 Giftedness

Dai and Chen (2013) describe three paradigms of gifted education: *The Gifted Child Paradigm*; *The Talent Development Paradigm*; and *The Differentiated Paradigm*. These paradigms are very useful for understanding the context of this study. In their descriptions of the paradigms, Dai and Chen describe four elements for each. These elements basically ask four questions with respect to each paradigm: *What* is the giftedness?; *Why* is there a need to provide for the gifted?; *Who* are the gifted and how can they be identified; and *How* are the educational needs of the gifted provided? (Dai & Chen, 2013). This study was conducted in the context of *The Gifted Child Paradigm* and the aspects of giftedness pertinent to this study are shown in the concept map in Figure 2.3. Dai and Chen's four elements of *what*, *why*, *who* and *how* are shown in italics on Figure 2.3.

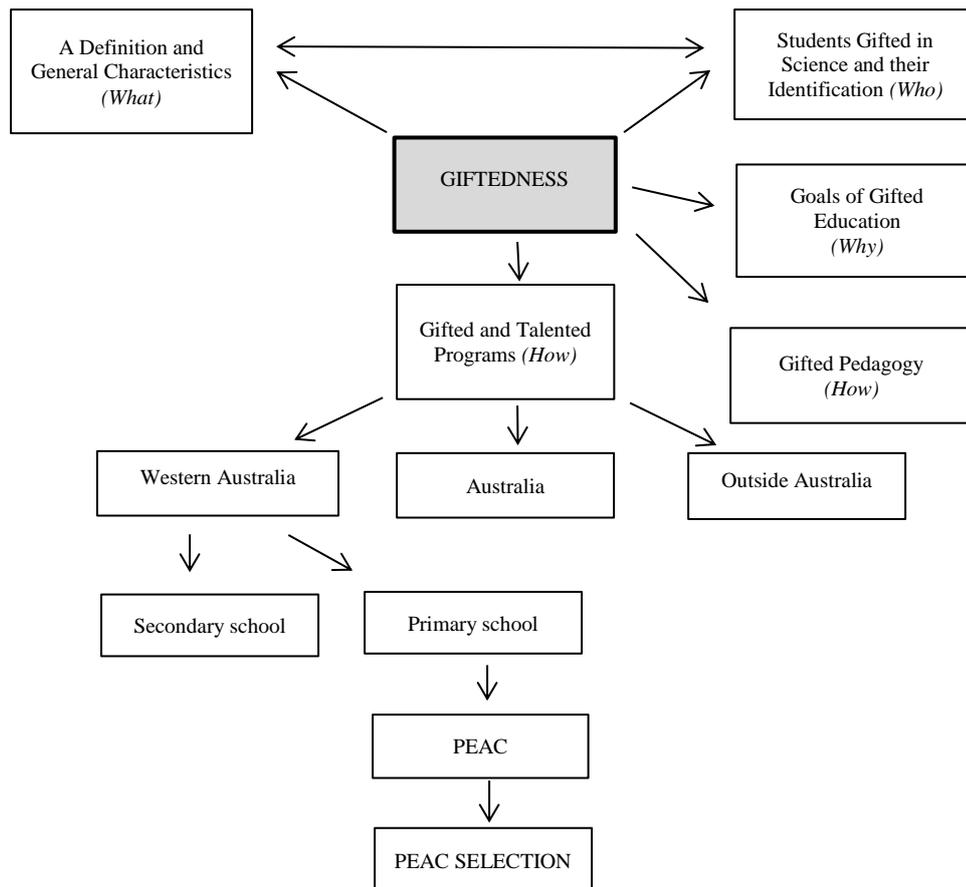


Figure 2.3 Structure of the Giftedness review.

2.2.1 A definition of giftedness

Defining giftedness based on research has been found to be quite difficult. This is due to the diversity of the gifted and talented population and the many definitions put forward (Sternberg & Davidson, 2005). For many decades in the past, giftedness has been considered in terms of I.Q. scores (Terman, 1925). Now giftedness is defined in multidimensional aspects such as rapid learning, attention control, memory efficiency, desire to improve and commitment to task (Heller, Perleth, & Lim, 2005). Renzulli and Reis (1997) proposed a conception of giftedness that suggests gifted behaviours result from an interplay of interpersonal characteristics:

Gifted behaviour consists of behaviours that reflect an interaction among three basic clusters of human traits – above average ability, high levels of task commitment and high levels of creativity. Individuals capable of developing gifted behaviour are those possessing or capable of developing this composite set of traits and applying them to any potentially valuable area of human performance. (Renzulli & Reis, 1997, p. 8)

Similarly, a recent model has been proposed by Subotnik, Olszewski-Kubilius, and Worrell (2012) which views giftedness as developmental with the first stage being potential, leading to achievement as a measure of giftedness and finally fully developed talents leading to eminence. Plucker and Callahan state that this approach considers potential versus outcomes in a different way to other theories. This definition implies a changing construct as individuals develop (Plucker & Callahan, 2014). This is supported by Dai and Chen (2013) in their Talent Development Paradigm in which giftedness can be viewed as a set of developing cognitive or non-cognitive capabilities and potentialities.

This research was conducted within the gifted and talented program of the Department of Education of Western Australia. A document titled *eTags for Talented and Gifted Students* (Department of Education, 2010) was produced by the Gifted and Talented Branch of the Department of Education of Western Australia (DoE) and was issued to all public schools in 2010. The document outlines the policies and practices with respect to gifted and talented education adopted for use in Western Australian public schools. The PEAC program in Western Australia operates within very strict time constraints and these must be considered in any research. A primary aim of the research was to investigate the suitability of a three phase learning cycle as an effective and efficient teaching model for the specific use in the PEAC program. It is therefore essential that the study was done strictly within the constraints of the program.

Giftedness is defined in eTags as: “Giftedness designates the possession and use of outstanding natural abilities, called aptitudes, in at least one ability domain, to a degree that places a person at least among the top 10% of age peers.” (p. 7)

Talent is defined as: “Talent designates the outstanding mastery of systematically developed abilities called competencies (knowledge and skills), in at least one field of human activity to a degree that places a person among the top 10% of age peers who are or have been active in that field.” (p. 7)

These definitions are based on François Gagné’s Differentiated Model of Giftedness and Talent (Gagné, 2008), which have similarities to Subotnik et al.’s (2012) model of potential leading to achievement, leading to eminence and Renzulli and Reis’s (1997) conception of gifted behaviours resulting from an interplay of interpersonal characteristics. Gagné’s Differentiated Model of Giftedness and Talent (DMGT)

commences with natural abilities that progress into outstanding knowledge and skills in a specific occupational field. Gagné defines six domains of natural abilities: intellectual, creative, social, perceptual, muscular, and motor control. The competencies or field of talents, he defines as academic, technical, science and technology, arts, social services, administration, business operations, games and sports. In his model, Gagné states that the development of competencies can be influenced by two catalysts – environmental and intrapersonal factors (Gagné, 2008).

In a later paper Gagné defines the talent development process as: “...the systematic pursuit by talentees, over a significant and continuous period of time, of a structured program of activities leading to a specific excellence goal” (Gagné, 2013). In this paper Gagné maintains that gifts are not innate but develop during a child’s life and may be continuing into adulthood. However he offers three biological underpinnings for the DMGT: genetic foundations; physiological phenotypes; and anatomical phenotypes. These underpinnings that Gagné refers are supported by advancements in the neurosciences and neuroimaging.

The PEAC basic electronics course was designed to address the different domains of student abilities. An environment was created that addressed cognitive, affective and psychomotor domains. The use of a learning cycle embedded within a project based course complemented Gagné’s DMGT very well. The course covers many of the domains of natural abilities defined by Gagné and develops competencies in science and technology. The research participants in this study are in the top 3% of the Year 6 cohort and therefore fall within the 10% as defined by Gagné’.

2.2.2 Characteristics of giftedness

As mentioned in Section 2.2.1, Gagné does not believe that gifts and talents are innate. He states that gifted children “progresses rapidly and seemingly effortlessly through their talent development programs at a much more rapid pace than their learning peers” (Gagné, 2013, p. 13).

Silverman (2002) lists a set of characteristics of giftedness as DoE’s eTags (2010). These two lists are compared in Tables 2.1 and 2.2. Table 2.1 lists characteristics common to both, and Table 2.2 lists characteristics not common to both. Silverman’s (2002) list of characteristics was designed as a giftedness identifier and she claims that:

84% of children whose parents say that they fit 75% of the characteristics score at least 120 I.Q. and over 95% show giftedness in at least one area but are asynchronous in their development, and their weaknesses depress their I.Q. scores. (p. 1)

The early identification of a gifted child is very important in order for the teacher or school to provide support for the child and so avoid any emotional and social difficulties that may arise. (eTags, p. 9)

Table 2.1 General characteristics of giftedness common to eTags (2010) and Silverman (2002).

Indicators of Giftedness (eTags, 2010, p .9)	Characteristics of Giftedness (Silverman, 2002)
The ability to engage with numbers and written language at an early age.	Has facility with numbers. Early or avid reader.
The ability to ask introspective and searching questions.	Reasons well.
Highly developed vocabulary.	Has extensive vocabulary.
Easily fixated and absorbed into an area of study.	Has a long attention span if interested. Perseverant in their interests.
Rapidly learn and become frustrated by a slow learning environment.	Learns rapidly.
Greater retention ability with less need for reinforcement.	Has an excellent memory.
Greater intensity of emotional engagement and responses.	Intense. Sensitive.
Strong sense of justice.	Concerned with justice, fairness. Morally sensitive.
Empathetic nature.	Shows compassion.
Mature sense of humour.	Has a great sense of humour.
Prefer older company to age peers.	Prefers older companions or adults.

Table 2.2 General characteristics of giftedness not common to eTags (2010) and Silverman (1990).

Indicators of Giftedness (eTags, 2010, p.9)	Characteristics of Giftedness (Silverman, 2002)
Mask ability in order to gain peer acceptance.	Perfectionist.
Preference for independent study.	Has strong curiosity.
Thrive on complexity.	Is a keen observer.
Readily grasp abstract concepts.	Judgement mature at times.
Tendency to form fewer, deeper relationships.	Is highly creative.
	Tends to question authority.
	Good at jigsaw puzzles.
	Has high degree of energy.

Gifted students are usually quick to understand abstract concepts and are able to organise these into patterns. They tend to be lateral thinkers and solve problems in unorthodox ways. The gifted student needs to be continually challenged. Repetition in their learning activities quickly leads to boredom (Kelble, Howard, & Tapp, 1994). As they assimilate knowledge quickly, they need opportunities to use that knowledge productively (Watters, 2004).

Disengagement of gifted students in mainstream education is often attributed to lack of motivation and therefore poor achievement and behaviour (eTags, 2010), consequently this research will investigate the effect of a three phase learning cycle on a student's enjoyment of science lessons and their attitude to scientific inquiry. The DMGT lists motivation as an important intrapersonal catalyst in the development of talent competencies. (Gagné, 2013). Boredom is a key factor in the disengagement of gifted students. Little (2012) states that: "Boredom is not merely a lack of interest or enjoyment in a topic or activity rather it is an emotion that reflects an individual's lack of valuing the topic or activity which includes an element of desire to avoid the activity". (p. 699). Little refers to research by Acee et al. (2010) on students perceptions of boredom relating to under-challenging and over-challenging situations. Results indicate two forms of boredom: task-focussed boredom where students described the tasks as boring, tedious or meaningless; and self-focussed boredom which emphasised emotions, frustration and dissatisfaction. Over-challenging tasks produced both types of boredom and under-challenging tasks tended to led to general boredom related to the task (Little, 2012)

2.2.3 Students gifted in science

This research is conducted within the discipline of science and therefore it is appropriate to examine the characteristics of gifted students with respect to science. Watters (2004, p. 4) lists characteristics of students gifted in science as shown in italics below. These characteristics need to be considered when designing courses for gifted students. For example, their questioning nature is a desirable characteristic in the exploration phase of a learning cycle as used in this research. These characteristics are compared with the general characteristics from Table 2.1 and 2.2, and these general characteristics are shown in brackets.

Seek meaning and explanation of phenomena. Their questioning nature leads to a passion for exploration, reading scientific books and watching documentaries (consistent with having a strong curiosity, being an avid reader, and the ability to ask searching questions).

An awareness of the complexities of the world. They are sensitive to their environment and have a desire to organize and understand it (consistent with thriving on complexity, having a wide range of interests).

Often categorise natural phenomena in an abstract way. They are able to sort items using more abstract criteria than shape or colour (consistent with being able to readily grasp abstract concepts, being a keen observer and highly creative).

Often exhibit an intense and persistent interest in a particular area of science and persistent in exploring these areas for understanding. They have a passion for topics such as dinosaurs and astronomy go far beyond their peers (consistent with being absorbed into an area of study and being an avid reader).

Collectors of materials and objects. They are passionate and persistent about understanding the objects they collect (consistent with being perseverant in their interest and a keen observer).

Pull objects apart and reassemble them. They have a desire to find out for themselves how things work. They demonstrate a strong investigative nature (consistent with independent study and a strong curiosity).

A passionate interest in the origin of things. The child has a need to explain where he or she came from and to understand the past and the future (consistent with having a strong curiosity and an ability to ask introspective questions).

Build and use artistic representations, solver puzzle, and have a well-developed sense of space. They have strong visualization skills (consistent with solving jigsaw puzzles, grasping abstract concepts, and a vivid imagination).

Gravitate to experts in their field of interest. They seek like minds to satisfy their thirst for knowledge and understanding (consistent with preferring older companions or adults).

Anxious and single minded in explaining ideas. They assume others share their interests (consistent with an empathetic nature and easily fixated and absorbed into an area of study).

Taber (2010) has a pragmatic view of giftedness in science. He states that it may be inappropriate to consider some students as permanently gifted in science, and regardless of their ability all students need to be engaged in activities that are intellectually challenging. His working definition of gifted science students are those that are "...able to achieve exceptionally high levels of attainment in all or some aspects of normal curriculum demands in school science." (p. 5)

It is evident from the general and science related characteristics of gifted children that special consideration is needed when creating an educational environment to optimize their learning, but is there *a gifted child pedagogy*? This question is discussed in Section 2.2.5 Gifted child pedagogy.

2.2.4 Identification of the gifted child

Terman (1925) states that giftedness is a general human quality that can be measured using intelligence tests. However even though a measure of general intelligence is still considered essential for identifying the gifted, current practice is more flexible and includes a variety of sources of information such as achievement tests and teacher observations (Dai & Chen, 2013; eTags, 2010). As this research is conducted within the gifted and talented policies of the Department of Education (DoE), it is appropriate

to review their recommended strategies. The general principles of identification suggested by the DoE are:

The identification process should:

- be inclusive to ensure gifted and talented students are not disadvantaged on the basis of racial, cultural, or socio-economic background, disabilities, geographic location, or gender
- be a flexible and continuous process to allow for the recognition of gifts and talents which may emerge or be recognised at any stage of a student's education.
- utilise information from a variety of sources including classroom teacher observation and assessment.
- help the teacher identify a student's intellectual strengths, talents, and social and emotional needs. (eTags, 2010, p.8)

To identify a student using this general framework, a range of techniques is needed by a school or teacher. Such a range should include classroom and school-based information, standardised assessments, parent/guardian information, and information from peers and self-reflections (eTags, 2010). If these procedures are comprehensively used, identification of gifted and talented students would be possible for all three of Dai and Chen's (2013) paradigms of gifted education; however, the PEAC students (the subjects in this research) fall within the Gifted Child Paradigm and their identification is almost entirely based on standardised tests of general intelligence. Only a few places are reserved for students recommended by their teachers. All primary students in Western Australia are given the opportunity to undertake testing for selection into the PEAC extension program. The testing involves two tests and they are the:

- TOLA - The Test of Learning Ability. This test has been designed to measure broad language and reasoning ability, which correlates with academic success.
- SPM – The Standard Progressive Matrices. This instrument is a nonverbal test of general intelligence and is designed to measure students' ability to see relationships and solve problems.

When this research commenced, the top 3% of students, based on their test scores, were selected for the PEAC program. However, during the research government funding cuts to the program reduced the number of students to the top 2%.

2.2.5 Goal of gifted education

The goal of a gifted education program is well described by Fraser-Seeto (2013):

A country's continued prosperity and growth relies on the creative potential of its people. To remain a competitive force and contributor in the innovations and discoveries of the future, the educational and developmental needs of all students must remain a priority for educators, government and society collectively.

(p. 29)

This is supported by Watters (2004) who states that 'education of the gifted student in science is of paramount importance from a national interest perspective' (p. 2). In a later paper he states: "Converting an economy based on agriculture and rich natural resources into one sustained by the export of knowledge is a national priority. A key strategy to achieve this is the education of the gifted"(Watters & Diezmann, 2008, p.1). Export of knowledge is evident in many universities in Australia. For example in 2015, 32% of students enrolled in a higher degree by research were international students (<https://www.australia.gov.au>, 2015). To cater for these students, quality teaching and research staff are required in Australian universities and it can be assumed that many of these would come from gifted students in our primary and secondary schools.

There has been a tendency in the past to assume that gifted students will succeed academically regardless of any special intervention (Rowley, 2008). In many cases this may be so, but does that child reach his or her full potential? Watters (2004) states that the gifted student is rarely challenged in the mainstream classroom situation because the pacing and depth of content required to challenge the student does not often happen. The practical demands of attending to the needs of students with more normal intellect results in the gifted child being neglected. Watters suggests that unless pedagogical practices and curriculum cater for the gifted, students risk failing. This point is supported by Plucker and Callahan (2014) who state that: "...the absence of interventions for advanced students provides little challenge for students who have

already mastered the content and skill or can learn the material at an above average pace” (p. 393).

Watters’ concern stated above is supported in a study by Brighton, Hertberg, Moon, Tomlinson, and Callahan (2005) who found that when teachers do give extra attention to students in the classroom it is to those who have difficulties in learning. Too often they consider that the gifted students can cope by themselves.

2.2.6 Gifted child pedagogy

The question asked in Section 2.2.3, *Is there a gifted child pedagogy?* is the title of an article written by Kaplan (2003) in which she states “there is no pedagogy solely developed for any one type of learner. Instead there is a repertoire of instructional practices from which teachers must select for the pedagogical strategies most appropriate for the diversity of the learner.” (p. 165) She goes on to say that the repertoire could range from direct or teacher-centred teaching to student-centred inquiry learning. Gifted students need to be exposed to a wide range of teaching–learning experiences to enable them to establish their own unique learning style. However, the teacher needs to determine the most appropriate strategy for each particular occasion. To make the decision of what strategy is appropriate, an effective teacher needs to consider the “triadic relationship between content or subject matter, pedagogy or teaching strategy, and the student population” (Kaplan, 2003, p. 165). This concept of a variety of strategies is supported by Rowley (2008), who states: “It could be argued that a variety of instructional strategies should be used not only with the gifted learner but also with all learners as each student has individual needs, learning styles and preferences” (p. 39).

Even though there may not be a specific pedagogy solely for gifted students, it would appear that the emphasis would tend towards student-centred inquiry learning rather than teacher-centred didactic teaching. This point is evident from the list of science-related characteristics described by Watters (2004) that students gifted in science are passionate about exploration of the natural world. The point is supported by Kelbe, Howard and Tapp (1994) who state that gifted students need the opportunities offered by activity-based exploratory science because this type of science provides cognitive mastery, social interaction and is highly motivating. Watters (2004) maintains that exploration requires both observation and thinking; however schools may develop

observation skills through practical work but thinking about the observations rarely happens with many school students.

Bloom's Revised Taxonomy lists six levels of thinking which provides a good foundation for considering curriculum planning whether for gifted or core students. These levels are creating, evaluating, analysing, applying, understanding and remembering (eTags, 2010). The emphasis of each level of thinking however needs to be changed for gifted students. A simple model to illustrate this is shown in Figure 2.4. This model indicates that core students need more time on lower levels of thinking such as remembering than gifted students do. Gifted students who have an excellent memory need less time. The reverse is true for higher levels of thinking such as creating.

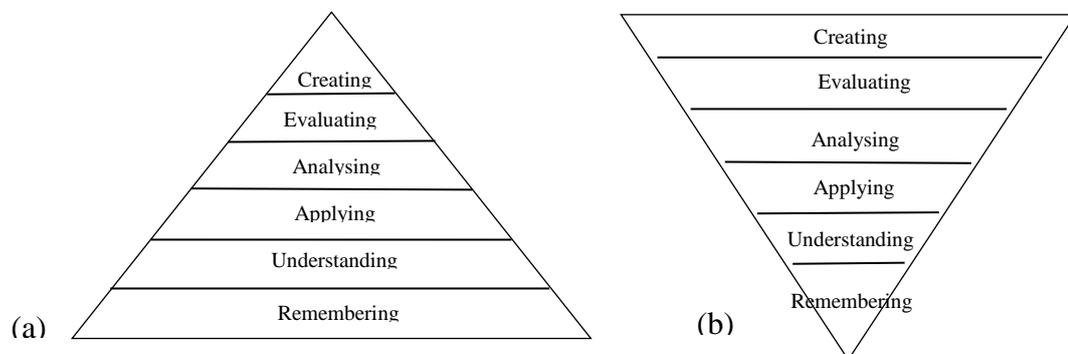


Figure 2.4 Emphasis of Bloom's Revised Taxonomy of Thinking Levels:

for (a) core students and (b) gifted students, in curriculum design (eTags, 2010, p. 23).

In his paper, *In pursuit of excellence in science*, Watters (2004) describes three issues that should be considered in an effective science program for gifted students. Firstly, the processes of science should be emphasised before facts and information. Secondly, established principles of differentiation, that is, environment, process, products, and content, in a science context should be considered. These principles are key elements of the Maker model (Maker, 1982) and are recommended by the DoE (eTags, 2010). The third consideration suggested by Watters should be the use of open inquiry as a learning strategy. Gifted students should experience the challenges of complex problems in a scientific context (Watters, 2004).

With respect to gifted child pedagogy, Taber (2010) states:

The task of the teacher of gifted learners, however we may define them, is (as with all other students) to scaffold them to achieve what is currently just

beyond their capability but possible with structured support. A good working hypothesis for a teacher will be that gifted learners can be challenged by scaffolding which assumes these particular learners will need to be provided with less explicitly detailed structure than their peer group. (p. 4)

Taber recommends that the environment for teaching gifted students gifted in science should focus on conceptual content, emphasise inquiry, demand higher levels of thinking, support intra and inter-personal learning, and offer pace, variety and choice.

A common theme that seems to thread through much of the literature on gifted and talented education is the need for adequately trained teachers. In the late 1980's and early 1990's, Australian universities offered high quality courses in gifted education. However, by the year 2000 these courses had basically disappeared. McCann (2005) attributes this to the "lack of government support for mandated training of teachers in gifted education as one of Australia's greatest shortcomings" (McCann, 2005, p. 91). A study by Taylor and Milton (2006) found that in most states, universities provided little or no teacher training in gifted education and Fraser-Seeto (2013) stated that up to the year 2013 there seems to be little research to say that the situation, described by Taylor and Milton, had changed. However a differentiated curriculum for the gifted student does not necessarily require direct government funding. This research will demonstrate that the individual teacher is capable of meeting the needs of gifted students by the use of learning cycles. The use of learning cycles does not require large changes in a teacher's preparation. However a better understanding of the characteristics of a gifted child is essential so that this can be achieved with the use of some very good professional development packages produced for in-service training. For example, *eTags* was produced by the DoE (eTags, 2010) and issued to all government schools in WA in 2010, and the *Gifted and Talent Education: Professional Development Package for Teachers* (GERRIC, 2017) that was issued to all schools in Australia in 2005. With respect to the latter, Fraser-Seeto (2013) stated that "the level of awareness and the use of this package currently remains an unknown quantity" (p. 32). However, eTags and the GERRIC modules were used in the development of this research and although they were found to be very useful, a busy teacher without formal training in gifted education may find it a daunting task to use them to develop a classroom teaching strategy. A major purpose of this research is to investigate whether or not a three phase learning cycle can achieve the major recommendations stated in

eTags and GERRIC for a differentiated curriculum for gifted education. The learning cycle is based on sound learning theories and can be adapted to suit most situations. A more in-depth discussion of the teaching skills required by teachers of the gifted and how they relate to the learning cycle are discussed in Section 2.3 Learning Cycles.

2.2.7 Gifted and talented programs in Australia.

The Australian National Curriculum recognises that gifted and talented students are entitled to rigorous, relevant and engaging learning experiences in their education. These should be aligned with their individual learning needs, strengths, and interests. The Australian Curriculum Assessment and Reporting Authority (ACARA) acknowledge that gifted and talented students vary in abilities and aptitudes; vary in level of giftedness; vary in achievement; are not always visible and easy to identify; exhibit a large range of personal characteristics; and come from diverse backgrounds (<https://australiancurriculum.edu.au>).

An overview of Australian initiatives in providing for academically gifted students are described in the journal *Gifted Education International*, Vol. 19, 2005. An article titled *Our greatest natural resource: Gifted education in Australia* by Maria McCann (2005) provides an overview of gifted education in Australia from the early 1980's to 2005. Details of this for example would infer that an individual's performance and development can be assisted specific programs for each Australian state are described on each states respective websites (<https://education.nsw.gov.au>; <http://education.qld.gov.au>; <https://www.education.wa.edu.au>; <http://www.education.vic.gov.au>; <https://www.decd.sa.gov.au>). A few specific examples are mentioned in the summary of provisions for gifted and talented students listed by McCann in the next paragraph..

McCann (2005) outlined five provisions for gifted students in Australia. These were:

1. *Special programs within regular schools which utilise a differentiated curriculum.* These programs include accelerated enrichment and extension of normal curriculum and can be achieved by partial streaming within schools. For example, many schools stream gifted and talented students into special extension classes for mathematics which fit into the normal timetable. This is evident in New South Wales (NSW), Queensland (QLD), Western Australia

(WA) and Victoria (VIC). In South Australia (SA) support for individual students can be given in the form of Individual Education Plans.

2. *Selective entry lighthouse schools.* Students with a talent in areas such as music, performing arts, languages, mathematics, science, aeronautics, and various sports are selected for entry to these schools. Most of these schools are secondary schools, however music programs often commence in upper primary years. NSW primary schools offer Opportunity Classes for high achieving students in Years 5 and 6. In these classes students are offered new challenges within the existing curriculum and the opportunity to learn with their gifted and talented peers. The PEAC program in WA is a primary extension program that can be placed into this category.
3. *Schools with selective entry into secondary school for academically gifted students.* Selection into these schools is based on general academic skill and I.Q. scores. Most states in Australia have these schools. The IGNITE program in SA and the SEAL program in VIC are examples of this provision. The IGNITE program is a fast paced program whereby students can complete Years 8, 9, and 10 in two years. The program contains review and repetition than the normal curriculum. The SEAL (Select Entry Accelerated Learning) program in VIC allows students to complete Years 7 to 10 in three years. In WA Perth Modern School is a fully selective secondary school and provides a differentiated curriculum on the basis of acceleration. Acceleration is achieved by curriculum compaction, advanced placement by subject and advanced placement by year. Curriculum compaction rationalises the syllabus to provide extra time for enrichment and extension. Advanced placement by subject enables a student to take one or more subjects a year or two earlier. Advanced placement by year allows students to progress through schooling at least one year ahead of age peers.
4. *Providing gifted students with access to tertiary and other advanced studies by universities and schools linking together.* In the states of NSW, QLD, VIC, and WA high achieving students in Years 11 and 12 are given the opportunity to study extension units at tertiary institutions. Students may be given credit for these units on entry to the tertiary institution. The Gifted Education Research, Resource and Information Centre (GERRIC) at the University of New South Wales is an initiative in this category. In 2005, GERRIC sent a

professional development package for teachers in the form of a CD to all government schools. The package is a six module computer-based course on the education of gifted and talented students. Aspects of this package were used in background research for this study.

5. *Special schools for gifted students.* These schools are rare in Australia as entry into state schools based on I.Q. only was not government policy. However Western Australia has such a school – Perth Modern School. A variation of this option can be found in South Australia where a special school, the Australian Science and Mathematics School (ASMS) established on the campus of Flinders University, was designed for Years 10 to 12 and focussed on ‘new science’ such as biotechnology, information technology and nanotechnology.

(McCann, 2005, pp. 95-98)

Gifted and talented programs in Western Australia

In an article titled *Three Paradigms of Gifted Education: In Search of Conceptual Clarity in Research and Practice* Dai and Chen (2013) compared three paradigms of gifted education “...so that researchers and practitioners can be more explicit about their assumptions, goals, and educational strategies in their research and practice” (p. 151). These paradigms are discussed in Section 2.2.

Dai and Chen’s three paradigms of gifted education are all evident in the Western Australian public school system. *The Gifted Child Paradigm* is evident in the PEAC program (the subject of this research) and Perth Modern School where students are selected for a gifted secondary education program on the basis of rigorous intellectual ability testing. Entrance into the PEAC is for Years 5 and 6 and entrance into Perth Modern School was for a student’s five years (now six years) of secondary education. *The Talent Development Paradigm* is evident in the other specialist schools for music, languages, visual arts, performing arts, and various sports such as cricket and hockey. Selection is usually specific and based on auditions, portfolios or established skills as in sport. *The Differentiated Paradigm* advocates a curriculum based on the individual needs of gifted students. This paradigm paradoxically is more evident in meeting the needs of students at educational risk rather than gifted students. However some schools have extension work for high achieving students within their normal classrooms and by the provision of extra curricula programs.

As this research is conducted within the gifted and talented policy of the DoE in Western Australia, it is appropriate to look in some detail at their policy for differentiated curricula for gifted students. eTags (2010), a DoE publication produced by the Gifted and Talented Branch, states that:

Gifted and talented students should be provided with a curriculum that is differentiated in terms of learning processes, teaching methods and teacher expectations. They need to be challenged with a curriculum that is conceptually demanding, complex and wide ranging in scope. Modifications to the content, processes, product and learning environment will ensure the needs of all students are met whilst specifically addressing the learning requirements of gifted and talented students. (p. 11)

The DoE has three general approaches to providing a differentiated curriculum for gifted and talented students. These approaches include *extension*, *enrichment*, and *acceleration*; examples of activities provided in each approach are summarized in Table 2.3. The strategies recommended in eTags covers each of the four elements (the 'what', 'why', 'who', and 'how') used by Dai and Chen to define each of their three paradigms. Table 2.3 lists a range of 'how' activities that may be used for each of the three DoE approaches. *Enrichment* activities are designed to increase the range of experience of students and enable gifted students to work at a higher level than non-gifted students. *Extension* activities are intended to expand knowledge and skills and enable students to express individuality. PEAC program activities are largely enrichment and extension. *Acceleration* activities such as year skipping, can be tailored to the individual and cluster grouping can be used for small groups of gifted students in a normal classroom setting. Acceleration activities are ideal for use in remote District High Schools (combined primary and secondary schools) where there are less options available for gifted students. This table is not a list of 'must do' activities but rather a list of suggestions, many of which can be used also for extending non-gifted students.

Table 2.3 Modes of provision of differentiated curriculum in Western Australian State Schools
(eTags, 2010, p. 20).

Enrichment	Extension	Acceleration
<ul style="list-style-type: none"> • Independence training • Critical and thinking skills • Higher levels of questioning • Problem solving • Guest speakers • Online learning 	<ul style="list-style-type: none"> • Learning centres • Challenge corners • Parallel programming • Tiered learning activities • Contracts • Mentors • Complex ICT activities • Camps 	<ul style="list-style-type: none"> • Cross setting • Cross grading • Cluster grouping • Compacting curriculum • Subject specific acceleration • Year skipping

The principles behind differentiated curriculum design suggested by the DoE in eTags (2010) are based on four elements that Maker (1982) believes need to be addressed. These elements are content, process, product, and learning environment.

The key aspects of these elements are the basis of the Maker Model (Gross, Sleaf, & Pretorius, 1999) and the Kaplan Model (Gross, 2000). These two instructional models are recommended in Australia by both the DoE in Western Australia and New South Wales, for use with gifted students.

As mentioned previously, gifted primary students in Western Australia are able to participate in an extension program called Primary Extension and Challenge (PEAC). Once selected for PEAC, students stay in the program until the completion of their primary education. PEAC courses are supplementary extension programs, and in the main address the three approaches of enrichment, extension and acceleration in providing a differentiated curriculum as outlined in Table 2.3. The research reported in this thesis is designed to investigate whether or not learning cycles can be an effective instructional model for implementing a differentiated curriculum within the PEAC extension program in Western Australia. The learning cycle model is discussed in the next Section 2.3.

Gifted and talented programs in countries other than Australia

This section is included in order to determine where Australia, and Western Australia in particular, ranks compared to international practices with respect to gifted education. It can be seen from this discussion that there is a very large range in gifted education policies. McCann (2005) states that in the 1980's and the 1990's Australia was arguably "second to no other country" (p. 90) with respect to gifted education diversity and quality. Many of these initiatives have disappeared due to various states changing their funding policies. Similar patterns can be seen in other countries such as in the USA.

Continental Europe

Mönks, Pflüger, and Nijmegen (2005) surveyed 21 European countries with regard to the range of GATE programs offered. The results of the survey indicate there is a wide range of approaches to the recognition of gifted students and differentiated curricula. There is a continuum, with Austria at one extreme with strong policies and practices in most aspects of GATE, and Italy at the other, with an official decision to ignore GATE. Some countries are in the process of developing policies and practices, such as Sweden, which are using the Austrian model as their guide.

England (UK)

In 1999 the British Government, for the first time, introduced a gifted and talented education policy. Under this policy teachers were expected to identify and provide appropriate education for the top 5-10% of students in their schools. This policy led to the establishment of the Excellence in Cities (EiC) initiative. The EiC was designed to support gifted and talented students from low income families and improving their aspirations and chances of entering university. By 2003 the EiC was extended to include all local authorities in England and a National Academy for Gifted and Talent Youth (NAGTY) was established at Warwick University. However, by 2011 funding for gifted and talented programs was cut (Casey & Koshy, 2013).

The situation in England since 2011 seems to be uncertain and can be summarized by Casey and Koshy (2013) as follows:

Having begun the journey along the gifted and talented education policy highway, practitioners in England find themselves at a crossroads whereby central government policy has been abandoned in relation to direct funding and

support, yet schools are still expected to provide School Inspectors with evidence of appropriate provision for their higher ability students. (p. 24)

The United States of America (USA)

In the mid-20th century gifted education in the USA was given a financial stimulus as a result of the launch of the Russian *Sputnik* satellite (1957) and federal funding for research on giftedness was available during the Cold War years (Plucker & Callahan, 2014; Tannenbaum, 1979). GATE however was neglected until the late 1970's. In this period of neglect, attention was mainly given to disadvantaged and underachieving learners (Tannenbaum, 1979). In 2001 the *No Child Left Behind* (NCLB) legislation was introduced and became a national focus in education. The NCLB policy was intended to bring all students up to a benchmark proficiency. However, the needs of the gifted student, who may have appeared proficient by normal standards, tended to be ignored. The gifted students had become invisible (Colangelo, Assouline, & Gross, 2004).

During the 20th century, identification of gifted students was largely done by IQ testing. Towards the end of the 20th and the beginning of the 21st century there was a movement away from IQ testing to more multifaceted and comprehensive testing. At the same time, the definition of giftedness changed from achievement and intelligence to one that included contextual, development and talent aspects (McClain & Pfeiffer, 2012). McClain and Pfeifer state that all 50 states no longer use a single IQ score for identifying gifted students, but they also state that only approximately half the states have an official policy to identify minority group gifted students.

Many models for provision of a differentiated curriculum for the gifted have been developed or are in use in the USA. These include *The Stanley Model*; *The Renzulli Schoolwide Enrichment Model*; *Gardner's Multiple Intelligences*; *The Maker Matrix*; and *The Van Tassel-Baska Integrated Curriculum Model* (Van Tassel-Baska & Brown, 2007). Of these, Plucker (2014) states that Renzulli's model which focussed on the interaction between ability, creativity, and task commitment is the best known. Despite the research on giftedness, its nature and definition, and developed curriculum models, Van Tassel-Baska (2015) states that little has changed in practice in the USA over the last 20 years. For example, most states do not have a diagnostic procedure for identifying the gifted; few states have evidence based differentiated curricula; and despite evidence to support acceleration strategies, few states practice them. With

respect to training for teachers of the gifted, Gallagher (2000) states that training was often haphazard and superficial, consisting mainly of summer workshops and three day conferences. Most teachers are expected to undergo their own professional development in strategies for the gifted. Van Tassel-Baska confirms that little has changed since then. University-based teacher training programs only occur in 17 states and in-service professional development activities in gifted education are very limited (Van Tassel-Baska, 2015).

Concluding Comments

A study of the GATE policies and practices in Australia and other countries such as the United States, Austria, and the United Kingdom indicate that sound government policy and funding are critical criteria for a unified approach to an effective GATE program. Countries such as the USA provided funding when stimulated by the Sputnik satellite and the cold war, but this enthusiasm for GATE seems to have faded in favour of the educationally disadvantaged. In the *No Child Left Behind* program the gifted child became invisible. Similar patterns are evident in Australia with the State of Victoria changing their emphasis from GATE to elite sport. Subtle changes occurred in Western Australia while this research was being conducted. For example, changing the cutoff for entrance into the PEAC program from the upper 3% to 2%, reduced the number of students significantly. The cutoff of 2% seems to contradict the DoE's definition of gifted as being students in the top 10% (eTags, 2004).

2.3 Learning Cycles.

The structure of this section is shown in Figure 2.5.

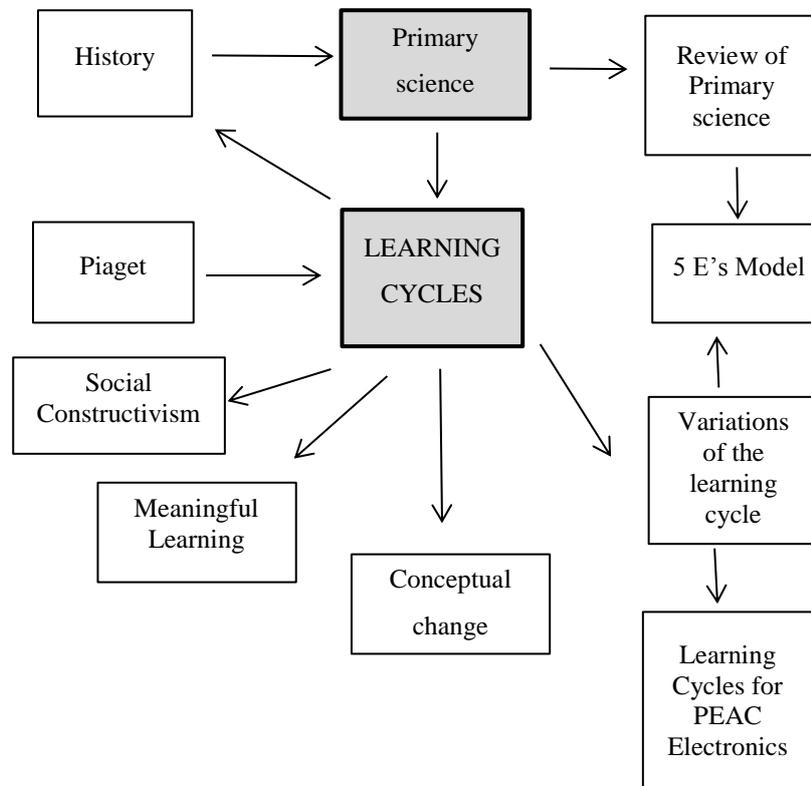


Figure 2.5 Structure of Learning Cycles review.

2.3.1 Primary Science

Kelble et al. (1994) suggest that primary schooling provides the foundation for literacy in science. This foundation is more critical for the gifted primary student. Too often science is ‘dumbed down’ to cater for the non-gifted student, which does not enable the gifted student to be intellectually challenged (Watters, 2004). Kelble et al. (1994) and Watters (2004) make the point that gifted students often make career choices in primary or elementary years and therefore it is important to sustain the young gifted student’s interest in science through to secondary school and beyond.

In 2001, The Australian Academy of Science produced a report on the status of science in Australian schools (Goodrum, Hackling, & Rennie, 2001). One of the findings in this report was the lack of exposure to science for students in Years 1 to 7. One reason for this is that primary teachers are not well trained in science teaching and often lack confidence in teaching science (van Aalderen-Smeets, Walma van der Molen, & Asma, 2012). The concern for the lack of exposure to science led to the development of *Primary Connections* (Hackling, Peers, & Prain, 2007). In their introduction to

Primary Connections, Hackling et al. state: “Australia needs a scientifically literate community if it is to develop a knowledge-based economy, address environmental concerns about water conservation and global warming, and health issues such as obesity and diabetes” (p. 2).

The Australian Academy of Science developed a *Primary Connections* teaching and learning model that included curricula and teacher development materials in an effort to improve the status of science in primary schools. As illustrated in Table 2.4, *Primary Connections* is based on the 5Es model: Engage, Explore, Explain, Elaborate and Evaluate. The 5 E’s model is discussed in more detail in Section 2.3.2. (History of the learning cycle).

Table 2.4 The Primary Connections 5Es teaching and learning model. (Hackling et al., 2007, p. 141)

PHASE	FOCUS
Engage	Engage students and elicit prior knowledge
Explore	Provide hands-on experience of the phenomenon
Explain	Develop science explanations for experiences and representations of developing understandings
Elaborate	Extend understandings to a new context or make connections to additional concepts through student planned investigations
Evaluate	Re-represent understandings, reflect on learning journeys and collect evidence about achievement of outcomes

This research complements the *Primary Connections* model in that it addresses the need for an effective and efficient teaching/learning model such as the three phase learning cycle would help PEAC teachers, largely untrained in GATE and science, develop a greater confidence and positive attitude towards science teaching. The three phase learning cycle has a lot in common with the 5 E’s model, however is more suited to the time constraints of the PEAC program. The similarities between the three phase learning cycle and the 5 E’s model are given in Table 2.5 in the next section.

2.3.2 History of the learning cycle

The three phase learning cycle has its origins in the early work of Robert Karplus, a physicist at the University of California. Karplus was asked by his second grade daughter to give a science talk to her class. This talk was successful and led to other

talks on physics-related topics which in turn led to Karplus thinking about developing an elementary science program. In 1961, Karplus and Aitken, a professor of education at the University of Illinois, developed a theory of guided discovery teaching (Lawson, 1995). The guided discovery strategy was designed to imitate the way scientists worked in making and using discoveries (Atkin & Karplus, 2002). After trialling the guided discovery strategy it became clear to Karplus that students needed to explore at their own pace before introducing an analytical approach. In 1967 in association with Herbert Thier, a three-stage sequence was developed: preliminary exploration, invention and discovery (Karplus & Thier, 1967).

The learning cycle as developed by Karplus, Atkin, and Thier was made for the physical sciences. A similar process happened in the biological sciences. In 1956 the National Science Foundation under the direction of Chester Lawson developed a source book of laboratory and field activities for use in secondary school courses. The resource did not provide a teaching model but it led Chester Lawson (C. Lawson) and others to search for one. The search led to the Biological Science Curriculum Study (Lawson, 1995). As with Karplus, Chester Lawson used the history of science to help his understanding of the process of conceptual invention and the development of his description of scientific invention. He described the pattern as belief – expectation – test, that is, conceptual invention constitutes a belief, which in turn leads to an expectation that needs to be tested. If the belief is supported by evidence, the conceptual invention is retained; if not it is rejected in favour of another belief (Lawson, 1995).

C. Lawson as the biologist, and Karplus as the physicist, worked together in the Science Curriculum Improvement Study (SCIS) to produce a Kindergarten to Grade 6 science curriculum based on what is now known as the learning cycle. The term ‘learning cycle’ did not appear in SCIS publications until 1970. Initially the three phases of the learning were called exploration, invention, and discovery. However, this created confusion in the context of a classroom, and as a result the names of the three phases were changed to exploration, term introduction, and concept application (Lawson, 1995). To further reduce confusion in the classroom when using learning cycles in this study the stage of ‘term introduction’ was renamed ‘concept development’.

A direct descendent of the SCIS three stage learning cycle is the 5Es model which was developed as a result of a grant from IBM to the Biological Sciences Curriculum Study (BSCS) to develop an instruction model for a new elementary school science and health curriculum (Bybee et al., 2006; Tanner, 2010). The process of developing the model began with the Science Curriculum Improvement Study's (SCIS) learning cycle as mentioned previously. A comparison between the SCIS model and the BSCS model is made in Table 2.5.

Table 2.5 Comparison of the SCIS Model and the BSCS 5Es Model. (Bybee et al., 2006, p.7).

SCIS Model	BSCS 5E Model
	Engagement (new phase)
Exploration	Exploration (adapted from SCIS)
Invention (Term Introduction)	Explanation (adapted from SCIS)
Discovery (Concept Application)	Elaboration (adapted from SCIS)
	Evaluation (new phase)

The two extra stages of the 5 Es model exist informally in many cases in the three stage learning cycle model. Stage 1 of the 5 Es model, *Engage*, is often achieved by eliciting a student's prior knowledge through engaging questions about any related experiences students may have had. Tanner (2010) stated that teachers often leave out this phase of the 5E model. In a spiral curriculum where one lesson leads directly to the next, a reflection on the previous lesson would constitute '*engagement*'. Similarly, Stage 5 of the 5E model, *Evaluate*, is also often present informally in the three-stage cycle. For example, in closing comments to a lesson teachers often recapitulate on the main concepts by quizzing the class with reflective questions to determine the level of understanding and look forward to concepts in the next lesson. These reflections may relate to the opening *Engage* questions. This aspect is supported by Singer and Moscovici (2008) who suggested that evaluation should not be seen as a final process such as an end of unit test, but a process of reflection on what they have discovered and what they need to look forward to.

Madu (2012) used a four phase learning cycle in a study to examine its effectiveness in bringing about conceptual change in student understanding of simple harmonic motion. The four phases were exploration, explanation, expansion, and evaluation. A four-phase cycle was chosen because the instructional course was based on students'

existing knowledge which was determined by a pre-test. Madu (2012) found that a four-phase cycle was effective in teaching most of the concepts in simple harmonic.

Singer and Moscovici (2008) identified four problems with teaching/learning models and propose a model, IMSTRA, to address these problems. Firstly, they considered there was too much teacher-centredness in the *term introduction* phase of a three-phase model. This comment may be true of A. Lawson's (1995) descriptive learning cycle (DLC), which provides a high degree of student scaffolding, but is not true of his hypothetical-deductive learning cycle (HDLC). A full description of a DLC and a HDLC is given in Chapter 3, Section 3.4.2. In the HDLC, students formulate hypotheses, design experiments and draw conclusions based on their own data. Students are encouraged to analyse and discuss their data in pairs or groups. Whether a DLC or a HDLC is used, the degree of scaffolding would depend on the developmental level of the student.

Secondly, Singer and Moscovici stated that there is too much rigidity in using the linear approach of the 5E model. The rigidity does not provide feedback loops whereby students can revisit a stage or go forward to another. Again this is not true of the HDLC where students can reformulate hypotheses based on their own empirical data. A third issue regards the social aspect of the classroom, that is, the problem that students have in adapting to the format of a teaching model and determining teacher expectations. Singer and Moscovici stated that a model needs to be flexible enough to allow a variety of social interactions. Fourthly, they argued that a teacher sees a classroom of students as a unit that has a specific behaviour and tends not to focus on individuals.

To overcome the four problems stated above, Singer and Moscovici (2008) put forward a modified three phase learning cycle which they called IMSTRA. The three phases being Immersion, Structure, and Applying. Each phase had two sub-phases for the teacher and two sub-phases for the student. The sub-phases served to highlight the roles of the teacher and the student. The IMSTRA model can be used in a spiral sequence similarly to the Lawson learning cycle. The IMSTRA model is summarized in Table 2.6.

Table 2.6 The IMSTRA Learning Cycle model summary (Singer & Moscovici, 2008).

PHASE	TEACHER ROLE	STUDENT ROLE
Immersion	• Actualization and anticipation	• Evoking
	• Problem construction	• Exploring
Structuring	• Systematization	• Synthesizing
	• Conceptualization	• Explaining
Applying	• Reinforcement	• Practicing
	• Transfer	• Extending

A common core of three stages or phases can be found in each model described in this section – a stage of exploration, a stage of conceptualization or concept development and a concept application stage. After review of the three, four and five phase models it was decided that the simplicity of the three-phase model was preferred for this research. The lessons used in this study were sequenced to form a spiral curriculum with the previous lesson being reviewed at the commencement of the next. This review served as an *engagement*. Individual lessons were reviewed on their completion, and this served as an *evaluation*. Consequently, it could be argued that elements of a 5E model are actually present in the three phase model used in this research.

2.3.3. Learning cycles and Piaget’s model of mental functioning

Although the learning cycle seems to be a very simple instructional model, it is, however, built on sound educational theory. In the early stages of developing a teaching model, in the school year 1959-60, the analysis of trials indicated to Karplus evidence of serious student misconceptions, which prompted him to ask the question: “How can we create a learning experience that achieves a secure connection between the pupil’s intuitive attitudes and the concepts of the modern scientific point of view?” (Lawson, 1995, p. 158). To help answer this question he tried to understand how students viewed natural phenomena. He also made a visit to the research institute of Jean Piaget. As a result of these experiences Karplus returned to the classroom with the intent to stress learning through student observations and experiences. Subsequently, Karplus used the developmental theory of Piaget to design instructional

methods for the learning cycle. The relationship between the learning cycle and Piaget’s theory of learning is summarised in Figure 2.6.

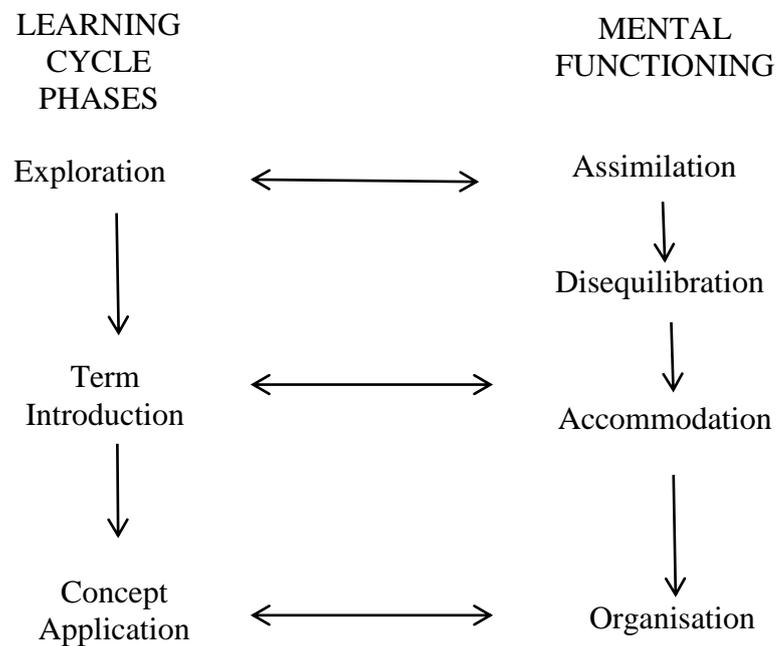


Figure 2.6. The learning cycle and Piaget’s model of mental functioning. (Marek & Cavallo, 1997, p. 70)

To better understand the relationship between the learning cycle and mental functioning it is necessary to define the terms used in Figure 2.6. *Assimilation* is the process of incorporating data into existing mental structures. Mental structures are referred to as variants by Piaget, that is, they vary according to the developmental level of the individual. Mental structures develop from birth and are used to help process data from the environment. The process of assimilation into mental structures is a process that only the individual can do. *Disequilibrium* is the mismatch between existing mental structures and newly assimilated data. In this state the learner asks questions such as ‘Why did it happen?’ *Accommodation* is the change of mental structures to accommodate the mismatch between a mental structure and environmental input. Accommodation leads to a state of equilibrium. Assimilation and subsequent accommodation lead to an adaptation, and *organisation* is the relationship that exists between a new mental structure and existing mental structures (Marek & Cavallo, 1997).

Piaget refers to a third factor of intelligence, that is, content. Content can be considered to be “the way a child believes the world works” (Marek & Cavallo, 1997, p. 64). For

example, a young child might think that a mass having a large surface area as in a pancake has more mass than a sphere of the same mass. This is because that is the way a child believes the world works. This content factor is a variant and can be reconstructed through assimilation, disequilibrium, and accommodation (Marek & Cavallo, 1997).

It is useful to reflect on Piaget's four levels of intellectual development and how they affect the learner's ability to benefit from a learning cycle. These levels of development are relevant to students of all abilities; however, the gifted child would progress through the levels at a faster rate than the non-gifted child. These levels are sensorimotor stage, preoperational stage, concrete operational stage, and formal operational stage. It is very important to know the general developmental level of a group of students when planning teaching strategies. For example, this research investigates the suitability of a hypothetical-deductive learning cycle (HDLC) for teaching Year 6 PEAC students. For a HDLC to be effective students would need to be approaching the formal operational stage. Is this type of learning cycle appropriate for PEAC students in Year 6? Are they developmentally ready? These questions are investigated in this research.

The moment we are born we need to process data from the surrounding environment. How we deal with that data depends on our intellectual development stage. When a baby can repeat an action such as picking up an object a mental structure has been established which Piaget has termed a scheme. Eventually a set of schemes are established and integrated to form a cognitive structure. Assimilation occurs as new schemes are integrated into structures, and this requires experience. Giving a child information is not sufficient.

As more cognitive structures are established, the child moves into the next mental stage. It is important to note that assimilation into a cognitive structure cannot occur if that structure is not present in the child. If a preoperational child is asked to assimilate a concrete operational concept, the concept may not be assimilated, or erroneously assimilated into the child's existing structures. The preoperational child does not necessarily understand what he or she is asked to assimilate.

The concrete operational child is aware that he or she needs to understand the incoming data to be able to assimilate it. If there is a mismatch with the data and an existing

cognitive structure, disequilibrium occurs. Mental structures need to be revised to make meaningful assimilation possible and re-establish equilibrium. This process is called equilibration and indicates that the learner is moving forward in his or her stage or advancing to a higher stage. Assimilation, accommodation, adaptation, and organisation are referred to by Piaget as invariants of intelligence. That is, the process does not vary regardless of the individual.

Although Piaget's theory of cognitive development attracted a lot of attention in the 1960s and the 1970's, current research is indicating some major concerns with some aspects. Studies to evaluate his theory can be classified into two broad categories: firstly studies to evaluate if Piagetian phenomena were real and reliably present; and secondly studies to examine if Piaget is right in assuming that there is an overarching structure of the whole at each major development which underlies understanding over different domains. With respect to the first category Demetriou (2016) states that this research can be summarized in the following statement: "Whenever a replication study remained close to the original Piagetian conditions, the phenomena were observed in more or less the same way at more or less the same age." (Demetriou, 2016, p. 3)

With respect to the second category of research into Piagetian theory of cognitive development, the expectation was not confirmed. These studies indicate that people usually operate at different levels in different domains. These studies have led to new theories of cognitive development known as neo- Piagetian theories. For example many studies have indicated that extra-logical factors such as memory, language and communication, familiarity with tasks and procedures, and interest have an influence on the performance and development of individuals regardless of their age. This, for example, would infer that an individual's performance and development can be assisted if they are trained to remember strategies. Other studies have demonstrated that individuals usually operate on different levels in different domains suggesting that there are factors governing cognitive processes which are not explained by Piaget's concept of the whole (Demetriou, 2016).

Graeme Halford (1989), a neo-Piagetian, suggests that analogical reasoning is the fundamental means for understanding new concepts, because it enables us to transfer meaning from concepts we already know to the new concepts. This point is relevant

to this research because analogies were a significant scaffolding strategy used in the Descriptive Learning Cycle.

Kurt Fischer (1980), also a neo-Piagetian, has a theory of cognitive development that uses ideas based on those of Lev Vygotsky (1978). Fischer's theory is explained by the idea of internalization and the zone of proximal development (ZPD). Internalization being where the child reconstructs the products of his or her observations and experiences in a way that makes them their own. The ZPD expresses the idea that potential ability is always greater than actual ability. Vygotsky's theory will be discussed in more detail in Section 2.3.4. Structured social interaction, scaffolding and internalization gradually allow potential to become actual. This concept of development through experiences in different domains can explain the variations in the development of different mental skills. Fischer maintains that the differences in cognitive development across different domains is the rule rather than the exception (Demetrious, 2016). Fischer's theory is highly applicable to the learning cycle. The learning cycle provides an experiential environment within a science context, structured scaffolding, and social interaction.

This account of Piaget's model of intelligence and neo-Piagetian theories is essential for understanding the learning processes happening in a learning cycle. When considering the implementation of a learning cycle one starts from assimilation because this is the process whereby students perceive what they are experiencing and adjust their mental structures to arrive at some sort of meaning. The *exploration* phase of the learning cycle is where most assimilation takes place. When students collect data and make an initial analysis and evaluation. During *term introduction* data collected needs to be processed in order to construct knowledge and concepts. By doing so, accommodation takes place leading to an adaptation. In the *concept application* phase the new knowledge constructs are applied in a new situation enabling students to organise their knowledge and construct generalisations. When constructing a learning cycle for use in the classroom, the content to be studied by the students needs to be carefully organised to suit the existing knowledge and developmental level of the students.

2.3.4 Learning Cycles and Social Constructivism.

The theory of social constructivism was put forward by Lev Vygotsky, a Russian psychologist (1896-1934). It is useful to examine his theory because it complements Piaget's cognitive theories. Vygotsky's work was suppressed for many years due to the communist regime under which he lived. With the fall of the Soviet Union his work is now more widely known. Social constructivism basically states "that individuals are members of certain cultures that cannot be separated from their learning experiences" (Marek & Cavallo, 1997, p. 94). The concept of culture does not however refer to just ethnicity. It can also refer to sub-cultures within major cultures. For example, it could refer to a fundamentalist Christian, who might be greatly influenced by the beliefs of his or her sub-culture when learning some aspects of biology. The science community could be considered to be a sub-culture. Science has its own variations of language, behaviour, and philosophies. Students learning science in Australia are largely immersed in that culture. The learning cycle with respect to science operates within the sub-culture of science and incorporates the essential experiences of science.

Social constructivism is based on assumptions regarding reality, knowledge and learning. With regard to reality, the social constructivist believes that reality is constructed through human activity. Reality is not discovered but is a result of human invention (Kukla, 2000). In the PEAC Electronics course students explore by manipulating real objects and constructing real electronic circuits, unlike many courses in the PEAC program that are conducted in the virtual world of the computer screen. Similarly, knowledge is constructed through social and cultural interactions (Ernest, 1999). Learning is seen by the social constructivist as a social process. It does not only occur within the individual, but as a social interaction between individuals (McMahon, 1997). This aspect is applied in the PEAC Electronics course by the use of student pairs. All exploration activities and subsequent discussions are conducted in pairs. Before recording observations, answers to questions, or conclusions, students are encouraged to come to a consensus by discussion.

Vygotsky, similar to Piaget, believed that the developmental level of the child is important when considering his or her learning ability. He stated that educators need to be aware of two levels of development of the child: the actual developmental level of the child or what the child can actually do; and the potential developmental level of

the child or what the child can mentally do with help from an adult or competent peer. Vygotsky termed the zone of proximal development (ZPD) the distance between the two levels and maintained that it was important for educators to know this for each child. If the potential level is achieved, it then becomes the new actual level and a new potential level is established.

It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peer. The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state. (Vygotsky, 1978, as cited in Marek & Cavallo, 1997, p. 95)

Two aspects of Vygotsky's social constructivist theory that are highly relevant to learning cycles are the culture of science and scaffolding. For example, the formulation of hypotheses and designing experiments to test them is an important aspect of the scientific method and which in turn is an important aspect of the culture of science. The learning cycle design imitates some aspects of the scientific method, particularly in the hypothetical-deductive learning cycle as described in Section 2.3.7 Learning Cycles for PEAC Electronics.

The process of elevating a student to a new level is termed scaffolding and can be achieved with the help of a More Knowledgeable Other (MKO). In the case of the PEAC Electronics course the MKO was the teacher. However, during discussion a student's partner may become the MKO. The amount of help will reduce as the student approaches their new developmental level. Examples of scaffolding are modelling (analogies), questioning, giving hints during discussion, and demonstrating procedures in a first time experience (Jackson, Karp, Patrick, & Thrower, 2006). Such instructional tools are only effective when they are within the developmental level (ZPD) of the student. New concepts such as a specific graphing technique would need to be demonstrated in a similar and familiar context before students are asked to use it. Such strategies are ideal for the use in a learning cycle situation (Marek & Cavallo, 1997).

2.3.5 Learning Cycles and Meaningful Learning

Meaningful learning is a theory put forward by David Ausubel (1963). In meaningful learning students relate new ideas with what they already know. This is in contrast to rote learning where students memorize facts without relating to other information. Needless to say students often find these facts meaningless and hard to remember.

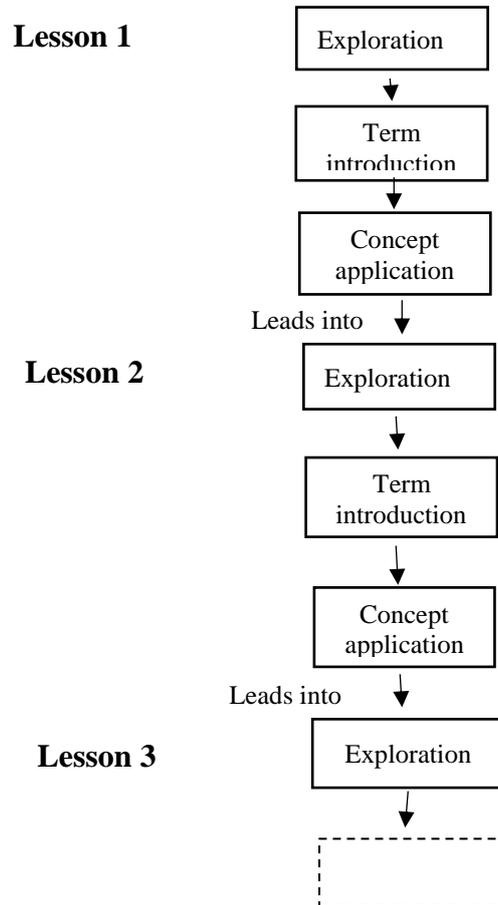


Figure 2.7 A Spiral Curriculum. The concept application phase of one lesson leads into the exploration phase of the next. (Adapted from Lawson, 1995, p. 138).

Ausubel defined three criteria necessary for promoting meaningful learning: (1) prior knowledge or a framework of understanding from which to draw on, (2) the learner must actively relate new ideas with their conceptual frameworks (what they already know), and (3) the learner must be given meaningful learning tasks, preferably tasks that give the student direct experience with objects and phenomena (Ausubel, 1963; Marek & Cavallo, 1997). Of these three criteria, Ausubel (1968) considered prior knowledge the most critical: “If I had to reduce all of educational psychology to just

one principle I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach accordingly” (Ausubel, 1968, p. 337).

With regard to his third criterion, Ausubel (1963) stated that it is important that learners who have not developed beyond the concrete stage of cognitive development, need direct experience with physical objects. These criteria of meaningful learning fit very well with the concepts underlying the learning cycle. Firstly, the exploration phase provides concrete direct experience such as observing, measuring, and recording. If an experiment using equipment is involved, students are able to manipulate physical objects rather than look at an abstract diagram in a textbook or on a two dimensional computer screen. Students are then able to construct and explain their ideas from hands-on experience. Secondly, prior knowledge from one learning cycle can be used in the next and thus form a spiral curriculum, a model of which is presented in Figure 2.7.

Ausubel’s criterion is particularly relevant to this study because of the high possibility that many of the subjects could be in the concrete stage of with respect to scientific thinking due to their lack of exposure to science in their primary education age. Gagné (2013) maintains that gifted children develop their cognitive abilities by going through the same developmental stages as any other child so it is logical to suggest that if students have not been exposed to higher level thinking activities in their primary education they may not have developed abstract thinking skills with respect to science. With this in mind the learning cycles designed for the intervention in this study contained hands-on activities in the exploration phase and a large project component in the concept application phase. Scientific thinking skills are developed in the learning cycle, particularly the hypothetical-deductive learning cycle.

2.3.6 Learning cycles and conceptual change

Conceptual change and the cognitive domain

The theory of conceptual change was first put forward by Posner (1982) as a means of explaining the cause of student misconceptions or alternative frameworks, and why they were so “highly robust” (p. 211). They also stated that Piaget’s theory of concept acquisition needed to be modified to focus “more on the actual content of student’s ideas and less on underlying logical structures” (Driver, 1978, p. 76). This latter

statement is relevant to this study because it used an intervention which contained subject matter that was in most cases new to the students. For example it was found in this study that the acquisition of a difficult theoretical concept (voltage) was made possible by relating it to another concept (gravity) that was familiar to the students.

The initial understandings of conceptual change involved an understanding of the evolution of student conceptions. Constructivist ideas developed from a merger of Piagetian theory of assimilation and accommodation with radical constructivism. Constructivism also considered social aspects that shape conceptual change. They also stated that inquiry and learning are achieved using the learner's existing knowledge. Without this existing knowledge it is impossible for the learner to inquire about the new concept being introduced. This concept is consistent with Ausubel's statement that the most important factor in teaching is knowing what the student already knows (Ausubel, 1968).

Working with elementary (primary) school students, Driver (1989) developed a teaching model that led to conceptual change. This model allowed students to explore their preconceptions prior to a new learning experience. New ideas constructed during the experience were reviewed in the light of their original conceptions (Lawson, 1995). According to Lawson this model has a lot in common with the learning cycle and a comparison between Driver's Model and Lawson's three phase learning cycle is shown in Figure 2.8 (p. 50).

Vosniadou's (1994) has an approach to conceptual change that is based on the students' theoretical frameworks or constraints. She describes a hierarchy of theoretical constraints. A brief description of these theoretical constraints is made here, as they are useful in explaining observations made in this study.

A naïve framework theory of physics: The human mind operates on a number of domain specific constraints such as the knowledge of the physical world. For example, a child seems to have developed from an early age five constraints about the behaviour of physical objects - continuity, solidity, no action at distance, gravity, and inertia.

Specific theories: These are sets of interrelated beliefs that describe the behaviour of physical objects.

Mental models: Mental models are representations that can be used to explain observations in and make predictions about the physical world. Analogies are useful mental models (Vosniadou, 1994).

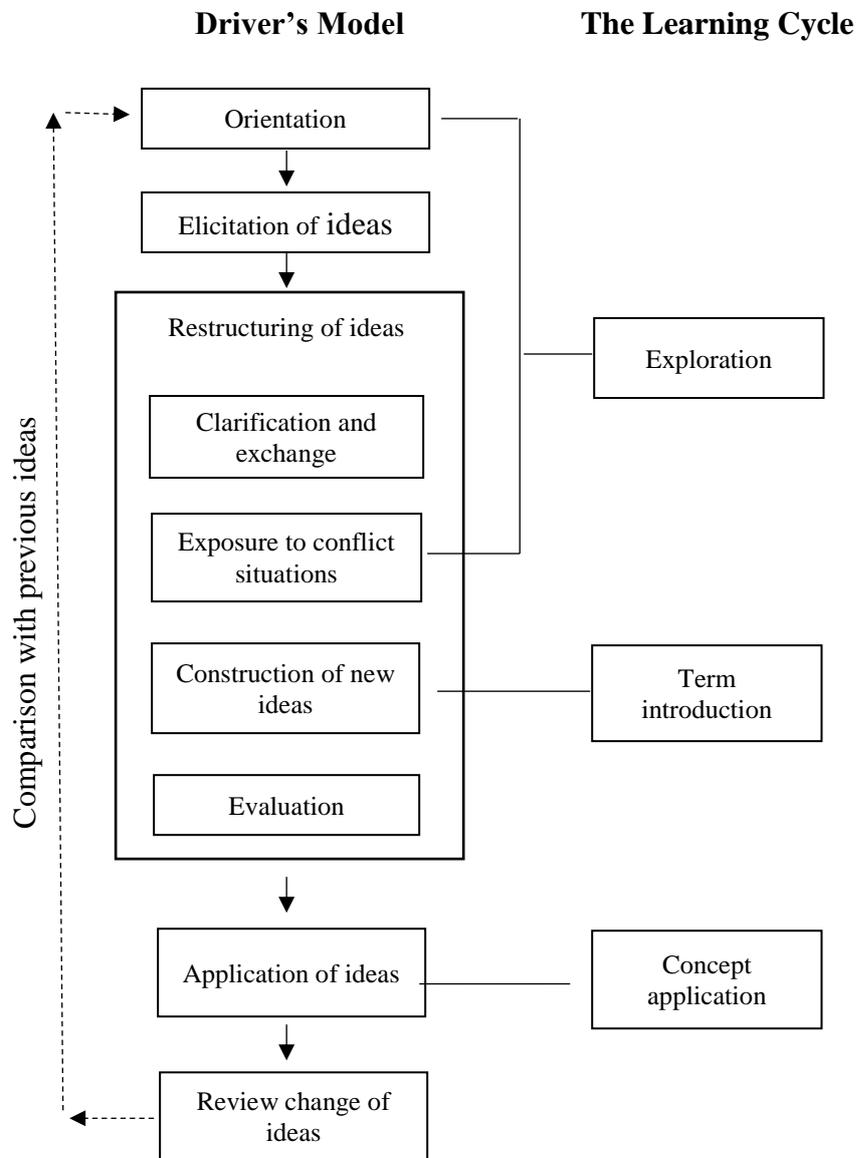


Figure 2. 8 Comparison of Driver's General Teaching Sequence, The Learning Cycle and the 5 Es model (Lawson, 1995, p. 162).

Vosniadou (1994) describes two types of conceptual change:

Enrichment of existing structures. This involves the simple addition of information into existing theoretical frameworks. It is considered an easy process if the new information adds to existing information.

Revision. This is required when acquired information does not fit existing beliefs or presuppositions. Such revision could be of specific theories or framework theories. The former being easier than the latter. Conceptual change can be very difficult if new information is constrained by a framework theory. Framework theories have been established in the child by years of everyday experiences with the physical and social world, making conceptual change difficult. During the intervention of this study some difficult concepts were explained using analogies that referred to existing frameworks that the students held, for example, the water analogy was used to explain flow of electrical charge (current).

All the different approaches to conceptual change and concept acquisition seem to have many common factors. The starting point seems to be classical learning theory such as those put forward by Piaget, Vygotsky and Ausubel, and this is changed to fit various emphases. Many aspects of all the theories and models of learning and conceptual change discussed are relevant to this study.

Conceptual change and the affective domain

The affective domain needs to be considered as a perspective of conceptual change. Treagust and Duit (2008) stated that student interest and motivation need to be developed because they play an important role in conceptual change. Pintrich et al. (1993) states that only concentrating on the cognitive domain does not explain why some students with good prior knowledge do not use that knowledge to function well at school. They also argue that there needs to be a consideration of the motivational constructs and attention to the context of the classroom in order to modify the original conceptual change theories.

The level of engagement a student makes in the classroom is a choice made by the student and this choice is likely to be influenced by their level of motivation (Pintrich & De Groot, 1990). One such motivational factor that can be adopted by a gifted learner is a goal focussed on learning and mastery. Watter's (2004) list of characteristics of students gifted in science indicate they have a passion for exploration and learning. Research indicates that students who have a mastery goal orientation are more likely to use cognitive processing that leads to conceptual change and growth. The adoption of a mastery goal is in turn dependent on the available classroom tasks which must be challenging and relate to the real world (Pintrich et al., 1993).

Vosniadou (2007) suggests, based on the studies of Hatano & Inagaki (2003), that one way a teacher can enhance student motivation is by providing a sociocultural environment that favours prolonged comprehension activity and that this can be achieved by the use of student discussion. Student discussion is a fundamental design feature of the lesson strategies used in this research. All students were required to work in pairs for both hands-on activities and the discussion of their observations and conclusions.

LaForgia (1988) stated “that the affective domain related to science education is basically concerned with attitudes related to science” (p. 409). Although the term attitude has been loosely used in the literature, Gardener (1975) placed science attitudes into two categories: attitudes towards science (i.e. science in general, scientists, and social responsibility) and scientific attitudes (i.e. open-mindedness, honesty, scepticism). He defined attitudes towards science as: “...a person’s attitude to science as a learned disposition to evaluate in certain ways objects, people, actions, situations or propositions involved in learning science” (p. 7).

When this view was published in 1975, science teachers were concerned about whether students found the content of science dull or exciting. Designing curricula to maximize student interest was a major concern. However, Gardener also reported that British teachers placed affective outcomes below experimental skills. Schibeci (1981) made similar findings amongst Australian teachers who regarded cognitive objectives as more important than affective objectives. In 2008, Blalock et al. (2008) stated that:

Educators and policy makers are increasingly concerned about the quality of science education and how this relates to the interests and understanding among young people. Students’ declining interest in school science (but not science in general) and a striking disinterest in science careers have prompted multiple research studies. (p. 961)

It appears that 33 years later, affective domain issues are still a major concern in science education. Consequently, this research examines the effect that different types of learning cycle may have on student interest and subsequently, conceptual change.

2.4 Inquiry Learning

Section 2.4 looks at the definition, nature, levels and effectiveness of inquiry learning. This section will look at the nature of inquiry learning, levels of inquiry teaching/learning, and the effectiveness of inquiry learning. Marek and Cavallo (1997) state that "...children should have experiences with objects, phenomena, and/or nature that raise questions that begin a process of inquiry" (p. 21). The learning cycle provides these experiences and therefore it is important to this study to examine the nature and effectiveness of inquiry learning.

2.4.1 Definition and nature of Inquiry Learning

Educational policy makers around the world in the last 50 years have advocated that students learn science by engaging in activities and thinking processes similar to scientists. Such an approach has been described as inquiry-based teaching or learning. For such an approach to be considered inquiry learning, students would need to use their scientific knowledge to ask science-oriented questions and to collect and analyse data, draw conclusions from experiments and communicate these findings within their educational community (Furtak, Seidal, Iverson, & Briggs, 2012).

Inquiry in a science educational context could have several meanings. It could mean 'science as inquiry, learning as inquiry, teaching as inquiry' or combinations of all three (Anderson, 2002). Marek and Cavallo (1997) describe inquiry "...as a search for information, a quest for knowledge, or an exploration of certain phenomena to understand the world better" (p. 21). John Dewey (1916) argued that science instruction should incorporate a method of inquiry and stated that "science is primarily the method of intelligence at work in observation, in inquiry and experimental testing" (Lawson, 1995, p. 156). The National Research Council (NRC) in the USA describes five core components of classroom inquiry from the learners' perspective: "learners are engaged by scientifically oriented questions; learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions; learners formulate explanations from evidence to address scientifically oriented questions; learners evaluate their explanations in light of alternative explanations; learners communicate and justify their proposed explanations" (Minner, Levy, & Century, 2010, p. 3). The National Science Education Standards (NSES) in the USA use the word inquiry in three main ways: *Scientific inquiry* which "refers to the diverse ways in which scientists study the natural world

and propose explanations based on evidence derived from their work”; *Inquiry learning* which “refers to a learning process in which students are engaged”; *Inquiry teaching* which refers to “authentic questions generated from students experiences as the central strategy for teaching science” (Anderson, 2002, p. 2; Minner et al., 2010).

In order to conduct a meta-analysis of the relevant literature, Furtek et al. (2012) found it necessary to clearly state a framework for inquiry-based teaching and learning research. Such a framework helps to define the nature of inquiry teaching and learning. They state two dimensions for their framework: the *cognitive and social* activities in which the students are engaged; and the *level of guidance*, by teacher or students, within the activities. In the cognitive dimension, Furtek et al. (2012) describe four categories: “the *conceptual domain* consisting of facts, theories and principles of science”; the *epistemic domain* which is the students’ knowledge of “how scientific knowledge is generated”; the *social domain* consisting of “collaborative and communicative processes”; and the *procedural domain* which includes “the procedures of the scientific method” (p. 305). The *guidance dimension* is discussed further in Section 2.4.2.

Similarly Minner et al. (2010) established a framework for their meta-analysis of ‘Inquiry-based science instruction’. In their framework they described three aspects of inquiry science instruction: “the presence of science content; student engagement with science content; student responsibility for learning, student active thinking, or student motivation within at least one mode of instruction - question, design, data, conclusion or communication” (p. 5).

It is obvious from the examples above that finding a definition of inquiry-based learning or inquiry-based instruction can be difficult. Definitions mentioned above even though containing many common elements, are quite varied. However Bell, Smetana, and Binns (2005) state a very concise definition that captures the key ‘spirit’ of inquiry learning: “At its heart, inquiry is an active learning process in which students answer research questions through data analysis” (Bell et al., 2005, p. 30).

2.4.2 Levels of inquiry learning

Furtek et al. describe inquiry-based education as a continuum from teacher led traditional instruction to student led inquiry learning. This is illustrated in Figure 2.9.

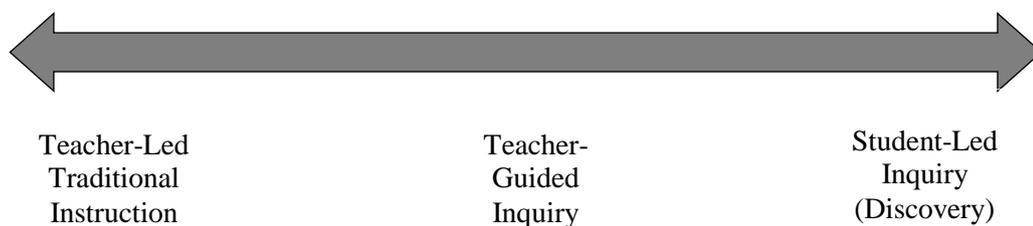


Figure 2.9 Continuum of guidance in inquiry-based science teaching. (Furtek et al., 2012, p. 306).

Rezba, Auldridge and Rhea (1999) developed a four-level model of science inquiry instruction based on the work of Schwab (1961) and Herron (1971). A summary described by Bell et al. (2005) is as follows:

- Level 1 *Confirmation.* Students confirm a principle through an activity in which the results are known in advance.
- Level 2 *Structured inquiry.* Students investigate a teacher presented question through a prescribed procedure.
- Level 3 *Guided inquiry.* Students investigate a teacher presented question using student designed or selected procedures.
- Level 4 *Open inquiry.* Students investigate topic related questions that are student formulated through student designed or selected procedures. (Bell et al., 2005, p. 4)

This four level model was simplified by Bell et al. (2005) into a framework, based on the amount of information given to students for the purposes of designing or assessing lessons and activities in science instruction (Table 2.7). These authors proposed a simple framework based on the degree of scaffolding or amount of information supplied, to determine the level of inquiry in an instructional model.

The fundamental difference between each level is the degree of support or *scaffolding* given to the students. Furtak et al. (2012) consider the amount of support given to students is a crucial dimension of inquiry. They state that there is a constant

progression of responsibility for learning from the teacher to the student. Over time this progression forms a continuum of guidance as shown in Figure 2.10.

Table 2.7 Simplified framework checklist for four level model of inquiry (Bell et al., 2005, p. 32).

Level of inquiry	Questions?	Methods?	Solution?
1	✓	✓	✓
2	✓	✓	X
3	✓	X	X
4	X	X	X

Kirschner, Sweller and Clarke (2006) take a more dichotomous view on inquiry teaching in their research on the effectiveness of minimally guided instruction. In their discussion, they defined minimally guided instruction as instruction “in which learners, rather than being presented with essential information, must discover or construct essential information for themselves” (p. 75). Examples they give of this type of inquiry instruction include discovery learning, problem-based learning, inquiry learning, experiential learning and constructivist learning. They define “direct instructional guidance as providing information that fully explains the concepts and procedures the students are required to learn” (p 75). These two definitions ignore the various levels of support that may be present in some inquiry models. The definitions represent the two extremes of Furtak et al.’s continuum of inquiry-based science teaching (Figure 2.9).

2.4.3 Effectiveness of inquiry learning

An insight into some of the arguments concerned with the effectiveness of inquiry learning can be gained with an examination of two contrasting papers: a paper by Kirschner et al. (2006), mentioned previously, and a critique of that paper made by Hmelo-Silver, Duncan, and Chin (2007).

As mentioned in Section 2.4.2, Kirschner et al. (2006) took a dichotomous view of science instruction – direct instruction versus minimally guided instruction. Although this view ignores various levels in-between, it is useful to compare the two extremes as it highlights the need for a variety of in between strategies to suit various developmental levels of learners. Kirschner et al. state that minimally guided instruction does not work. In their analysis of minimally guided instructional methods

they cite many studies that support direct instruction as being more effective than instructional methods that are based on pure discovery. Hmelo-Silver, et al. (2007) agree with Kirschner et al. in “that there is little evidence to suggest that unguided and experientially-based approaches foster learning” (p.100). However, they challenge the assertion made by Kirschner et al. that problem-based and inquiry learning are minimally guided. Hmelo-Silver et al. state that problem-based and inquiry learning are not minimally guided because they provide many forms of scaffolding. Such scaffolding provides learners with opportunities to deal with complex tasks, which lie within their zone of proximal development (Vygotsky, 1978). They state that “most proponents of inquiry learning are in favour of structured guidance in an environment that affords choice, hands-on and minds-on experiences, and rich student collaborations” (Hmelo-Silver et al., 2007, p. 104).

Hmelo-Silver et al. (2007) come to the conclusion that there is considerable support for inquiry and problem-based learning strategies even though controlled experimental studies are scarce. The few that do exist however, show significant and marked effect sizes in favour of inquiry learning (Hickey, Kindfield, Horwitz, & Christie, 1999; Hickey, Wolfe, & Kindfield, 2000; Lynch, Kuipers, Pyke, & Szesze, 2005). Hmelo-Silver et al. (2007) and Kirschner et al. (2006) both agree that scaffolding (guided support) is essential to successful inquiry learning although they appear to approach the matter from different directions. Kirschner et al. look at research where guidance is low and argue that guidance should be higher, and Hmelo-Silver et al. look at the successes where guidance is high. They both seem to come to the same conclusion – scaffolding or guidance is critical to the process.

Kirschner et al. (2006) base their argument against minimally guided instruction on the nature of human cognitive architecture - specifically the relationship between working memory and long-term memory. They consider an understanding of the relationship between the types of memory, in the context of the cognitive processes involved in learning, extremely important for purposes of planning inquiry instruction. They suggest that this understanding is not always evident: “Minimally guided instruction appears to proceed with no reference to the characteristics of working memory, long term memory, or the relations between them” (p. 76).

Working memory is a conscious cognitive processing structure with a duration of about thirty seconds and a limited capacity of about four to seven elements. Kirschner et al. state that in minimally guided instruction a heavy load is placed on working memory while problem solving, particularly with novice learners. This process does not contribute to long-term memory, but rather excludes its use. Learning may not occur. Long-term memory is the result of many learning experiences and is considered the central dominant structure of human cognition. We depend on long term memory in nearly all we hear, see and think about. The limitations of short-term memory however do not apply if information is drawn from long-term memory. The limitations only apply to new information (Kirschner et al. 2006). Kirschner et al. argue that if an instructional model based on constructivist theory, where teaching emphasis shifts from science as a body of knowledge to emphasis on the procedures of science, it makes no distinction between the experienced scientist with a large long-term memory and the novice student who is still establishing a long-term memory. The scientist can draw on information from long-term memory without the short-term memory limitations and thus reduce cognitive load. Such is not the case with the novice student who is processing new information in short-term memory with the corresponding limitations. To reduce the cognitive load on the novice students, Kirschner et al. suggest scaffolding by the use of worked examples and process worksheets. They recognise that the degree of scaffolding will be reduced as the students becomes more experienced. Kalyuga, Ayres, Chandler, and Sweller (2003) refer to this as an expertise reversal effect, a notion supported by Bell et al. (2005) who state that “most students need substantial scaffolding before they are ready to develop scientific questions and design effective data collection procedures to answer these questions” (p. 30). Scaffolding with the use of process worksheets is relevant to this study as they will be used in the learning cycle lessons.

2.5 Concept Mapping

A concept mapping task was used in this study as an instrument for measuring prior knowledge and the amount of conceptual growth in the subjects as a result of a course learning such as the Electronic course in this study. Concept maps are a valuable tool for measuring both the depth and structure of a student’s knowledge. An indication of the depth of a student’s knowledge can be given by the number of concepts recalled and the depth can be indicated by the manner in which the student organises the map

into clusters of related concepts. Concept maps can be difficult to interpret, therefore, it was considered relevant to review the literature on concept mapping and to justify the type of concept mapping task to be used and a valid and reliable scoring method.

Concept mapping was first described in the 1960s and further expanded in 1984 by Novak and Gowin. (1984). Miller, Koury, Fitzgerald, Hollingsead, Mithchem, Tsai, and Park (2009) describe a concept map as: "...a graphic representation of a person's structural knowledge or conceptual understanding of a particular topic" (Miller et al., 2009, p. 366). A concept map is a diagram that usually looks like a scattering of 'word bubbles'. Each 'bubble' contains a concept related to a particular topic. These concepts are linked with connecting lines, which in turn have associated linking words or phrases to indicate the relationship between them. For example, a simple conceptual relationship shown in Figure 2.10 would be:

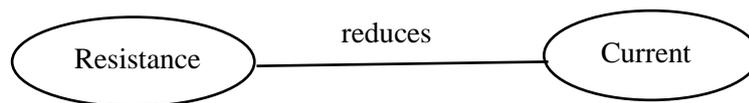


Figure 2.10 A single conceptual relationship or proposition.

This relationship is termed a proposition and is the basic building block of a concept map.

A proposition can be added to form chains and clusters as in Figure 2.11:

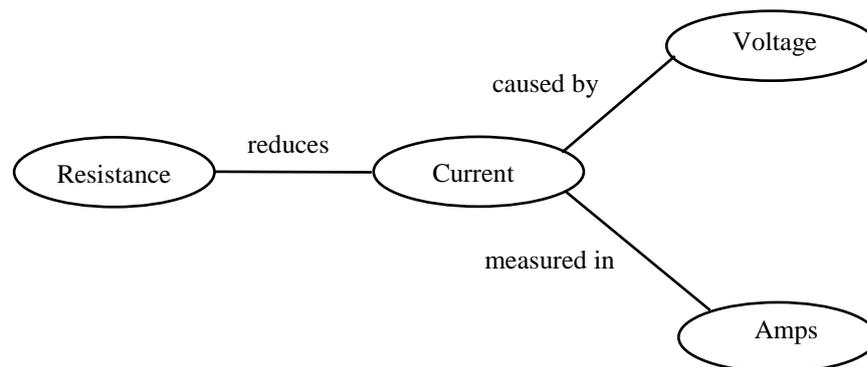


Figure 2.11 A concept map of three propositions.

Concept maps can be classified as either open ended or constrained (Stoddart, Abrams, Gasper, & Canaday, 2000). The open ended concept map allows the mapmaker to use any concepts or linking phrases they can recall. There are no restrictions on the

structure of the map. Such maps vary greatly and enable the maker to be creative in demonstrating his or her knowledge constructs. The constrained map requires the maker to construct a map from a list of concepts and linking phrases. It may even require the maker to structure the map in a particular style such as linear, hub, tree or network (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). This style would be well suited for young students, as in this study, or students who are not particularly familiar with concept mapping techniques.

Consequently, the choice of a concept mapping style for this study was made on the basis of research conducted by Yin et al. (2005). In their research they compared two map construction techniques:

1. The C (create) technique where students create their own linking phrases.
2. The S (select) technique where students select a linking phrase from a list provided.

In both techniques students were given the subject concepts. A slightly modified ‘S’ technique was chosen for this study. Students were able to create concept links if the list supplied was not sufficient.

Yin et al. (2005) found that the C technique mean scores were higher, maps more complex, and students took less time; however, standard deviations and pre-test-post-test correlations were very similar. They also found the C technique harder to score due to the variety of created responses. Bearing in mind these findings it was considered that due to the age of the students in this study (Year 6 aged 11), selecting a phrase with the option of creating extras if needed was a good compromise. The primary focus of this research was the number and accuracy of propositions in the student maps in a pre-test – post-test design enabling the determination of any conceptual growth occurring as a result of a ten week course in basic electronics.

Arguably the biggest problem with concept maps is how to score them. There are numerous methods, but they can be grouped into two general categories – quantitative and qualitative. Quantitative scoring systems largely have their origin in systems proposed by Novak and Gowin (1984). Such systems base their score on:

- a. The number of unique nodes or concept propositions indicating knowledge
- b. The number of links indicating complexity
- c. The number of levels indicating depth. (Miller et al., 2009, p. 366)

Qualitative scoring systems aim to determine validity and accuracy of information within the concept map. This can be done in a number of ways:

- Comparing nodes on student maps with a list of desired concept propositions (Koury, 1996).
- Rating maps against expert created maps (Herl, Baker, & Niemi, 1996).
- Correlation of map scores with interview performance (Rye & Rubba, 2002).

Scoring systems are well summarized by Ruiz-Primo and Shavelson (1996) and address practical matters associated with reliability and validity. Reliability refers to the consistency of scores of the student's maps and validity the extent to which students' cognitive structures can be supported logically and empirically on the basis of their concept map scores (Ruiz-Primo & Shavelson, 1996). To maximize reliability and content validity in this study, a procedure described by Yin et al. (2005) was used whereby all propositions were extracted from all maps and each rated on a five point scale by two expert raters. They were rated with respect to how well they represented the subject domain. The Yin method indicated the depth of a student's knowledge and to some extent the quality. In order to ascertain a measure of the structure of that knowledge, a method described by Miller et al. was used (2009). These procedures are discussed in more detail in Chapter 3.

The distinction between descriptive and theoretical concepts was made according to definitions made by Lawson, Alkhoury, Benford, Clark, and Falconer (2000): "descriptive concepts have directly observable exemplars; theoretical concepts do not have directly observable exemplars" (p. 996).

2.6 Two-tiered multiple choice test

The choice of a two-tiered multiple-choice style of item for this study was made because of its ability to ascertain a student's acquired knowledge on a topic and the ability to use that knowledge. Simple multiple-choice (MC) style items are very popular because of their ease of administration and high reliability, however they are often criticized for their emphasis on recall and simple applications of concepts. No provision made for explanation of answers therefore losing information on student reasoning. Created response (CR) questions can measure complex understandings but have low reliability and are difficult to score (Liu, Lee, & Linn, 2011).

A two-tiered multiple-choice or explanation multiple-choice (MC-EMC) can combine advantages of both MC and CR style items. A MC-EMC item has two responses for each item. In the first response the student chooses an answer to the question from a choice of two, three or four alternatives. Some of the alternative responses could include common misconceptions. In the second response students are asked to justify their first response. The second response may have up to six alternatives to choose from. Each explanation alternative should relate to and attempt to justify an alternative from the first set whether they are correct or not. It is this aspect of the MC-EMC item that is strong in diagnosing misconceptions (Liu et al., 2011; Treagust, 1988). Further discussion of the MC-EMC is made in Chapter 3 Methodology, Section 3.5.

2.7 Evaluation of the affective domain in science

Hopkins and Stanley (1981) list the main evaluation techniques used in the affective domain as: the interview schedule; open ended questions; projective techniques; closed item questionnaire; and preference ranking. Of these, the closed item questionnaire, which includes Thurstone scales, Likert scales, rating scales, semantic differential scales and self-report inventories, are effective and efficient to use in the classroom situation.

To evaluate attitudinal change in this study the Test of Science Related Attitudes (TOSRA) was chosen. This test was developed by Fraser (1978) and has been a popular test for many years (Blalock et al., 2008; Welch, 2010). The TOSRA consists of seven subscales: 1. Social implications of science; 2. Normality of scientists; 3. Enjoyment of science lessons; 4. Leisure interest in science; 5. Career interest in science; 6. Attitude to scientific inquiry; 7. Adoption of scientific attitudes.

Subscales 1-6 deal with *attitudes towards science* and Subscale 7 deals with *scientific attitudes* as categorized by Gardener (1975). Each set measures a distinct science related attitude and has ten items. Each item has a five point scale ranging from strongly agree to strongly disagree. Items alternate between positive and negative statements and the scoring of which are adjusted on marking the responses. Due to the constraints of only 20 hours student contact time, time taken for assessments needed to be kept to a minimum therefore only two sets were used – Enjoyment of Science and Attitude to Scientific Inquiry.

The TOSRA was included in a review of science attitude instruments developed between 1935 and 2005 (Blalock et al., 2008) and scored a very high rank. In this review instruments were placed into the following categories: Attitudes towards science; Scientific attitudes; The nature of science; Science career interest; Other categories; and Multiple categories.

The TOSRA was categorized as a multiple category instrument for the purposes of this review. This category contained 33 instruments out of a total of 66 reviewed. A rubric was used to assess the instruments. The rubric used to score and rank the instruments is shown in Table 2.8.

Table 2.8 Rubric to rank science attitude instrument between 1935-2005 (Blalock et al., 2008)

Aspect	Possible Score
Theory	3
Reliability	9
Validity	9
Dimensionality	6
Development and usage	1
TOTAL POSSIBLE	28

In the review, the TOSRA scored 19 out of a possible score of 28. This score ranked the TOSRA second in the category. The highest rank in the multiple category was an instrument by Rennie (1986) with a score of 21. The highest score in any category was 23 for an instrument by Germann (1988). Although the Rennie and Germann instruments scored higher than the TOSRA, neither instrument suited this study. Rennie's instrument was designed for a longitudinal study where students reflected on past performance and expected future performance and was not appropriate for this study. Germann's instrument was designed to determine a general attitude toward science and not ideally suited to the study. The TOSRA had the advantage of being flexible and can be tailored to suit a particular purpose.

It can be concluded from this review that the TOSRA is a robust instrument for testing science related attitudes. After rigorous trials in Australia and the United States the TOSRA proved to be internally consistent with cross-cultural and discriminate validity (LaForgia, 1988). A recent use of the TOSRA in the U.S.A. (Welch, 2010) was made

using sample sizes ($n = 25$) similar to this study and gave a Cronbach's alpha coefficient of 0.97 which is consistent with values quoted in the TOSRA handbook (Fraser, 1981, p.5).

The choice of TOSRA is consistent with the recommended uses stated in the handbook:

...a teacher might employ TOSRA to obtain information about the science-related attitudes of individual students or, preferably, whole classes. This could be done at one particular time or could involve changes in attitude occurring over time. (Fraser, 1981, p. 6)

2.8 Classroom Test of Scientific Reasoning (LCTSR).

In order to determine a general Piagetian developmental level of Year 6 PEAC students, a version of Lawson's Classroom Test of Scientific Reasoning (LCTSR) was used. It was considered that this information would be valuable in interpreting the results of the research. For example, was a hypothetical-deductive learning cycle appropriate for the developmental level of Year 6 PEAC students? If it was not, this should be kept in mind when interpreting results.

The LCTSR was developed to provide a reliable and valid classroom test to determine a student's developmental level. Prior to the test's development, developmental levels were determined by individually administered Piagetian tasks. These were time consuming and required experienced interviewers and therefore were not suitable for group situations. A format was designed where the administrator demonstrated a situation, asked a question and students answered in their own test booklet. The questions and a range of possible answers were included in the test booklet. Students needed to tick the correct alternative and write a reason for their choice. The test contained 15 items which required the students to be able to demonstrate an understanding of isolation and control of variables, combinational reasoning and proportional thinking (Lawson, 1978).

The LCTSR evolved into a 'paper and pencil' multiple-choice format of 24 items. In this version the reason for the choice of an answer is treated as a separate question, hence the 24 items. This version appears to be widely used in research such as that by Bao et al. (2009) in a study comparing learning and scientific reasoning in U.S. and Chinese students. The multiple choice version, however, was considered too difficult

for Year 6 PEAC students. Questions 21 to 24 for example were considered too 'wordy'. A modified paper version of the original test was used in this study. This version consisted of 12 items, most of which were two-tiered questions with the first tier being multiple-choice and the second tier being a written or created response as a reason for the first tier choice. The scale used to estimate the developmental level of the research participants was that stated by Lawson in his book *Science Teaching and the development of thinking*: 0-4 Empirical-inductive; 5-8 Transitional; 9-12 Hypothetical-deductive (Lawson, 1995, p. 445).

2.9 Chapter Summary

The aim of Chapter 2 was firstly to review the literature relevant to Giftedness, Inquiry Learning and Learning Cycles; and secondly to review the literature relevant to the testing instruments used in the research, that is, the concept mapping task, the two-tiered multiple choice test, the attitude questionnaire (TOSRA) and Lawson's Classroom Test of Scientific Reasoning (LCTSR).

Giftedness. Giftedness, for the purposes of this research, was defined in terms of Gagne's (2008) Differential Model of Giftedness and Talent (DMGT). It was appropriate to choose this model as it is the model accepted by the Western Australian Department of Education (DoE) under which this research was conducted. The DMGT was found to have similarities with models described by Subotnik (2011) and Renzulli and Reis (1997). General indicators of giftedness were discussed and compared to indicators of giftedness in science. The literature indicated a consistency between the indicators of general giftedness and giftedness in science.

Identifying giftedness. A range of assessments are required to identify a gifted child. These assessments may include school-based tests, standardized tests, peer and parent information, and self-reflection. The subjects for this research were identified by the use of standardized tests.

Gifted child pedagogy. There is no specific pedagogy for the gifted child, but rather a range of strategies that can be used (Kaplan, 2003). With respect to science pedagogy for the gifted child, Watters (2004) describes three issues that should be considered: the process of science; established principles of differentiation for the gifted in a science context; and the use of open inquiry.

Gifted and talented programs. A review of gifted and talented programs in Australia revealed a history of neglect for teacher training in gifted and talented education (GATE). This research is significant in that it provides a relatively simple strategy for teaching science to gifted primary students and addresses the three issues described by Watters.

Learning Cycles. Learning cycles have their origins in primary science and are an appropriate intervention strategy for use in this research. They are primarily based on Piaget's model of mental functioning and are supported by other learning theories such as social constructivism, meaningful learning, and conceptual change. The effectiveness of two learning cycle models described by Lawson (1995), a descriptive learning cycle (DLC), and a hypothetical-deductive learning cycle (HDLC), were used in this research.

Inquiry Learning. Inquiry learning was described as a continuum ranging from teacher-directed instruction to student-led inquiry learning. The degree of inquiry depends on the amount of scaffolding given by the teacher. Many authors agree that some degree of scaffolding is required for inquiry learning, particularly with primary age students. The effectiveness of inquiry learning is dependent on many factors such as the degree of scaffolding, the developmental level of the students, the age of the student, and prior knowledge. Most proponents of inquiry learning favour structured guidance with hands-on and mind-on experiences. It appears that scaffolding or guidance is critical to inquiry learning. This conclusion supports the use of learning cycles in this research, because learning cycles can be classified as a form of guided inquiry.

Research Instruments. Concept mapping was chosen as an assessment strategy due to its ability to ascertain both the depth and the structure of a student's knowledge. Various types of mapping tasks are described in the literature, ranging from open-ended tasks to guided or constrained tasks. A constrained task, where students *are* given the concepts and linking phrases then asked to link them on a map, was chosen for this research. This type of concept mapping task was chosen due to the age of the students and their unfamiliarity with the subject (electronics). The literature argues that the scoring of concept maps is one of the biggest problems associated with them. Two methods of scoring were used: the first described by Yin et al. (2005) which

emphasised the number of correct concepts; the second described by Miller et al. (2009) that emphasised map structure and hence map quality. Using two methods enabled a correlation to be made to help determine reliability.

A multiple choice-explanation multiple choice (MC-EMC) was chosen to measure conceptual acquisition and application because it combined the advantages of simple multiple choice questions and creative response questions. A better assessment of the student's depth of understanding is possible.

Attitudinal change as a result of using learning cycles was measured by using two scales of the TOSRA; Enjoyment of science lessons and Attitude to scientific inquiry. The literature indicates that the TOSRA is widely used giving consistent and reliable results, and was ranked second in a review of multiple category attitude questionnaires (Blalock et al., 2008).

Lawson's Classroom Test of Scientific Reasoning (LCTSR) was used to determine the Piagetian developmental level of Year 6 PEAC students. It was considered valuable to know the developmental level of Year 6 PEAC students to enable a meaningful interpretation of the results of the research. An early version of the test consisting of 12 items was used because it was considered more suitable for primary age students.

CHAPTER 3 Methodology

3.1 Introduction

The methodology is structured in six sections: Section 3.2, Research Questions; Section 3.3, Research design; Section 3.4, Intervention curriculum and subjects; Section 3.5, Research instruments; Section 3.6, Teacher as the researcher; and Section 3.7, Ethics and data Storage.

3.2 Research Questions

The purpose of this study was to investigate the effectiveness of a three phase learning cycle as a suitable model for teaching PEAC science courses and to compare two different types of learning cycles to determine the most effective with respect to bringing about conceptual growth in gifted Year 6 students. The study also investigates the effectiveness of learning cycles in changing the students' enjoyment of science lessons and their attitude towards scientific inquiry. As mentioned in Chapter 1, Section 1.5, the research questions fall into two groups: Questions 1, 3, and 5 are concerned with the general effectiveness of a three phase learning cycle; and Questions 2, 4 and 6 are concerned with the difference in effectiveness between two types of learning cycle. The following research questions are addressed:

Research Question 1:

Is a three phase learning cycle an effective teaching model for bringing about conceptual growth in PEAC students studying basic electronics?

Research Question 2:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in bringing about conceptual growth in PEAC students studying basic electronics?

Research Question 3:

Does a three phase learning cycle change PEAC students' attitude toward scientific inquiry?

Research Question 4:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing PEAC students' attitude toward scientific inquiry?

Research Question 5:

Does a three phase learning cycle change PEAC students' enjoyment of science lessons?

Research Question 6:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing PEAC students' enjoyment of science lessons?

3.3 Research Design**3.3.1 Selection of a research design**

A post-positive paradigm approach to the study was used in the initial stages of planning for this research. Post-positive research can be used to systematically and objectively collect empirical data to compare different teaching strategies. Post-positivists endeavour to use formal research designs that provide data that logically and self-evidently explain the educational phenomenon being studied (Treagust, Won, & Duit, 2014). This research planned to collect empirical quantitative data, using a pre- and post-test procedure, to objectively compare the effectiveness of two different forms of a learning cycle. This is consistent with an example cited by Treagust et al. (2014, p. 4) of a study by Ryoo and Linn (2012), which looked at a new teaching method and its effectiveness on student achievement, using a pre- and post-test procedure.

3.3.2 Design of the research

The research compared the effectiveness of two teaching-learning models (learning cycles) in a quasi-experimental design. A quasi-experimental design with a pre-test/post-test procedure was chosen to investigate causality between the intervention (the type of learning cycle) and the desired outcomes of the PEAC Electronics course. Each type of teaching-learning model was taught to a separate but equivalent group of students. The student groups were determined by the school timetable rather than being chosen randomly thus making the design quasi-experimental. The selection process is discussed later in the chapter.

3.3.3 Research Method

Within the quasi-experimental design, both quantitative and qualitative data were collected. With respect to quantitative data in the cognitive domain, the research used two instruments, a two-tiered multiple-choice test and a concept-mapping task. These instruments assessed aspects such as concept acquisition and conceptual change. An attitude questionnaire was used to assess attitudinal change in the students, an aspect of the affective domain. Each instrument was given to the students before the commencement of the instruction treatment as a pre-test, and again at the completion of the course as a post-test.

The qualitative data used were based on the teacher reflections and recorded lessons. The research examined the dynamic relationship between the teacher and the students to best understand the outcomes of the research treatments (teaching strategies) used. The data included specific strategies such as analogies and problem solving tasks used in the lessons to present specific concepts to the students. An overview of the research design and methodology is summarized in Figure 3.1

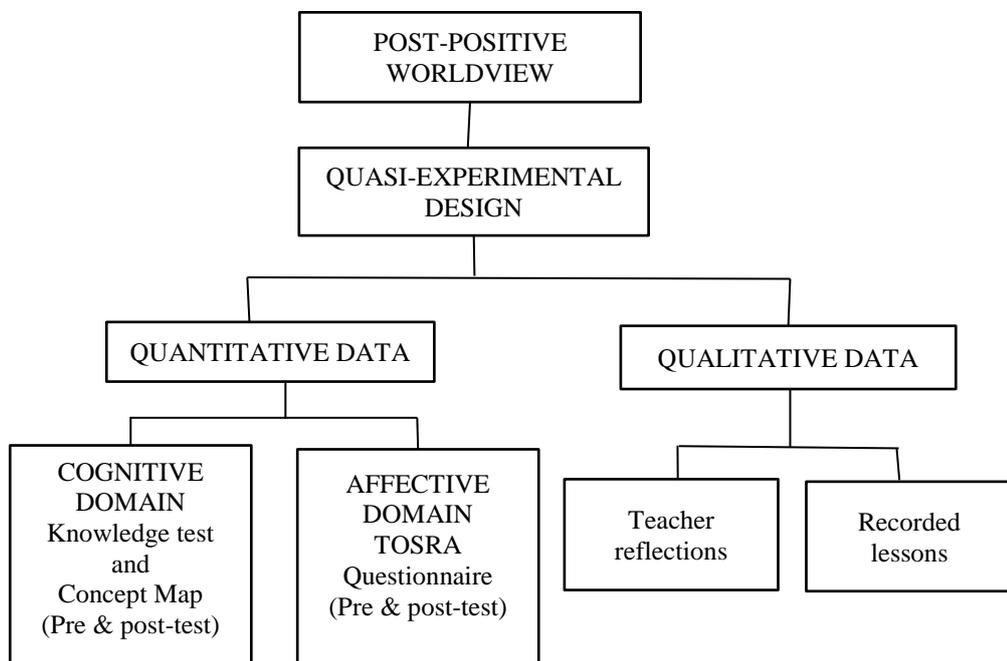


Figure 3. 1 Overview of research design and methodology.
(Marek and Cavallo, 1997, p. 77).

3.3.4 Research Constraints

As mentioned in the previous section, several practical constraints reduced the potential scope of this study. However it was considered important to keep the research in the exact context and constraints of the school program (PEAC). One of the aims of this research was to provide teachers, working within the PEAC program, with a simple, effective and efficient teaching model. The constraints imposed on this research as a result of being conducted within the PEAC program were:

Class contact time. As mentioned previously, the course was limited to 20 hours, and in some cases 18 hours, of student contact time. Two to three hours of this time was used for pre- and post- testing.

Restricted access to students. The teacher had no access to students outside the course's allocated lesson times. Students returned to their respective schools immediately after the lesson. Consequently, student interviews for example, were not possible.

Frequency of classes. There was only three Electronics classes each year. This reduced the scope for developing and trialling research instruments. Four classes were used for trials and six classes for the study data. The ten classes spanned a period from Term 1, 2011 to Term 1, 2014.

Age of students. Initially most classes consisted of a mix of Year 5, Year 6 and Year 7 students, typically of ages 10, 11, and 12 respectively. The ratio of Year groups varied according to the term. Term 1 contained no Year 5 students and Term 3 contained no Year 7 students, and as already mentioned Year 7 students are now considered secondary students. The only consistent age group was Year 6. Consequently, this study concentrates on Year 6 students. A balance of Year 6 students for each treatment was possible, however the sample sizes were small.

3.4 Intervention curriculum and participants

3.4.1 Learning cycles for PEAC Electronics

The learning cycle as a basis for lesson structure has been chosen for this study because it can be demonstrated that it incorporates many aspects of various learning theories discussed in the previous sections. Also research has established that three functions are needed for an instructional strategy to be effective. These functions are to 1. explore and identify a pattern (*exploration*) 2. discuss the pattern and introduce terms

to describe the pattern (*concept development*), and 3. apply the concept in a new situation (*concept application*) (Renner, Abraham, & Birnie, 1988).

These functions can be used to create learning cycles in two basic ways by changing the order of the first two functions. An inductive sequence would be *explore, concept development, and concept application*. A deductive sequence would be *concept development, explore, and concept application*. The latter is a very common approach to teaching. An inductive learning cycle is effective because it uses all three of these functions and in a sequence that better stimulates thinking. The sequence of *explore, concept development and concept application* (an inductive sequence) has been found to be more effective than the sequence *concept development, explore, and concept application* (a deductive sequence) when learning new concepts (Abraham & Renner, 1986).

The learning cycle was further refined by Lawson in his *book Science teaching and the development of thinking* (Lawson, 1995). It is these learning cycles that will be used in the research. Lawson developed three types of learning cycles: *descriptive, empirical-abductive, and hypothetical-deductive*. Each type maintains the three basic phases of *exploration, term introduction, and concept application* but the level of thinking required by the student varies. A summary of the types is:

Descriptive learning cycles (Lawson, 1995, p.140)

- a. The teacher identifies the concept(s) to be taught.
- b. The teacher identifies some phenomenon that involves the pattern on which the concept is based.
- c. *Exploration phase*: The students explore the phenomenon and attempt to discover and describe the pattern.
- d. *Term introduction phase*: The students report their data, and they or their teacher describe the pattern; the teacher then introduces a term or terms to refer to the pattern.
- e. *Concept application phase*: Additional phenomena are discussed or explored that involve the same concept.

Empirical-Abductive learning cycles (Lawson, 1995, p.140)

- a. The teacher identifies concept(s) to be taught.
- b. The teacher identifies some phenomenon that involves the pattern on which the concepts are based.
- c. *Exploration phase*: The teacher or students ask a descriptive question.
- d. Students gather data to answer descriptive question.
- e. Data to answer the descriptive question are displayed on the board.
- f. The descriptive question answered, and the causal question is raised.
- g. Alternative hypotheses are advanced to answer the causal question, and the already gathered data are examined to allow an initial test of the alternatives.
- h. *Term introduction phase*: Terms are introduced that relate to the explored phenomenon and to the most likely hypothesised explanation.
- i. *Concept application phase*: Additional phenomenon are discussed or explored that involve the same concepts.

Hypothetical-Deductive learning cycles (Lawson, 1995, p.141)

- a. The teacher identifies the concept(s) to be taught.
- b. The teacher identifies some phenomenon that involves the pattern on which the concept is based.
- c. *Exploration phase*: The students explore a phenomenon that raises a causal question, or the teacher raises the causal question.
- d. In class discussion, hypotheses are advanced, and either students are told to work in groups to deduce implications and design experiments or this step is done in class discussion.
- e. The students conduct the experiments.
- f. *Term introduction phase*: Data are compared and analysed, terms are introduced, and conclusions are drawn.
- g. *Concept application phase*: Additional phenomena are discussed or explored that involve the same concept.

These three learning cycles are compared in Table 3.1. The Descriptive Learning Cycle (DLC) does not ask descriptive or causal questions of the students. Such questions that may arise in a student's mind are answered by the teacher. In the Empirical-Abductive Learning Cycle (EALC) descriptive questions are asked and

student data and observations are used to answer the questions. Teacher input can be made at this point. In the Hypothetical-Deductive Learning Cycle (HDLC) causal questions are asked and hypotheses are advanced to explain the phenomena. Students are then asked to design experiments to test the hypotheses. Conclusions are drawn after analysis of the experimental data.

The DLC and a combination of both the EALC and HDLC have been chosen as the instructional models for use in this research. A combination of the latter two cycles was decided upon because it was not always suitable or appropriate to use a HDLC. For example, in the lesson examining the function of a switch as a device for breaking the continuity of a simple circuit, an EALC was more appropriate for such a simple concept. However a HDLC was mostly used and for ease of reporting in this study the non-DLC lessons will be referred to as HDLC lessons.

Table 3. 1 Similarities and difference between the descriptive, empirical-abductive, and hypothetical-deductive learning cycles.

Learning Cycle Feature	Descriptive	Empirical-Abductive	Hypothetical-Deductive
Teacher identifies concept	✓	✓	✓
Teacher identifies related phenomena	✓	✓	✓
Students explore phenomenon and make observations	✓	✓	✓
Students collect and report data	✓	✓	✓
Descriptive questions asked	x	✓	x
Data used to answer descriptive questions	x	✓	x
Causal questions asked	x	✓	✓
Hypotheses advanced to answer causal questions	x	✓	✓
Students design experiments to test hypotheses	x	x	✓
Students conduct experiments	x	x	✓
Teacher introduces related terms	✓	✓	✓
Conclusions to experiments drawn	x	x	✓
Additional phenomena discussed that involve same concept	✓	✓	✓

In this research the name of the second phase, *term introduction* has been changed to *concept development* because it was considered that it was more meaningful to the students because it is in this stage that observations and the concepts being explored are explained.

In conjunction with Lawson’s learning cycle models, the PEAC learning cycles were based on the design principles of Marek and Cavallo (1997) because their design was focussed mainly on elementary or primary school science. Using the two designs created a good balance – Lawson’s design gave the overall level of learning cycle (descriptive or hypothetical-deductive) and Marek and Cavallo’s design gave the fine structure such as the learning experiences to be used. When modifying these learning cycles for developing a PEAC course in basic electronics, design features such as the six essential experiences of science, namely, observing, measuring, interpreting, experimenting, model building and predicting, were incorporated where possible. When incorporating essential experiences into a learning cycle, the sequence is important. For example the science process starts with observing and measuring, then the data are interpreted and possibly displayed in some way. Further experiments may be designed to test hypotheses. The processes can then be applied to a new situation in the concept application phase. This sequence basically follows the culture of science (social constructivism) and the design fits well with Ausubel’s meaningful learning model (Marek & Cavallo, 1997). Each process may not be given equal emphasise in every lesson. However the sequence will remain the same. Different lessons can be designed to emphasis different processes. Examples of the six essential experiences of science as incorporated in the PEAC Electronics course are shown in Table 3.2 and Figure 3.2.

Table 3. 2 The six essential experiences of science and the PEAC Electronics course.

Essential experience of science	Examples in PEAC Electronics
Observing	Recording circuit observations during the exploration phase.
Measuring	Measuring voltage, current and resistance using meters.
Interpreting	Interpreting observations to explain phenomena.
Experimenting	Testing hypotheses regarding current resistance and voltage.
Model building	Use of analogies (mental); explaining observations in own words.
Predicting	Predicting current when voltage is increased.

Rowley (2008) stated that research had identified 12 instructional categories used by teachers trained in gifted education that were demonstrated to be successful. These categories are stated in Table 3.1. A major purpose of the research in this study is to investigate whether or not a three phase learning cycle is an effective instructional model for teaching gifted and talented students (GATS), therefore it was considered appropriate to ascertain the degree to which these categories were present in the learning cycle.

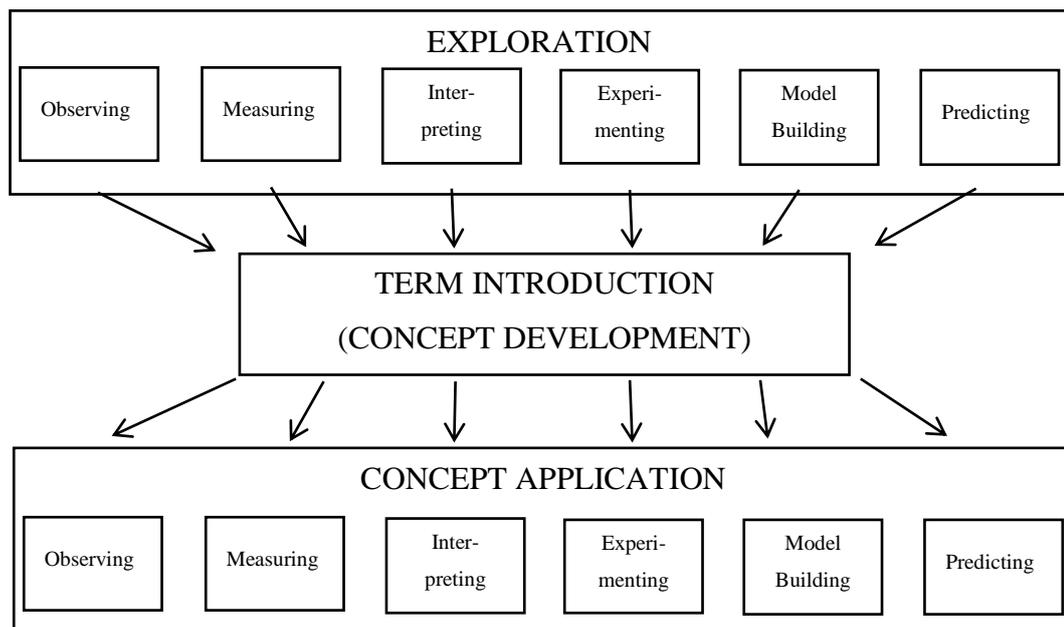


Figure 3. 2 The processes of science as applied to each phase of the learning cycle. (adapted from Marek & Cavallo, 1997, p. 77)

It should be noted that a particular lesson or a short course such as PEAC Electronics would not be expected to cover all these categories, however as shown in Table 3.1 many categories are present. The degree of representation of each instructional category in the descriptive learning cycle (DLC) and the hypothetical-deductive learning cycle (HDLC) as applied in the PEAC Electronics Course is shown as: Strongly represented - 3; Moderately represented - 2; and Limited or no representation - 1.

Tables 3.1 and 3.2, and Figure 3.2 indicate that the learning cycle as a teaching/learning model is well suited for satisfying the essential categories of GATS education and essential science experiences. The only exceptions were creativity and

goal setting as instructional methods which were not included due to the nature of the electronics course rather than being a limitation of the learning cycle model.

Table 3. 3 Successful instructional categories for GATS compared to the learning cycle.

Instructional Strategy for GATS (Rowley, 2008)	Learning Cycle – Presence of GATS Instructional strategies
Curriculum should be broad and concept related.	Electronics course is concept oriented and in the context of electronic projects. (DLC 3; HDLC 3)
Effective communication skills	Teacher/student discussion following exploration to explain phenomena; use of analogies. (DLC 3; HDLC 3)
High motivational tasks	Project aspect is task oriented and highly motivating; students enjoy psychomotor aspect. (DLC 3; HDLC 3)
Students encouraged to build their own conceptual constructs – appropriate pacing required	Individual pace is possible in exploration; hypothesis setting allows students to build own constructs. (DLC 2; HDLC 3)
Self-determination of activities	Projects allow for self-determination – students work at their own pace; some tasks completed at home. (DLC 3; HDLC 3)
Variety of learning experiences	Hands-on activities, small group discussion, whole group discussion. (DLC 2; HDLC 2)
Teacher-student interaction to promote group learning and problem solving	Students always worked in pairs; all activities were student centred; teacher scaffolding when necessary. (DLC 2; HDLC 2)
Student goal setting	Very limited due to nature of course. (DLC 1; HDLC 1)
Emphasis on higher level thinking	Higher level thinking required in interpretation of observations and hypothesis setting. (DLC 2; HDLC 3)
Emphasis on creativity	Creativity was not a strong aspect due to the nature of the course. (DLC 1; HDLC 1)
Teacher planning to be flexible and student centred	DLC required normal science lesson preparation; HDLC required more equipment availability for hypothesis testing. (DLC 2; HDLC 3)
Teaching/learning aids to be appropriate, clear and varied.	Appropriate and reliable equipment available; some specialised teaching aids required. (DLC 3; HDLC 3)

3.4.2 Intervention curriculum content

The PEAC (Primary Extension and Challenge) Electronics course consists of eight formal lessons embedded in a project-based course of 20 hours. An electronics course, previously developed by the researcher, had been operating for several years within the PEAC extension program for gifted students prior to this research. It seemed an ideal course to trial teaching strategies because it could introduce concepts unfamiliar to most students of primary school age. The course was modified for this research using a program development model created by the researcher in a study of the curriculum planning ability of secondary science teachers (Lake, 1990). The model is summarized in Figure 3.3.

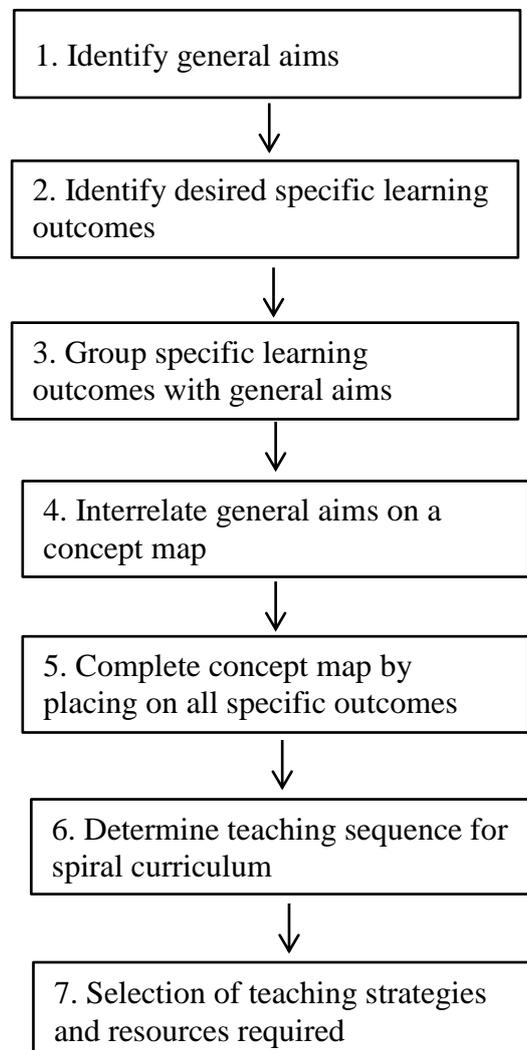


Figure 3. 3 Program development model used to develop the PEAC Electronics course.

The formal lessons were modified into two forms of learning cycles for use in this research which are discussed later in Section 3.4.1. The characteristics of gifted students discussed in Chapter 2 were kept in mind when modifying the lessons. For example, the lesson design ensured that learning tasks enabled students to explore electronic phenomena in an independent manner; very little repetition was used; new concepts acquired could be used in the next lesson; and there was no attempt to simplify the language specific to electronics.

There were four general aims of PEAC Electronics: firstly, to provide a learning environment within which students can develop psychomotor skills associated with the construction of simple electronic circuits; secondly, to provide a learning environment within which students can learn and apply the basic concepts of voltage, current and resistance within the context of a simple direct current electronic circuit; thirdly, to enable students to develop their science process skills; and finally, to provide an engaging learning environment to enhance the attitude of the students towards electronics and enjoyment of science lessons. The specific student outcomes can be found in Appendix A. Generally because a PEAC course only lasts for 20 hours, the subjects offered are quite small in their scope and are conducted in a variety of venues.

The concept map created in Step 5 of Figure 3.3 was created by two experienced physics teachers by consensus as a true representation of the course. It is shown in Appendix B and was used as the ‘expert map’ on which student maps were compared. With regard to Step 6 of the teaching sequence, it was decided to start with the least difficult concept – the concept of resistance. Table 3.4 is a summary of Step 6 (teaching sequence) and Step 7 (selection of resources). The teaching strategies in all lessons were the three phase learning cycle.

The sequence of each lesson was carefully considered so that the concept acquired in one lesson becomes essential knowledge for the next. Such a sequence establishes a spiral learning cycle. The project aspect of the course covered circuit construction and fault finding. During the course students were given the opportunity to complete up to six projects. Each project was designed to complement the key concepts and to develop the students’ psychomotor skills. The projects also served the important role of being a motivating factor to maintain interest in the course. The table of specific

student outcomes for the electronics course can be found in Appendix A PEAC Electronics Student Outcomes.

Table 3. 4 Teaching sequence and resources for the PEAC Electronics course.

Lesson	Resources
1. Electrical Circuits	Students use laboratory equipment to construct a simple circuit to include a globe and dry cell battery pack (6V); worksheets.
2. The Switch	As for Lesson 1; switch; worksheets.
3. Resistance and Short Circuits	As for Lesson 1; 2 globes; 5 ohm and 20 ohm laboratory resistors; switch; worksheets.
4. Resistor Code	Resistor code handout, sets of miniature four band resistors; worksheets.
5. Electrical Current	As for Lesson 3; D.C.; ammeter; worksheets.
6. Electrical Voltage	As for Lesson 5; extra dry cell battery pack; worksheets.
7. Diodes	As for Lesson 1; PCB mounted power diodes and LEDs; worksheets.
8. Transistors	As for Lesson 1; PCB mounted transistors; worksheets.

3.4.3 Lesson structure

Each lesson used a carefully scripted and guided worksheet. This gave the students a record of the lesson and ensured uniformity of instruction. Uniformity of instruction was essential for two reasons. Firstly each learning cycle was repeated three times and secondly the same teacher conducted both types of learning cycle. By having carefully scripted lessons the variable of teacher bias was largely controlled. This is also consistent with Kirschner et al.'s (2006) suggestion that process worksheets provide a valuable form of scaffolding to reduce cognitive load for novice learners.

Each lesson in both types of learning cycle had the same three-phase learning cycle structure:

Concept Exploration Phase. During this phase students were given laboratory electronics equipment and asked to construct a circuit to use to explore the particular concept. This is a 'hands-on' phase. In the case of the hypothetical-deductive cycle, hypotheses were generated and experiments designed to test the hypotheses.

Concept Development Phase. Phenomena experienced in the exploration phase are reported, attempts are made to give reasons, and terminology is introduced.

Concept Application Phase. Additional phenomena are discussed that involve the same concept and application tasks given to the students. The projects became an ideal concept application.

The lessons were structured in two forms – A descriptive learning cycle (DLC), and a hypothetical-deductive learning cycle (HDLC) as described in Chapter 2. Lesson 3 is used as an example of a typical lesson and how it follows the structure described by Lawson (1995, p. 145). In this lesson, students construct a simple circuit with one globe, a switch and a battery pack power supply. They use a circuit similar to previous lessons and are guided through a series of steps and make observations as they proceed. The structures of a descriptive learning cycle and a hypothetical learning cycle and how they were adapted for teaching electronics are key aspects of this research. Consequently the structure of a sample lesson in its two different forms is discussed in detail. Work sheets for some other lessons can be found in Appendix C. In the following description of *Lesson 3 – Resistance and Short Circuits*, sections in italics are descriptions of the respective learning cycles as described by Lawson (1995) and normal text describes how the electronics lesson follows the learning cycle structure. The discussion is centred on the student worksheet. A descriptive learning cycle is discussed first.

Lesson 3 – Resistance and Short Circuits

Descriptive Learning Cycle (Lawson, 1995, p. 140)

- (a) *The teacher identifies the concepts to be taught.*
- (b) *The teacher identifies some phenomenon that involves the pattern on which the concept is based.*

Steps (a) and (b) are dealt with verbally as an introduction to the lesson. The teacher gives examples of a volume control on a radio and a light dimmer and asks the students if they know how they work.

- (c) ***Exploration phase:*** *The students explore the phenomenon and attempt to discover and describe any pattern.*

No causal questions are raised in the exploration phase of the DLC. However by recording their observations the students are describing a pattern. The teacher may ask the class if they noticed that the light became dimmer. In each lesson of the course students are asked to draw a circuit diagram. In Lesson 1 students sketched the equipment used. These sketches in later lessons were replaced with circuit symbols to make a circuit diagram. In the DLC the students are given the symbols to use and are instructed on the whiteboard by the teacher on how to use them.

LESSON 3 – RESISTANCE

CONCEPT EXPLORATION

Task 1: Set up a simple circuit with one globe and a switch. Note the brightness of the globe and record your observation.

Observation: _____

Add a 5 ohm resistor to the circuit and note the brightness of the globe.

Observation: _____

Is there a change in the brightness of the globe? _____

Draw a diagram of your circuit in the space below, using the circuit symbols shown.



Task 2: Replace the 5 ohm resistor with a 20 ohm resistor. Record the brightness of the globe.

Observation: _____

Is there a change in the brightness of the globe compared to Task 1? _____

(d) **Term Introduction (Concept Development):** *The students report their data, and they or their teacher describe the pattern; the teacher then introduces a term to refer to the pattern.*

CONCEPT DEVELOPMENT

Is there a relationship between the size of the resistor (or resistance) and the brightness of the globe in the circuit of Task 1 and Task 2? _____

What is the relationship?

New Terms

1. Electrical resistance is

2. An ohm is

The questions in this phase are first asked by the teacher and answered verbally by the students. Then after discussion by the teacher, the students write the answer given by the teacher into their worksheets. If appropriate, analogies can be used at this stage by the teacher to explain any concepts being developed. The teacher gives the definition, on the white board, of the new terms for the students to write in their worksheets. This aspect of the DLC is didactic in nature.

(e) **Concept application phase:** *Additional phenomena are discussed or explored that involve the same concept.*

In this phase the concept of resistance is extended to demonstrate the effect of very low resistance. Introducing the concept of a short circuit does this. At this early stage of introducing electrical concepts there is no attempt to make measurements of current. The effect of resistance on the brightness of the globe is the key observation. The concept of current and its measurement is dealt with in a later lesson. The ‘rule of

thumb' given above will be used by students in the project aspect of their course when looking for circuit faults such as too much solder causing a short circuit.

CONCEPT APPLICATION

Replace the 20 ohm resistor with another globe. Switch on the circuit and record your observation.

Observation: _____

Connect a spare lead from one side of a globe to the other and switch on the circuit again. Record your observation.

Observation: _____

What do you think happened?

What you have observed is a **short circuit**.

A **short circuit** is _____

Electrical 'rule of thumb':

Electricity takes the path of least resistance.

Hypothetical-deductive learning cycle (Lawson, 1995, p.141).

- (a) *The teacher identifies the concepts to be taught.*
- (b) *The teacher identifies some phenomenon that involves the pattern on which the concept is based.*

This aspect of the HDLC is the same as for the descriptive learning cycle in that it is a verbal introduction of the topic.

- (c) **Exploration phase:** *The students explore a phenomenon that raises a causal question, or the teacher raises the causal question.*
- (d) *In class discussion, hypotheses are advanced, and either students are told to work in groups to deduce implications and design an experiment or this step is done in class discussion.*
- (e) *The students conduct the experiment.*

LESSON 3 RESISTANCE

CONCEPT EXPLORATION

Set up a simple circuit with one globe and a switch. Note the brightness of the globe and record your observation.

Observation: _____

Add a 5 ohm resistor to the circuit and note the brightness of the globe.

Observation: _____

Is there a change in the brightness of the globe? _____

Discuss with your partner a possible reason for any change in the brightness and record your answer.

With the help of your partner design another experiment you could conduct to support your idea above

Draw a circuit diagram in the space below, using circuit symbols, of your planned experiment. Your teacher will give you a sheet of circuit symbols from which you can choose the correct symbol.

Modify your circuit to test your idea (hypothesis) as to why a resistor might change the brightness of a globe in a circuit.

Observation: _____

In the HDLC students are asked to discuss their ideas with their partner before writing an answer. Students must attempt an explanation of a phenomenon before recording it. After writing a possible explanation for their observation, students then design and conduct an experiment to test their idea or hypothesis. The teacher checks with each group to determine if the experiment is practical. Suggestions by the teacher may be made if necessary.

(f) **Term introduction phase (Concept Development):** Data are compared and analysed, terms are introduced, and conclusions are drawn.

CONCEPT DEVELOPMENT

From your observations can you say there is a relationship between the size of the resistance and the brightness of the globe? _____

What is the relationship?

New Terms

At home, research the meanings of the two terms below and complete the statements.

1. Electrical resistance is _____

and is caused by _____

2. An ohm is

In the HDLC students are given a brief verbal explanation of terms such as resistance and then asked to research the new terms for homework. Their responses to the homework are discussed in the next lesson. This discussion forms a link with the next lesson, thus creating a spiral curriculum.

Concept application phase: Additional phenomena are discussed or explored that involve the same concept.

CONCEPT APPLICATION

Replace the 20 ohm resistor with another globe. Switch on the circuit and record your observation.

Observation: _____

Connect a spare lead from one side of one globe to the other and switch on the circuit again. Record your observation.

Observation: _____

Discuss with your partner a possible reason for your observation above.

What you have observed is a [**short circuit**]. (*To be added after class discussion*)

Electrical ‘rule of thumb’: [**Electricity takes the path of least resistance**]. (*To be added after class discussion*)

In the HDLC the teacher attempts to elicit the correct answer from the class by questioning. Students are asked to discuss a possible reason with their partners before answering. This can be a fairly long process compared to the DLC where the students are given the correct answer quite quickly. Similarly, when a student’s project circuit did not function properly, due to too much solder making a short circuit for example, DLC students were told of the problem and told how to fix it. HDLC students were initially told to go back to their workstation and use a checklist to ascertain the problem for themselves and come back to the teacher with a strategy for fixing it. If this failed they were then given the solution.

It is important to note at this stage that some concepts are not suited to a particular type of learning cycle. For example it is not appropriate to teach the resistor colour code, a descriptive concept, using a HDLC because it is a universally recognised convention rather than a principle that can be discovered by experimentation. The HDLC students, however were given the code as a puzzle to solve from a description of the code convention. However, a theoretical concept such as the general nature of resistance,

as in Lesson 3, is ideally suited to a hypothetical-deductive approach. The nature of resistance can be ‘discovered’ from experimental data.

3.4.4 Research Participants

The participants in this research were students from the Primary Extension and Challenge (PEAC) program of the Western Australian Department of Education (DoE). As mentioned in Chapter 2, this program was a coeducational *withdrawal* extension program for gifted primary students from school Years 5, 6, and 7. The program is classified as *withdrawal* because students are withdrawn from their normal classes to attend the program, usually at another venue. Selection for participation in the PEAC program was made on the basis of the students’ scores on the TOLA (The Test of Learning Ability) and the SPM (Standard Progressive Matrices). Students need to score at least 98% on either test to be selected. After 2014, however, the program only applied to Years 5 and 6 because Year 7 students moved to secondary school, due to a change in educational policy. When students enter this program in Year 5, they remain in the program until they enter secondary school. This policy change resulted in Year 7 students leaving the PEAC program.

A typical PEAC year consists of three terms or cycles of ten weeks. The typical lesson runs for two hours. Once a week students leave their own school and go to a site offering the course they chose. The site is usually another school, but it could be a museum, zoological garden, or environmental location. The electronics course offered in this study required specialized equipment not available in a primary school and was therefore conducted at a major secondary school under full laboratory conditions. Although the school site at which the research was conducted was a relatively high socio-economic area, the students come from primary schools from a very wide range of socio-economic areas.

Prior to the commencement of a course, students are given a booklet of courses available in the PEAC program. There are many and varied courses available which include the arts, humanities, science and mathematics. From these courses the students are free to choose a course that suits their interests. The students need to choose three of these courses to make a preference list. When a course reaches its maximum of 22 students, further students wanting to do that course are allocated to their second or third choice. Courses are designed to offer curriculum material that is not found in the

normal primary curriculum. The electronics course satisfies this criterion. Because students choose a course that suits their interests they are usually highly motivated and industrious. There was a possibility that a student could have chosen the course because of previous experience with electronics, hence it was considered necessary to commence each course with a pre-test to ascertain prior knowledge. This was a factor in a few cases. As with all PEAC courses gender was not considered in the selection process and was not a factor taken into consideration in this research. All students worked in pairs in both learning cycles. Students were encouraged to collaborate at all stages of the course. This aspect worked very well.

As mentioned in Chapter 1, in order to reduce the variable of age, only Year 6 students participated in the study. Even though PEAC students operate cognitively at levels above their age peers, age is still a variable within the PEAC cohort and it was deemed necessary to control that variable. Another reason for restricting the study to Year 6 students was the fact that it was the only age group that was common to all three cycles. Cycle 1 had no Year 5 students, and Cycle 3 had no Year 7 students. This was a limitation due to the regional timetabling of the PEAC program.

The two learning cycles, the descriptive learning cycle (DLC) and the hypothetical-deductive learning (HDLC) were administered according to the timetable in Table 3.5

Table 3. 5 Timetable for administration of the DLC and the HDLC

Year	PEAC Cycle	Learning cycle
2011	3	Trial DLC
2012	1	Trial HDLC
	2	DLC
	3	HDLC
2013	1	DLC
	2	HDLC
	3	DLC
2014	1	HDLC

Each learning cycle had to be administered three times in order to achieve a suitable sample size of Year 6 students. The allocation of each type of learning cycle evenly

to Cycle 1, 2 and 3 is an attempt to control the possible maturation of the students as the year progressed. All the Year 6 students from DLC and HDLC classes respectively were combined to achieve a suitable sample size. Each learning cycle was carefully scripted so that it could be assumed that each student in the DLC or the HDLC underwent the sample intervention treatment. In the trial classes the teaching scripts, and the research instruments were tested and refined.

3.5 Research Instruments

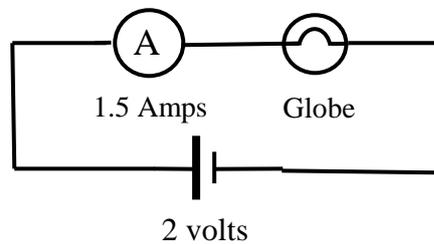
3.5.1 Knowledge Application Test

Test structure

A two-tiered multiple-choice test was used to test students' application of knowledge. The test was designed specifically for the research because the course was unique to the PEAC program. To ensure content validity the items were designed to assess the stated student outcomes of the course. The test was administered before the course as a pre-test and at the completion of the course as a post-test. The test included two items for each key objective for the purpose of using a split half method for determining reliability. A sample question is shown below:

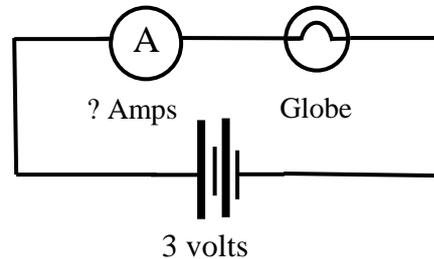
Question 3

Circuit 1.



The reading on the ammeter in the Circuit 1 is 1.5 amps.

Circuit 2.



In Circuit 2 the voltage is increased to 3 volts. Which reading below would be **closest** to the ammeter reading in Circuit 2?

- (a) 1.8 Amps
- (b) 2.0 Amps
- (c) 2.2 Amps

Choose the **best** alternative below as a reason for your above answer:

- (a) When the voltage increases, the globe will get a lot brighter because the current (Amps) increases.
- (b) The voltage increase is not enough to affect the current (Amps) or the globe's brightness.
- (c) If you increase the voltage, the current (Amps) will increase in proportion.

The test needed to suit a range of two year groups – Year 5 to Year 6. That is, the test did not contain vocabulary the students would possibly not have encounter in their education so far or in the electronics course specifically. The practice example shown in Chapter 2 Section 2.6 indicates the basic design of the test items. Students were instructed that a correct answer in the first part of a question would score 1, and another score of 1 if the correct reason was given, giving a total score of 2 for each question. No mark was given for just the correct reason. The practice example was unrelated to electronics and did not count for the total test score. A three alternative choice was decided on due to the age of the students. Initially the test was given to three experienced physics teachers to determine if the test adequately assessed the stated outcomes of the course and if there were any errors or ambiguities. Results for this trial are shown in Table 5.7, p.135. The test was then trialled with two classes – one DLC class and one HDLC class. During these trials some items were modified to ensure they were not too difficult and confusing alternatives made easier to understand.

An advantage of a MC-EMC test is the greater flexibility in scoring compared to a simple MC test. A simple MC item can only be scored correct or incorrect whereas Liu et al. offer a rubric for scoring MC-EMC items which gives credit for evidence of reasoning or knowledge integration (Linn, Lee, Tinker, Husic, & Chiu, 2006). The rubric suggested is shown in Table 3.6.

Table 3. 6 Rubric for scoring Explanation Multiple Choice items (Linn et al., 2006).

Knowledge integration level	Score
No answer or off task	0
Answer but no link	1
Partial link	2
Answer and full link	3

The four point rubric was not suitable for the knowledge test used in this research because questions where not constructed to include partial links, therefore the rubric was modified into a three point scale (0, 1 or 2). The modified rubric is shown in Table 3.7. Although this rubric does not give as much evidence of knowledge integration as that proposed by Linn et al., it does give more information than just a two point scale of correct or incorrect (0 or 1).

Table 3. 7 Scoring rubric for the Knowledge Test.

Knowledge integration level	Score
No or incorrect answer	0
Answer but incorrect reason	1
Answer and correct reason	2

For example the practice question in the test used in this study is:

Part A: A dog has very large and pointed canine teeth. This is useful for:

- (a) chasing cats
- (b) eating meat
- (c) barking

Part B: Choose the best alternative below as a reason for your above answer:

- (a) large canine teeth are good for tearing meat
- (b) large canine teeth make a loud bark
- (c) large canine teeth make a dog run fast.

The correct answers are (b) in Part A and (a) in the Part B. If a student chose both (b) and (a) the item score would be 2; if the student chose (b) in Part A but an incorrect response in Part B the score would be 1; an incorrect response in the Part A regardless of the response in Part B would score 0.

The full test can be found in Appendix D.

Reliability of the Knowledge Test

To establish a reliability coefficient for the Knowledge Test was not a simple task. Because the Cronbach's Alpha coefficient of internal consistency is based on multiple correlations between items in a test, it depends on the items being homogeneous, that is similar with respect to difficulty, mean and variance (Magnusson, 1966). The Knowledge Test does not satisfy these assumptions. The proportion of students with the correct answer to an item (p_i) varied from $p_i = 0.99$ (very easy item) to $p_i = 0.40$ (difficult item). Initial trials indicated the test had a large range of difficulties and variances between the items.

To overcome the problem of lack of homogeneity of items, a matched split-half parallel test procedure was used. The split half was made on the basis of content as this was built into the structure of the test. Because the content itself varied in

difficulty, pairing on the basis of content also created a match in difficulty in 80% of the items. Ideally the items in the test halves should be matched with regard to both content and difficulty (Magnussen, 1966, p.109). Rulon's equation was then used to determine the reliability using the two tests as split halves.

$$r_{tt} = 1 - \frac{S_d^2}{S_t^2} \quad (\text{Magnusson, 1966, p.111});$$

where:

r_{tt} = reliability of test half.

S_d^2 = variance of difference between matched items.

S_t^2 = variance of the whole test.

This coefficient however is only for one of the two test halves (5 items). Because the two test halves were selected by matching content as explained above, they can be assumed to be parallel tests. An estimate of the complete test of 10 items was made by applying the Spearman-Brown prophecy formula:

$$r_{tt_n} = \frac{nr_{tt}}{1 + (n-1)r_{tt}} \quad (\text{Magnusson, 1966, p.73});$$

where:

r_{tt_n} = reliability of increased test

r_{tt} = reliability of test half

n = factor increase of test length (in this case $n = 2$)

Neither of these two calculations were available in the SPSS package and therefore a template was developed by inserting the above two formulae into Microsoft Excel.

In addition to the reliability coefficient described above, a correlation between the total item scores for the DLC and the HDLC groups was made to indicate whether the items maintained their level of difficulty for each group. A Pearson product moment correlation using SPSS was used for this purpose.

Validity of the Knowledge Test

Content validity was established in two ways: firstly the test was constructed to evaluate key concepts taken directly from the learning cycle lessons; and secondly by giving the test to three experts (physics teachers) to complete. This was done just prior to the initial trial so that any amendments could be made.

3.5.2 Concept Mapping Task

As mentioned in Chapter 2, Section 2.5, a constrained concept mapping task was used. The concepts listed for the task were taken directly from the student outcomes stated in the course outline (Appendix A), thus ensuring content validity. All PEAC students are trained in mind mapping or concept mapping when they first enter the PEAC program. However, a training task was given to them so that the students were clearly aware of what was required in this research.

The training task was based on an unrelated theme – “Striking Sports”. The practice task is shown in Figure 3.4.

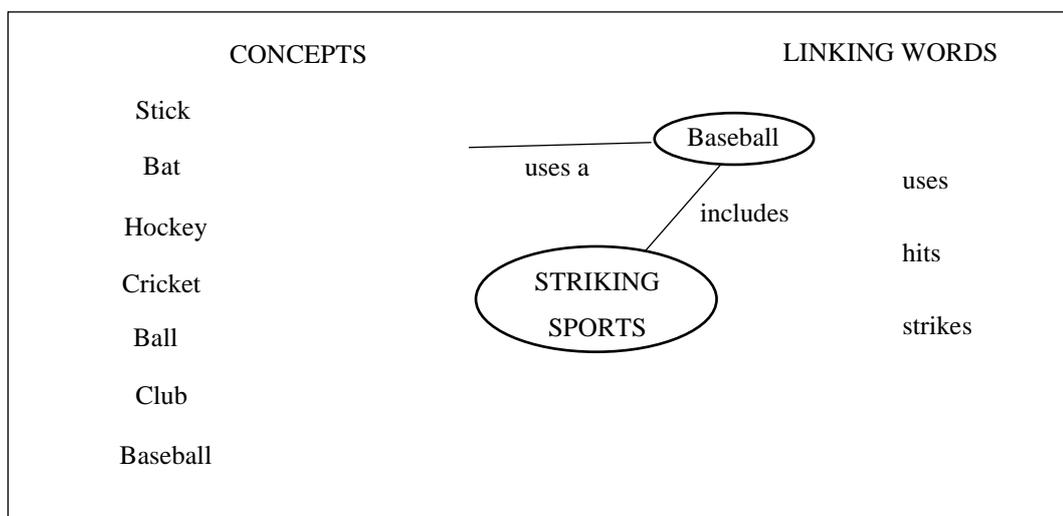


Figure 3. 4 Concept mapping practice task.

The practice concept mapping task was started so that students could see the format required. Their task was to complete the map. The practice mapping exercise was done on both the pre-test and the post-test. Ten minutes was allowed for the task. The actual concept mapping task sheet can be seen in Appendix I and a concept map completed by two experts for reference and validity check can be seen in Appendix B.

Two methods of scoring were used for the concept mapping task. The first scoring system used was that described by Yin et al. (2005). In this method all propositions were extracted from all the student maps and placed on an Excel spread sheet. The full spreadsheet can be seen in Appendix H. The list of concept propositions was given to two experts in the subject (physics teachers) who scored 1 to 5 for each proposition, with 1 being a slightly accurate proposition and five being a completely accurate proposition. An inter-rater correlation was made between the scores of the first two raters to determine reliability. A third expert from an electronics occupation was used

to mediate between scores that differed between the first two experts. For example, if Rater 1 scored a proposition as 3, and Rater 2 gave a score of 4, then Rater 3 would decide which was the most accurate and that would be used as the final score for that proposition. Each concept proposition was classified as either descriptive or theoretical. A proposition was considered descriptive if both concepts were descriptive (directly observable exemplars) and theoretical if one concept was theoretical (not directly observable exemplars). The first two raters made this determination by consensus. The propositional scores were recorded in four ways: total score for all propositions for each student; total score for descriptive propositions for each student; total score for theoretical propositions for each student; and total propositional score for each key concept. For the Yin method of scoring, a scoring template was glued onto each student's map for the initial scoring task. This template is shown in Figure 3.5.

Concept	Score
Descriptive	
Theoretical	
TOTAL	

Figure 3. 5 Scoring template for individual concept maps (Yin method).

The second method of concept map scoring was chosen because it took into consideration the structure and quality of the map rather than just the number of conceptual propositions. This method is based on a method described by Heinze-Fry and Novak (1990) and involves scoring by counting the number of linkages, the number of hierarchical levels (multiplied by 5), and the number of crosslinks (multiplied by 5). Levels and cross links form webs of relevant concepts and give an indication of cognitive structure. They indicate an understanding of relationships between different domains and help the learner relate new knowledge to existing knowledge. (Heinze-Fry & Novak, 1990). In addition to the Heinze-Fry and Novak scoring method, a quality score was made based on that described by Miller et al. (2009). A quality score of 0–10 was assigned to each map based on the rubric shown in Table 3.8. The 'Key Concepts' referred to in the rubric are for the five aspects of resistance current, voltage, units, and component function. When this rubric was

applied to the five aspects of resistance (R), voltage (V), current (I), units (U) and component function (C) the total quality score possible was 10.

Table 3. 8 Concept map quality scoring rubric.

Quality score	Quality score descriptor
0	Zero Key Concepts indicated.
1	One Key Concept indicated with development.
2	Two Key Concepts indicated with development.

For simplicity the combination of the Heinze-Fry and Novak method and the Miller quality score will be referred to as the Miller method. Miller et al. (2009) also scored links and levels but without the multipliers. A scoring template was made for the Miller scoring method and is shown in Figure 3.6.

Aspect	Count	Multiplier	Score	Quality
Links				R__ I__
Levels		x 5		V__ U__
Crosslinks		x 5		C__
		TOTALS		

Figure 3. 6 Scoring Template for individual concept maps (Miller method).

3.5.3 Classroom Test of Scientific Reasoning (LCTSR)

In order to determine the level of scientific thinking that may be expected of Year 6 PEAC students it was decided to administer the test to an independent group of such students. Permission from the author of the test was gained before the test was administered. Two sample questions are shown in Appendix E. The test could not be administered to the research groups because the test takes a minimum of 40 minutes and the class contact time constraint would not allow that. Hence two groups of 25 Year 6 PEAC students were tested at the same time and the data was recorded. The data from this test was not used directly to correlate with the learning cycle data, but rather to help in the interpretation of the results. For example, the test results should give an insight as to whether or not a hypothetical-deductive learning cycle is appropriate for Year 6 PEAC students.

3.5.4 Affective Domain

Test of Science Related Attitudes

As mentioned in Chapter 2, to evaluate attitudinal change in this study the Test of Science Related Attitudes (TOSRA) was used. Two sub-scales within the test were chosen: Subscale 3 – Enjoyment of Science Lessons and Subscale 6 – Attitude to Scientific Inquiry. . Each scale consisted of ten items with a five point Likert-type response format. The five responses being: Strongly Agree-SA, Agree-A, Not Sure-N, Disagree-D, Strongly Disagree-SD. Each scale alternated between positive items and negative items. For positive item responses SA, A, N, D, and SD are scored 5, 4, 3, 2, and 1 respectively. Negative item responses SA, A, N, D, and SD are scored 1, 2, 3, 4, and 5 respectively. Omitted and invalid responses scored 3. The question/answer sheet for the two sub-scales is shown in Appendix F. Questions for each sub-scale were alternated on the answer sheet. The TOSRA was administered as a pre-test and a post-test to ascertain any attitudinal change as a result of the two different learning cycles. The administration instructions and scoring technique recommended by the TOSRA Handbook was used (Fraser, 1981, p.9). A Cronbach's Alpha coefficient using SPSS was used to determine reliability.

3.5.5 Summary of Research Instrument Reliability and Validity

The establishment of reliability and validity of the instruments is summarized in Table 3.9

Table 3. 9 Summary of the establishment of research instrument reliability and validity.

Instrument	Research Question	Reliability	Validity
Constrained concept mapping task.	1 and 2.	Pearson 'r': between expert raters and between scoring methods (Yin and Miller).	Content validity based on course outcomes. Expert concept map.
Two-tiered multiple choice test.	1 and 2	Rulon's matched split-half and Spearman-Brown prophecy.	Content validity based on course outcomes. Test administered to experts.
TOSRA: Attitude to scientific inquiry scale.	3 and 4	Cronbach's alpha	Discriminant validity (Fraser, 1981, p. 6)
TOSRA: Enjoyment of science lessons scale.	5 and 6	Cronbach's alpha	Discriminant validity (Fraser, 1981, p. 6)

3.6 The Teacher as the Researcher

3.6.1 Teacher researcher issues

As is mentioned in Chapter 1, Section 1.7, the researcher in this study is the teacher conducting the intervention course. Teacher reflections from the administration of the intervention are used to provide qualitative data. Consequently this research has aspects common to action research. Action research is also referred to in the literature as teacher research, practitioner-based research and practitioner research. Cochran-Smith and Lytle (1990) define action research as "a systematic and intentional inquiry carried out by teachers" (p.3). Action research as a methodology in education has increased recently and grew from a need for more relevant and practical knowledge in the field. (Nolen & Vander Putten, 2007).

As stated in Chapter 1, Section 1.5 Rationale, there is a need for a specific science teaching/learning model for use with gifted primary students. Incorporating an aspect of action research in this study provided valuable qualitative data for interpretation of

the research quantitative data. Shagoury and Power (2012) state: “Teacher-researchers use their inquiries to study everything from the best way to teach reading and the most useful methods for organizing group activities to different ways girls and boys respond to science curriculum” (p. 2).

Action research or teacher research in education comes with many ethical issues. Nolen and Putten (2007) raise the following issues that need to be addressed: informed consent of the participants; protecting the confidentiality of the participants; autonomy of the participants; and ethical standards related to the discipline. All of these issues are addressed in this research and are discussed in Section 3.7 Data Collection and Analysis and Section 3.8.1 Ethical Issues.

3.6 2 Teacher reflections

The qualitative data collected consisted of a lesson journal kept by the teacher. This journal included lesson details such as analogies used, student responses, and personal reflections on various aspects of the lesson. Generally these comments were made regarding each specific phase of each lesson. The journal entries were made after each lesson as the teacher was the researcher and this made it too difficult to do during a lesson that demanded a high level of supervision and support to students. This intense support was basically due to the project nature of the course and the occupational health and safety issues associated with a course that involved hot objects such as soldering irons and dangerous chemicals such as etching acids. Chapter 5 is dedicated to these teacher reflections.

Each type of learning cycle was used three times, and after each repeat the original journal entry was reviewed and updated if necessary. One lesson was audio taped for the purpose of comparing times taken for each learning cycle. An audio transcript was made and times recorded for the different phases of the lessons. These times would indicate the relative time efficiency of each learning cycle.

3.7 Data Collection and Analysis

A normal PEAC group consisted of Years 5, 6 and 7 when this research commenced. In order to obtain a large enough group of Year 6 students, several classes had to be used for both the DLC and the HDLC interventions. The Year 6 students were extracted and combined. The respective interventions were carefully scripted to ensure firstly no teacher bias towards a particular intervention, and secondly, the same

conditions given to each class in each intervention thus enabling Year 6 scores to be aggregated.

In order to maintain student anonymity all students were assigned a student number at the beginning of the electronics course. This number was used on all assessment tasks. At no stage in this research was the identity of the student known during assessment procedures. The student number was also used to identify each student's project and project kits. All assessment tasks were administered in the classroom under full test conditions. The time allocation for the concept mapping task was 30 minutes; for the knowledge test, 20 minutes; and for the TOSRA, 10 minutes. These times were adequate for all students to complete the tasks. The data collected for each task was analyzed with respect to each research question.

A Q-Q plot was made for each data set to ascertain its degree of normality and hence whether parametric statistics would be appropriate. From these plots it was decided that the data was sufficiently normal for the use of parametric statistics. An ANCOVA was used to determine any relationships in the data, however this did not show any relationships, therefore 't' tests were used to determine the significance of the differences in the means as a consequence of the respective interventions. Effect sizes in all cases was determined using Cohen's 'd' (Cohen, 1992).

Research Question 1 concerned the effectiveness of learning cycles for bringing about conceptual growth. Conceptual growth was measured by comparing the difference between the pre and post intervention mean scores for both the concept mapping task and the knowledge test. The significance of the difference of the two means was made using a 't' test. This was done separately for each type of learning cycle.

Research Question 2 concerned which learning cycle, the descriptive learning (DLC) or the hypothetical-deductive learning cycle (HDLC), was the most effective in bringing about conceptual growth. This was investigated by testing the difference between the pre and post intervention difference means of the DLC and the HDLC by using a 't' test. Both the concept mapping task and the knowledge test were used in this analysis.

Research Question 3 was concerned with the change in attitude towards scientific inquiry as a result of the intervention. Change in attitude was determined by comparing the pre and post means of the *Attitude to Scientific Inquiry* scale of the TOSRA. The significance of the difference of the means was made using a 't' test. This was done separately for each learning cycle.

Research Question 4 investigated whether there was any difference between the DLC and the HDLC in bringing about a change in attitude towards scientific inquiry. The significance of the difference in the means of the change in attitude for each learning cycle was determined using a 't' test.

Research Question 5 was investigated in the same way as Research Question 3 but was concerned with the change in attitude towards enjoyment of science lessons as a result of the intervention. Change in attitude was determined by comparing the pre and post means of the *Enjoyment of Science Lessons* scale of the TOSRA. The significance of the difference of the means was made using a 't' test. This was done separately for each learning cycle.

Research Question 6 was investigated in the same way as Research Question 4 but was concerned with the difference between the DLC and the HDLC in bringing about a change in enjoyment of science lessons. The significance of the difference in the means of the change in attitude for each learning cycle was determined using a 't' test.

Table 3. 10 Summary of data collection and analysis for each research question.

Research Question	Data Collection	Data Analysis
Research Question 1.	Constrained concept mapping task. 10 item two tiered multiple choice test.	't' test between pre and post-test means for each group (DLC and HDLC).
Research Question 2.	Constrained concept mapping task. 10 item two tiered multiple choice test.	't' test between the DLC and HDLC mean difference scores
Research Question 3.	TOSRA: <i>Attitude to Scientific Inquiry</i> scale	't' test between pre and post-test means for each group (DLC and HDLC).
Research Question 4.	TOSRA: <i>Attitude to Scientific Inquiry</i> scale	't' test between the DLC and HDLC mean difference scores
Research Question 5.	TOSRA: <i>Enjoyment of Science Lessons</i> scale	't' test between pre and post-test means for each group (DLC and HDLC).
Research Question 6.	TOSRA: <i>Enjoyment of Science Lessons</i> scale	't' test between the DLC and HDLC mean difference scores

3.8 Ethical Issues and Data Storage

3.8.1 Ethical Issues

In this research the researcher was the teacher. At the commencement of the study the teacher had five years' experience teaching gifted primary students in the PEAC program over a range of science topics. Prior to this the teacher had three years' experience teaching gifted secondary students in a secondary science extension program in a major high school. The participants were Year 5, and 6 PEAC students in a ten-week basic electronics course necessitating ethical approval from both Curtin University and the Department of Education (DoE) in Western Australia. The approval for human research with low risk was granted by Curtin University on 2nd March 2012 (Approval No. SMEC-12-12). Approval to conduct research on DoE sites was granted by the Evaluation and Accountability Director of the DoE on 27th June 2012 (Ref. D12/0412742). As the research was conducted in a school, permission was required from the Principal of the school. The Principal was advised of the nature of

the research and written permission gained. The necessary working with children clearance of the teacher was in place throughout the research period. All the documentation of these ethics matters are in Appendix E

The students and their parents/guardians were given a letter advising them of the nature of the research. Samples of the letters can be found in Appendix E. The students were also advised during the selection process for their courses that the Electronics course was part of a research project of Curtin University. Students were not allocated randomly to the Electronics course, but rather they chose to do the course from a wide selection of courses. Written permission was obtained from both the parents or guardians and the students. Participants were advised that they could withdraw at any stage. Withdrawal meant that their results would not be used for research and the student would remain as a normal participating member of the class. The Electronics course, although modified into a learning cycle format, was an existing course within the PEAC extension program and the assessment items, with the exception of the TOSRA were used for normal school reporting.

Students' names were kept anonymous for purposes of the research. All students were given a student number at the beginning of the course and this number was used in all assessments. Although the teacher/researcher knew the identity of the students during normal classes, student numbers were used during marking. No reference was made to individuals by name in the dissertation or in related publications.

3.8.2 Data Storage

Data collected were both qualitative and quantitative in nature and were stored electronically during analysis. The data will be stored on campus on the Curtin Research Drive for a period of seven years after the completion of the research and then will be destroyed. Paper copies of assessments completed by participants will be destroyed at the completion of the study.

3.9 Chapter Summary

Chapter 3 states the research questions, and describes the research design and methodology, research instruments, research subjects, intervention curriculum, and data collection and data analysis.

Research Design. The research design of this research is quasi-experimental using quantitative and qualitative data. Data was collected in both the cognitive and affective domains. The intervention was a basic course in electronics.

Research instruments. In the cognitive domain a two-tiered multiple choice test of ten items and a constrained concept mapping task was used to ascertain conceptual growth as a result of the intervention course of basic electronics. For the affective domain the TOSRA questionnaire was used to measure any change in the attitude of students with respect to their enjoyment of science lessons and their attitude towards scientific inquiry. The establishment of validity and reliability of each instrument is summarized in Table 3.9, Section 3.5.5.

Intervention curriculum. The intervention curriculum was a 20 hour project-based course in basic electronics and presented as a descriptive learning cycle and a hypothetical-deductive learning cycle.

Research subjects. The subjects in this research were gifted Year 6 students (aged 11) in the PEAC program of the Western Australian Department of Education.

Data collection and analysis. All student responses to the assessment task were collected on pencil and paper. No electronic methods were available. All students were given a student number to be used on all assessment sheets to maintain their anonymity. Data was mostly analyzed using the SPSS package, but when this was not possible data was analyzed using Microsoft Excel. A summary of data collection and analysis for each research question is given in Table 3.10, Section 3.7.

CHAPTER 4 Teacher's Journal and Reflections.

4.1 Introduction

This chapter contains my account of the implementation of two learning cycles from the teacher-researcher point of view. The account includes my reflections on the process of preparation of the course and lessons and descriptions on the implementation of the actual lessons. In writing these reflections, I have briefly repeated some aspects from other chapters in order to give continuity to the chapter and to avoid the reader needing to refer back to previous chapters.

The number of science teachers involved in the PEAC extension program in Western Australian schools is very low. The majority of teachers are primary trained and do not have a strong science background. Consequently, some courses such as the electronics course used in this study are taught by secondary teachers in secondary schools. The fact that I was teaching the only electronics course available to students meant that as the researcher I also needed to be the teacher. This provided an ideal situation to make a case study of the planning and teaching process from the teacher's point of view. My academic background was ideally suited to the planning and development of the course because I had previously conducted research into content-specific pedagogical knowledge and teacher planning for my Master's degree (Lake, 1990). The knowledge of exactly how the lessons were taught turned out to be valuable for the interpretation of some of the quantitative results; for example knowing the analogies used for teaching certain concepts was important for explaining the differences in some of the class results. This chapter is in two parts: Section 5.2 Planning the Course; and Section 5.3 Teaching the Course.

4.2 Planning the Course

4.2.1 The Electronics course

The electronics course was originally a project-based course where the electronic theory was introduced to explain the functioning of their projects. I modified the course structure to that of a three phase learning cycle as described in Chapter 3. Because the original course was very popular I retained the project aspect to provide a context for the theory. The overall aim of the original course was to teach students the meaning of the concepts of voltage, current, and resistance, and how these can be controlled in an electronic circuit. The circuits that the students built were very simple

and designed to emphasise the function of specific electronic components such as transistors, resistors and diodes. For example, students were continually reminded of the function of diodes when they soldered them into circuits in reverse. The error of not observing a diode's polarity was a particularly powerful contextual lesson for them. If the diode was not connected correctly, the circuit did not work. The other important aspect of the projects was to develop the students' psycho-motor skills required for etching, drilling, and soldering. One of the great rewards of teaching is to see the pleasure on a student's face when they construct a project that actually works! This success was a strong motivating factor for the students. I encouraged the students to take their completed projects back to their normal classes and explain to their fellow students how they work. Many students did this and they became good advertisers for the electronics course which resulted in a waiting list to do the course.

The first step in the development of the course was to establish the key concepts to be taught and create a concept map to show the interrelationship of these concepts (Appendix B). My aim was to teach these concepts qualitatively; that is, I did not expect the students to be able to apply Ohm's Law calculations to voltage, current and resistance measurements. They only needed to understand, for example, that current is directly proportional to voltage and inversely proportional to resistance. I knew from my experience as a Year 12 physics teacher that with a sound understanding of voltage as a force, current as a quantity, resistance as a resistive force that opposes the flow of electrons and how each related to each other, the students would be well placed to understand the mathematical aspects of electricity at a later date.

In the learning cycle lessons I used laboratory equipment such as 6V dry cell battery packs with multiple voltage settings, leads, laboratory meters, tungsten globes, laboratory resistors and some specially mounted electronic components. This equipment enabled students to construct and deconstruct circuits during their exploration and experimentation. The course was conducted in a secondary school laboratory with full laboratory staff support.

4.2.2 The lessons

As mentioned in previous chapters, there was a time limitation to the electronics course – ten sessions each of two hours. The course needed to be restricted to eight lessons because the first session and the last session were required for assessment. The lessons

were sequenced to form a spiral curriculum so that the concepts from one lesson became prior knowledge for the next. It was at this stage a distinction was made between a descriptive learning cycle (DLC) and a hypothetical-deductive learning cycle (HDLC). To prevent teacher bias toward one form of learning cycle, I created structured worksheets for each lesson. This was necessary for two reasons: firstly to ensure that I accurately used each type of learning cycle model and did not implant personal bias on the lessons; and secondly to ensure each class was taught consistently because three classes were used for each type of learning cycle. Some concepts, such as the resistor code, were not suited to an ideal HDLC lesson. In cases like this I needed to deviate from the model but maintain a more problem-based task than in the DLC lesson. Students worked in pairs in both the DLC and the HDLC; however, more emphasis on discussion between partners was made with the HDLC. When a question was put to the class, students were asked to discuss the question with their partner before answering. A time of 30 seconds to one minute, depending on the difficulty of the question, was allowed for this. In the HDLC group discussion needed to be longer particularly when discussing a hypothesis to explain an observation, and also when planning an experiment to test that hypothesis. During discussion time, students were asked to write down their initial answers on their worksheets in pencil. After discussion and agreement on a correct answer, they were asked to amend their answers. Students adapted well to this process. Strong cooperative bonds developed between the partners.

Descriptive Learning Cycle lessons

I found the DLC lessons very easy to prepare because they were very similar to my normal teaching style. The main modification I needed to make was to ensure the *exploration* phase came first in a lesson. In a normal science class I tended to introduce the concept, talk about it for a while, give the students an activity to verify the concept with a hands-on activity, and then consolidate the concept with an application activity. In this lesson structure, the activity was not a true exploration. In a DLC lesson, I introduced the lesson with the concept title (e.g. '*Today we are going to explore voltage*') with possible reference to an everyday experience that a student could relate to, or a concept from the previous lesson, and then went straight into the exploration phase. It seemed a more 'natural' way to start a lesson because students were always

eager to get their hands onto the equipment - more eager than listening to a teacher talk about an abstract concept they may have never heard of!

In the *exploration* phase, students were expected to describe any phenomenon they observed and record it on their worksheet. I would instruct the students to briefly discuss the observations with their partner, then ask the class for a possible explanation and verbally construct an accurate explanation from their responses. When I was satisfied with an explanation, I would summarise it on the board, then ask the students to write in on their worksheets. Quizzing the class for an explanation was very brief in the DLC lesson. If the answer did not come quickly I offered the reason. If possible my explanations used simple language familiar to the students – specific terminology was avoided until it was introduced in the context of a lesson. Most lessons in the electronics course used a simple electrical circuit in the *exploration* phase. In the DLC I would guide the students on how to set up the circuit. This was usually done with a sketch on the board, however after the first lesson students needed very little guidance. Students were expected to draw this circuit on their worksheets as a freehand sketch. Gradually as the course progressed, the diagrams evolved from freehand sketches of equipment to neat formal circuit diagrams using correct circuit symbols. The appropriate symbol for each component was written on the board for the students to copy.

In the *concept development* phase the underlying concepts that explained the observations were introduced. I used student data and observations to support a concept. It was at this stage, if appropriate, I would use an analogy to explain an abstract concept. For example when relating current to resistance in a circuit I would use the ‘water in a pipe’ analogy (Asoko, 1996; Schwedes & Dudeck, 1996). Key words and concepts were clearly defined by me and students were asked to record them on their worksheet. These recordings did not consist of copious notes. They were brief and usually consisted of one short sentence. For example: *Cells supply electrical energy to a circuit; Connecting wires conduct electricity between components.*

The *concept application* phase extended the concept to a common application, or extended the *exploration* activity as consolidation of the concept. For example, in Lesson 3 (Resistance) concept application phase, a variety of resistor values were used

to confirm that the brightness of a globe, and hence the amount of electricity was reduced by increased resistance. The word electricity was used because the term current had not been introduced at this stage. Common appliances such as radios and light dimmers were examined for variable resistors. To further test their understanding of resistance, students were asked to connect another globe into the circuit, observe the brightness, then connect a lead across one globe creating a short circuit, and explain why that globe did not shine. In the DLC, lesson discussion was short and an explanation of a short circuit was given to the students to write down.

Hypothetical-deductive Learning Cycle lessons

The HDLC lessons were not as easy to prepare as DLC lessons. On the surface it would appear that the lessons are student-centred with less teacher involvement. I found that preparation was more time consuming and the lessons took much longer to conduct. In addition to this, more equipment had to be made available to the students for experimentation with their hypotheses.

In the *exploration* phase of a HDLC lesson, students were given minimal guidance when setting up circuits. I would write a list of the equipment they required on the board, and then instruct them to connect the equipment so that the light glowed brightly. Initially some students found this difficult as they had no prior experience in connecting circuits. If a student continued to have difficulty I would tell them to make a single pathway that would pass through all components. This advice invariably solved their problems. This course did not cover parallel circuits. When drawing circuit diagrams, HDLC students were given a comprehensive sheet of circuit symbols and an example of a typical circuit diagram as a guide. They had to choose the appropriate symbols for their diagrams.

When an observation was made in the *exploration* phase students discussed with their partner a possible reason for the observation. When they reached consensus the students wrote their reasons or ideas on the worksheet. At this stage I would move around the classroom checking their reasons. When a reason was clearly correct I instructed the students to design an experiment test their idea. There was no class discussion at this stage. In this course, an experiment usually involved setting up another circuit or modifying the existing circuit; for example, in Lesson 3 (Resistance), students needed to realise that increased resistance reduced the

brightness of the globe. To test this idea they needed to modify their circuit to create more resistance. This was easily done by replacing a low resistor with a high resistor or adding another resistor in series. All the necessary equipment was made available to the students on an equipment tray.

I tried not to discuss ideas openly with the class as a whole as some students simply followed these ideas and did not generate their own. Guidance was needed when a student was clearly thinking in the wrong direction. This stage of the lesson was very time consuming and extremely busy for me. After a few lessons I replaced the word 'idea' with the word 'hypothesis' and discussed the basics of the scientific method, that is, setting hypotheses and designing experiments to test them. I had to be very careful not to let individual students get too 'out of step' with the rest of the class.

In the HDLC *concept development* phase I avoided using analogies to explain concepts. I tried to elicit concepts from the class members by discussion. This was successful except for one concept, the concept of voltage as a force. This particular lesson was audio-taped and is discussed in Chapter 5, Section 5.3.1 Key concept analysis (p. 139). In the case of the lesson on resistance, I asked the students to write in their own words, using the observations from their experiments, what the relationship was between resistance and the brightness of the globe in the circuit. They needed to come up with the idea that as resistance increases, brightness decreases – an inverse relationship. When every student had completed the task, I discussed the concept with the class so that the students could correct their responses. Students were asked to research the meanings of key terms such as electrical resistance and the Ohm unit for homework which was checked and discussed at the beginning of the next lesson. This discussion only took a few minutes and acted as a review of the previous lesson. Ideally students would do this task at school, but computers were not available to the PEAC students because they were visitors to the school with no login credentials.

The *concept application* phase for the HDLC in the example given above was very similar to that for the DLC in that it used the concept of a short circuit; however, the students needed to arrive at an explanation by discussion with their partner. This was a good exercise as it required reverse thinking to the main exploration – the effect of

very low resistance. This concept led into discussion on safety with electricity in both learning cycles.

The major differences in the teaching strategies for the DLC group and the HDLC group are summarized in Table 4.1. Specific detail on each lesson is given in Section 4.3 Teaching the Course.

Table 4. 1 Comparison of strategies used in the DLC and HDLC lessons.

DLC (Mostly teacher centred).	HDLC (Mostly student centred).
1. Experimental observations are shared with the class and summarized by the teacher for recording on worksheets.	1. Students discuss experimental observations with their partners and write them on their worksheets. Teacher corrects individual responses.
2. All explanations for observations given by teacher after brief class discussion.	2. All explanation for observations written by students after consensus discussion with partners. Teacher corrects individuals.
3. Analogies used to explain concepts in electricity.	3. No analogies used.
4. Students not asked to design experiments to test ideas.	4. Students asked to design experiments to test ideas.
5. Procedures such as use of the resistor code is carefully explained with guided practice examples.	5. Procedures such as use of the resistor code is developed by the students with minimal written instructions.
6. Format of result tables given to the students by the teacher.	6. Students design their own result tables.
7. Concept application examples always down in class.	7. Concept application examples sometimes assigned as computer research at home.
8. Faults in project circuits are determined by the teacher.	8. Faults in project circuits determined by the student with some teacher guidance if necessary.

4.3 Teaching the Course

In this section I discuss significant aspects of each lesson. At the conclusion of each lesson I recorded my general feelings on how the lesson went, and any specific aspects of each learning cycle that were different. For example, I did not use analogies in the hypothetical-deductive learning cycle to explain abstract concepts. Students needed to arrive at an explanation by discussion with their partner. At times this was a very lengthy process due to the students' lack of prior knowledge about electricity. The early lessons required the most guidance.

The detailed descriptions of the teaching of each lesson are included in this chapter because they are a part of my reflections and provide valuable qualitative data for the interpretation of the quantitative data. On initial examination of the quantitative data there did not appear to be a clear pattern based purely on the type of learning cycle used. However, when strategies in each lesson were considered, conclusions could be drawn. For example, concepts were better understood when certain analogies were used.

Lesson 1 is described in detail in Section 4.3.1 to illustrate my basic approach to each type of learning cycle. A shorter description of all other lessons follows in Sections 4.3.2 to 4.3.8. A HDLC was limited in scope with a simple concept such as circuit continuity but it enabled me to establish a procedure with each group. Both groups adapted very well to their respective procedures and generally all students participated well in all lessons.

4.3.1 Lesson 1 – Electrical Circuits

Although Lesson 1 presented a simple concept, continuity of a circuit, it was very important in establishing lesson protocols. These protocols included writing down observations as they happened before going to the next step and generally keeping a neat and accurate record of the lesson. Students adapted very well to discussing observations with their partner before recording them.

Descriptive Learning Cycle (DLC)

Exploration:

Students were given a tray of equipment that included a dry cell battery pack (6 volts), a number of electrical leads, and two mounted 6V globes. They were asked to connect

the globes to the battery pack to make the globe as bright as possible. When the circuit was complete they were required to sketch the equipment on their worksheets.

Most students were able to connect the circuit to make the globe glow. Students who could not were immediately shown how to do this. Sketching required considerable guidance. I had to draw examples on the board to set the standard I required. The colour code of polarity needed to be explained – red is positive and black negative. When asked what caused the globe to light up, answers such as electricity, power, energy, and electrons were given. I needed to explain that friction of the electricity (*electrons* not yet introduced) in the filament caused heat which caused light. I used rubbing hands together to demonstrate friction causes heat. I asked the students to break the circuit at any point and observe what happens. Students observed that the flow of electricity could be stopped by breaking the circuit. They were able to explain that disconnecting the wires stopped the flow of electricity or energy.

Concept Development:

This section dealt with the function of cells, globe and connecting wires. When the class was quizzed students gave similar answers to those in the exploration phase. I needed to refine their answers: cells store energy; globe is an energy converter, converting electrical energy into light and heat energy; connecting wires carry electricity like water in a pipe. The water analogy was introduced at this stage.

Concept Application:

In this section students were introduced to circuit symbols and asked to redraw the previous sketch as a circuit diagram. I drew the diagram on the board and they copied it. Very few students drew straight lines – this needed constant supervision. Student drawing skills were not good. I used a torch (flashlight) to demonstrate the use of a simple circuit.

Hypothetical-Deductive Learning Cycle (HDLC)

Exploration:

As in the DLC groups, the HDLC students were able to connect the circuit with few problems, however when students could not, I asked them to make a *pathway* for electricity to follow. When asked to explain what caused the globe to glow, students were asked to discuss with their partners and propose an idea as to why, and to use the equipment to demonstrate their idea. Most students were able to say electricity from

the cells flows to the globe causing it to glow. Ideas and vocabulary were very similar to the DLC group. I was looking for a response that indicated something was flowing in the wire and to support this idea you could break the flow by disconnecting a lead. About half the students were able to disconnect a wire to demonstrate this. A lot of coaxing was required at this stage.

Concept Development:

Students were asked to discuss with their partner the function of the cells, globe, and connecting wires. They had to write down their answers, then amend them after research at home. Work was checked next session. Many students did not do the homework therefore a long discussion time was required. Getting students to do homework is always difficult, but it is particularly difficult in withdrawal extension classes such as PEAC because students do not always see the extension class as a part of their normal school routine.

Concept Application:

HDLC students were given a sheet with all the circuit symbols required for the course and asked to redraw their sketch diagram in symbol form, with little guidance from me. The same problems arose as for the DLC – few straight lines and untidiness. As in Lesson 1 for the DLC, students in the HDLC needed to arrive at their own explanations or ideas for observed phenomena by discussion with their partner. When they had written down their ideas, they had to plan a procedure that might support that idea, conduct the procedure; and come to a conclusion about the idea. The application of this idea led to the students designing a switch in Lesson 2.

4.3.2 Lesson 2 – The Switch

Lesson 2 was done as an extension of Lesson 1 within the same session. Students learnt that a switch was a more convenient way of breaking a circuit than disconnecting a lead. This lesson presented no problem to any student. DLC students were told to place a switch into the circuit and explain how it worked whereas HDLC students were asked to design a device that would do the same function as disconnecting a lead. All HDLC students were able to design a basic switch.

4.3.3 Lesson 3 – Resistance

Lesson 3 used the same basic circuit as Lesson 1 and students needed to predict the change in the brightness of a globe when a 5 ohm resistance was added to the circuit.

They tested their predictions and were asked to explain why. Verbal answers in both groups suggested that the resistor '*slows down the electricity*' and '*gives less power to the globe*'.

DLC students were then asked to confirm their observation by replacing the 5 ohm with a 20 ohm resistance and were then asked to suggest a relationship between the resistance and the brightness of the globe. This question was directed to the class as a whole. Answers were invariably specific to the experiment. That is *the 20 ohm made it duller*. I had to explain that when asked for a relationship between two variables such as brightness and resistance, it usually meant a general statement such as *increased resistance decreases brightness*. In the *Concept Development* phase I explained that a resistor can regulate the flow of electricity like a water tap can regulate the flow of water. Conveniently the classroom, being a laboratory, had taps on the side bench which made demonstration of the function of a tap very easy. The terms electrical resistance and the ohm unit were defined on the board and then written on their worksheets. As a *Concept Application*, dimmer switches and volume controls on radios were discussed. The exploration circuit was modified to include two globes, then used to demonstrate the effect of very low resistance – a short circuit. This was done by placing a lead across the terminals for one of the two globes. There seemed to be no problems with students understanding the concept. Safety issues concerning short circuits were discussed.

HDLC students were asked to discuss their observations with their partner and suggest a reason for the globe becoming dimmer. They then had to design an experiment using any equipment they saw on the tray to test their idea. On the tray were more globes and 20 ohm resistors. Most students chose to add the 20 ohm resistor to the circuit and some replaced the 5 ohm with the 20 ohm. No instructions on how to connect the circuit were given. One student connected the 20 ohm resistor in parallel and the globe got brighter! This appeared not to support his idea and led to an informal discussion on alternative pathways and parallel circuits. The word *hypothesis* was introduced in this lesson as a substitute for *idea*. The meanings of the terms *electrical resistance* and the *ohm* unit were set for homework. As in the DLC group, the short circuit was used to demonstrate the effect of low resistance. HDLC students had to arrive at a reason by discussion with their partner. This took a few minutes and the previous discussion about parallel circuits and alternative pathways became useful at this stage.

By Lesson 3 students in both groups had become very proficient in getting equipment and setting up circuits. Circuits diagrams were becoming neater and generally the students were conducting themselves very well within the lesson protocols, in fact they were enjoying the process of explore, discuss, and apply.

4.3.4 Lesson 4 – Electric Current

Lesson 4 uses quantitative measurements for the first time, which is the measurement of current with an ammeter. Both the DLC and the HDLC group commence their exploration with one globe in a circuit plus an ammeter. The laboratory ammeters were polarity sensitive therefore I carefully instructed all students on how to place them into the circuit. The general term of *electricity* used in previous lessons was now replaced with the term *current*. During the exploration a reflection on the findings of Lesson 3 was made, that is, changing resistance in the circuit was the cause of changing brightness in the globes. The DLC group were asked to record the reading on the ammeter with one globe and then predict the reading if two globes were used as in Lesson 3. I withheld the extra globe until all students had made their recording and made their predictions. Often students left the recording to their partner! Generally student predictions were half the original, but the actual readings varied a lot due to variations in the resistances of the globes. This was easily explained as students could see that not all the globes were equally bright. I then asked students to explain the change in brightness by relating the change to the ammeter reading. Many students had difficulty doing this and consequently I needed to explain that the current measured by the ammeter, the amps, was the *electricity* we referred to in previous lessons.

In the *Concept Development phase* students had difficulty writing a general statement to describe the relationship between current and brightness, particularly as this time it was a direct relationship. *Direct* and *inverse* relationships were discussed. In the DLC group I wrote the definition of the unit of current, the ampere, on the board. I used the water analogy to help explain that current was a quantity of particles flowing past a point in the circuit in one second just as water is measured in litres per minute in a pipe. I then wrote on the board the actual quantity in terms of electrons in 1 amp (6.24×10^{18} e's or 6,240,000,000,000,000 e's per second)! I thought this piece of trivia would bore the students – it had the opposite effect - the large number captured their interest and helped reinforce the concept. It seemed to bring reality to an abstract

concept. In the *Concept Application* students had no difficulty relating size of current to effects such as speed of motors, hotness of heaters and loudness of stereo speakers. This was possible due to the direct relationship involved – increased quantity, increased effect.

After taking the ammeter reading with one globe, the HDLC students were asked to predict the reading if a 5 ohm resistor was added to the circuit. They were encouraged to look at Lesson 3 to help in their prediction. Predictions were very varied, but all predicted a lower current. From these observations students were asked to write a hypothesis relating current with globe brightness, design an experiment to test the hypothesis, and then conduct the experiment. A variety of resistors and extra globes were made available to the students. Some support was required to help the students formulate the hypothesis. Students had no difficulties adding resistors to the circuit and taking further readings, however they demonstrated no consistent way of recording the results. This point is raised again in Lesson 5 (*Voltage*) which requires many readings to be recorded. In the *Concept Development* phase the class was asked what they thought current was. Answers offered were mostly ‘a flow of electricity’; however, a few students were able to say ‘a flow of electrons’. The definition of current and the ampere were written on the board to be recorded on their worksheets. The number of electrons per second was not mentioned. This was followed up in the *Concept Application* phase, where students were assigned the task of finding the exact value of the ampere for homework. This approach did not have the same impact as when I wrote the value on the board for the DLC group. Also in the *Concept Application phase* students were given the same task as the DLC group regarding the effect of current on a number of devices, and they needed to explain how you could vary the speed of an electric motor as in a scale electric model car. This was reasonably well done; however, the same problem of some students not doing the homework existed.

4.3.5 Lesson 5 – Voltage

Lesson 5 on voltage proved to be the pinnacle of the course in two ways. Firstly the concept of voltage was the most difficult concept in the course. It is difficult for students of any age and it proved very difficult for primary students. Secondly, the activity required more experimental process skills such as recording and interpretation of data than any other in the course. In anticipation of this I decided to audio record

both the DLC and HDLC lessons. This enabled me to accurately record the time for each section of the lesson to help determine the relative efficiency of each lesson. With the time constraints of a PEAC lesson, time efficiency is an important factor. Transcripts are written below. Inconsequential talk has been omitted. A copy of both the DLC and the HDLC student worksheets are in Appendix C.

Transcript of the DLC Lesson 5

Concept Exploration

Students set up the equipment using instructions on the worksheet. This process is now very efficient and no student needed any guidance. However no student in either group was allowed to switch on the circuit until the ammeter connections were checked for polarity.

Note: **T:** = Teacher; **S:** = Student

T: *Connect the lead to the 1.5 volt plug. I am not moving onto the next step until I see everyone has completed the step.*

Now record the reading on the ammeter...I see 0.2 (A) here.

Now without touching anything, predict any changes to the reading if you change the lead to the 3 volt plug.

T: *What do you think will happen to the brightness if you put it (the lead) into 3 volts?*

S: *It will get brighter.*

T: *I will not tell you at this stage if it is right or wrong.]*

T: *OK, now predict the ammeter reading. 1.5volts gave about 0.2 A.*

S: *About 0.35 -0.40.*

T: *So you have given me a range – that’s alright as long as the range is not too large. Hands up those who just doubled it (half the students). That’s a pretty good guess – you may even be correct. OK, now change the lead to the 3V and see what happens to the brightness. Who found it brighter, (all hands up) - yes it should be and what was the reading?*

S: *0.32 A.*

[12.00mins]

Concept Development

T: *You changed the voltage from 1.5 to 3.0 volts – what do you think the voltage increase has done in the circuit?*

S: *It has to get more electrons to carry to the globe.*

T: *You have the general idea, but not explaining it very well. Firstly what do you think voltage is?*

S: *It’s a unit of power.*

T: *It’s not power.*

S: *its electrons.*

T: *No it’s not electrons*

S: *It’s electricity.*

- T:** *No, that word is too general. Now watch this.* (the teacher hold up a duster).
What happens when I let it go?
- S:** *It falls.*
- T:** *Correct (lets duster drop) – what caused it to fall.*
- S's:** *Gravity.*
- T:** *Voltage is a force like gravity. In this battery (holds up 9v battery) is a force of 9 volts. It is always there just like gravity.* (Teacher writes definition of voltage on the board). *Voltage is sometimes called Electromagnet Force – or EMF.*

Note: The gravity analogy is used here but is very brief. Students are told that voltage is a force.

In this stage students record their current readings for 4.5 V and 6.0 V on a prepared table and graph. The axis scales for the graph are written on the board.

[17.00mins]

Concept Application

- T:** *What is the relationship between the voltage and the current in the circuit?*
- S:** *As the voltage increases, the current increases.*
- T:** *Perfect! You can all write down that answer.*

This section was done as a demonstration by the teacher to conserve equipment.

- T:** *Predict what would happen to a 6 volt globe if it was connected to 12 volts.*
- S:** *The globe will blow.*
- T:** *Anyone disagree with that?* [no response].
Let's see what happens –[globe glows very brightly but does not blow].
Normally the globe will burn out, but this seems to be a very good globe. Why do you think it would burn out?
- S:** *The voltage was too high.*
- T:** *Partly correct, but what does a high voltage do?*
- S:** *Increases the current.*
- T:** *Correct. Now I want you to answer Question 3 – Why is the voltage written on an electrical appliance such as this globe* [teacher points out 6V on side of the globe].

Lesson finished with a discussion on compliance plates and safety issues.

[30.00mins]

Transcript of the HDLC Lesson 5

Concept Exploration

Students set up the equipment using instructions on the worksheet. This process, as in the DLC, is now very efficient and no student needed any guidance.

- T:** *Connect the leads to the 1.5 volt plug and describe the brightness of the globe.*
 Students complete part (a) and (b) of the lesson.
- T:** *Move onto part (c) when you have taken your reading. Talk over your decisions with your neighbour and come to a decision between you. Compare others answers and if you disagree with your partner's answer try to come to an*

agreement. Don't forget to write your answer in pencil so that when we discuss it you can make corrections.

T: *Who predicted it would be brighter? OK, we all seem to be in agreement (most hands went up). What is the reason you think it got brighter?*

S: *There will be more voltage through the globe.*

T: *No, anyone else?*

S: *The voltage increases.*

T: *That is the same answer.*

S: *The voltage supplies more current and the more current the brighter the globe gets.*

T: *I wouldn't use the words supplies more current, but you are getting warmer.*

S: *More voltage gives more current which gives more current to the globe which gets brighter.*

T: *Yes, that is a little closer.*

Now change the lead to the 3 volts and take your reading.

T: *Who got a reading that doubled (no answers). Globes are not perfect and changes occur that prevent it doubling. What do you think the changes might be? Theoretically it should double.*

S: *It got brighter.*

T: *Yes, did anyone feel the globe?*

S: *Yes it got warmer.*

T: *That's right – heat changes the resistance of the globe.*

Now discuss with your partner what you think voltage does in the circuit. [Pause]

[19.00mins]

Concept Development

T: *Now I want you to think about what voltage actually is.*

Everyone has written an answer but I have not seen the correct answer yet, although some are getting close.

S: *Gives power to the circuit and voltage is more electricity.*

T: *Change the word power and you will be getting close.*

S: *Voltage is energy.*

T: *Not exactly, but can be considered a type of potential energy.*

S: *Voltage is current.*

T: *No, voltage is not current. I will have to give you a clue. Voltage is like gravity. Now if I put this object up here [on the desk] and push it over the edge, what made it fall?*

S's: *Gravity.*

T: *What is gravity?*

S's: *A force [in unison!]*

T: *Now let me ask again – What is voltage?*

S's: *It's a force! [in unison].*

T: *Yes, and sometimes it is called the ElectroMotive Force or EMF for short. Now you have a key piece of information which should change the way you think about electricity. This [voltage] is the driving force – it is what drives the current.*

Students complete the data recording and graph construction for voltage values 4.5 volts and 6 volts. They needed to design their own table for recording the data.

[23.00mins]

Concept Application

- T: What is the relationship between voltage and current in your circuit?*
S: Voltage is the driving force – the more driving force the more current there is.
T: Yes, but if you are going to write a ‘law’ you need to reduce your words a bit; Current in a circuit is directly proportional to the voltage [writes it on the board]. See if you can predict the current, using your graph, for 10 volts.
S: Take the 4.5 V current and double it.
[Students needed to be shown how to extrapolate their graph to 10 volts]
T: What will happen if we join to battery packs together and connect 12 volts to the globe?
S: The globe will burn out.
T: Any reason why?
S: Voltage is too high.
T: Almost right, I wouldn’t say the voltage was too high.
S: The voltage drives the current too high.
T: Exactly correct! [41.00mins]

As in the DLC group, HDLC students see voltage as the direct cause of the globe burning – not current. The HDLC lesson took 11 minutes longer to conduct than the DLC. This was due to more group discussion, longer time for students to formulate hypotheses and plan experiments in the HDLC group. It was difficult to draw understanding from the students regarding the abstract concept of voltage because of their lack of prior knowledge of electricity. However both groups understood immediately when the concept was compared to gravity. Gravity is a concept individuals are confronted with from their very early childhood.

4.3.6 Lesson 6 – Diodes

Lessons 6, 7, and 8 dealt with descriptive concepts and therefore a hypothetical-deductive learning cycle was not particularly appropriate. In these lessons the HDLC group tasks were more problem solving rather than hypothesis setting.

Concept Exploration

Lesson 6 deals with the function of diodes – a descriptive concept. The difference between the DLC and the HDLC lessons is small. Students are given a specially mounted power diode and a specially mounted light emitting diode (LED) and asked to connect them to a 3 volt power supply so the LED lights up. To do this they had to be aware that diodes are polarity sensitive. Most students could do this task in about five minutes by trial and error. A few student remembered from their projects that they could only be connected one way.

Concept Development

DLC students were given the rule for diode connection on the board and asked to reconnect their circuit using the rule. This proved to be no problem to any student and was well done.

HDLC students were asked to develop a set of rules to enable a person to connect diodes correctly into a circuit. This was done by discussion with their partner. They then asked another group to use the instructions to reconnect the circuit. This presented no problem for any student and was well done.

Concept Application

Both groups did a little exercise based on a circuit diagram (see Appendix K) of a Wheatstone bridge rectifier – a perfect example of a use for diodes. They had to trace the pathway of current through the bridge. All students did this very well. A short discussion followed as to why each of their projects had a protective diode in it.

4.3.7 Lesson 7 – Transistors

Lesson 7 was similar to Lesson 6 on diodes in that it dealt with the function of a specific component – the transistor. Specially mounted transistors and LEDs were used for the lesson. During the *concept exploration phase*, students were asked to connect a transistor, an LED and a 3 volt power supply into a circuit so that the LED glowed. They were given a circuit diagram for the task. This presented no problem to either the DLC or the HDLC group. The students were then asked to disconnect the base and change the base resistor, each time noting any changes to the brightness of the LED.

In the *concept development phase* the DLC group used these observations and class discussion to determine the basic functions of a transistor, that is, as a switch and a current amplifier. In the class discussion I explained the function of a transistor as similar to a water tap in that they both have an inlet, outlet and a flow regulator. The HDLC group were asked to compare the circuit that they just created with one of their project circuits – the moisture indicator for pot plants (a simple one transistor amplifier). The comparison of the analogy of the water tap with the DLC group proved to be more successful than using the circuit diagram in the HDLC group. Some students were able to see that the variation in resistance of soil in the pot due to moisture, was comparable to changing the base resistor in the exploration circuit. It

was obvious that some students could easily read a circuit and relate it to their project, and others could not.

As a *Concept Application* activity, all students were asked to form a chain by holding hands and become a part of the transistor's base circuit. The LED glowed moderately bright, a testament to the sensitivity of a simple 40c transistor and the ability of the body to conduct a current even with only 3 volts applied! One at a time students were removed from the circle and the brightness of the LED noted. Students noted that the LED became brighter as the resistance was reduced. On completion of a project after doing Lesson 6 and 7, students were asked to describe the function of the diodes and the transistors in their circuit as a part of their assessment and reinforcement of the concepts.

4.3.8 Lesson 8 – The Resistor Code

Although *The Resistor Code* was numbered as Lesson 8, it was conducted at a time when a knowledge of the code was needed by the students for construction of their projects. This varied from class to class and was used when required, which was relatively early in the course.

After a short exploration using resistors and multimeters, the resistor code was explained to the DLC students and a series of resistors given to them for practice. This code was understood by most students after a few practice resistors.

The HDLC groups, after doing the same exploration as the DLC group, were given the four basic points of the code: first band is the first digit; second band is the second digit; third band is the multiplier; fourth band is the quality or tolerance; and the numeric value of each colour. With the help of their partner, students had to 'crack the code' and determine the value of a given resistor. Some students cracked the code in less than five minutes, and all students in less than ten minutes. The only problem encountered was the tolerance band, which in all cases was gold. Most student had determined this by themselves, but a few I had to be advised to keep the gold band on the right when reading the colour sequence.

4.4 Chapter summary

Chapter 4 gives a description of the planning process and a description of the implementation of each lesson. Section 5.2, Planning the Course, included general comments on course preparation and lesson preparation. In this section I described measures I took to control such variables as teacher bias when conducting the two different learning cycles. In Section 5.3, Teaching the Course, I described specific details on how each lesson was conducted for each type of learning cycle. For example, the water analogy for current and the water tap analogy for the transistor are mentioned. The descriptions on planning and conducting lessons were used for interpreting some of the results obtained in the quantitative data.

CHAPTER 5 Results

5.1 Introduction

The quantitative results of this research are based on data from three instruments: a constrained concept mapping task; a two tiered multiple-choice test; and a questionnaire to measure science related attitudes (TOSRA). In addition to the three instrument results, the reflections of the teacher in the implementation of the two learning cycles and Lawson's Classroom Test of Scientific Reasoning (LCTSR) were used to help interpret the quantitative results. Instrument data are presented in the sections Section 5.2, and contain reliability and validity measures on the concept mapping task (Section 5.2.1) and the multiple choice test (Section 5.2.2). Section 5.3 contains data in response to the research questions. The research questions fall into two categories; the cognitive domain (Section 5.3.1) and the affective domain (Section 5.3.2). Additional quantitative data from LCTSR is in Section 5.4. The organization of the chapter is summarized in Figure 5.1.

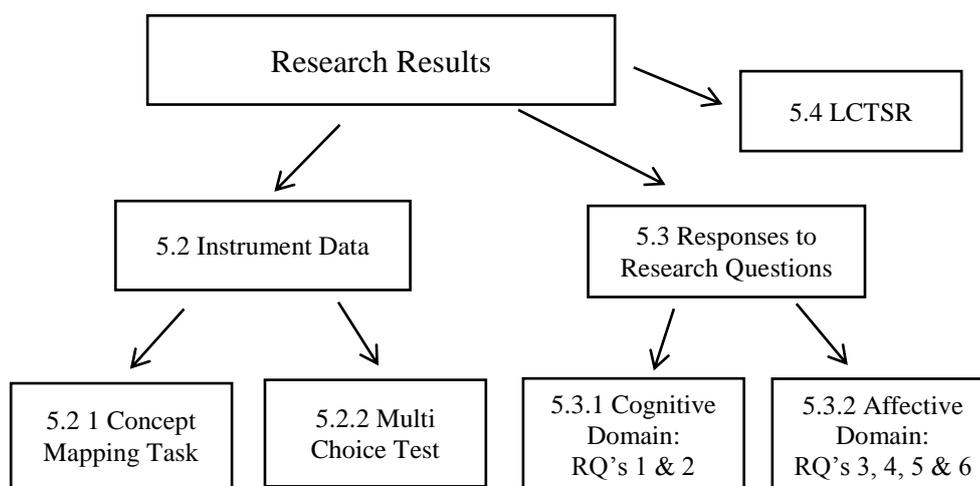


Figure 5. 1 General outline of Chapter 5.

Whenever possible statistical calculations have been made using the IBM program SPSS (IBM SPSS Statistics V. 22). Cohen's '*d*' is used to measure effect size with the following guidelines used: 0 – 0.29 = small effect, 0.30 – 0.59 = medium effect, greater than 0.60 = large effect (Cohen, 1992). However some calculations such as a matched split half correlation, Spearman-Brown prophecy formula, and Q-Q plots were not offered by SPSS. In those cases a template was created in Microsoft Excel for the purpose.

5.2 Instrument Data

This section is concerned with the establishment of the constrained concept mapping task and the two-tiered multiple choice test as reliable and valid instruments for use in this research.

5.2.1 Concept map scoring

The individual maps in the concept mapping task were scored using two different methods. The first method was one suggested by Yin et al. (2005) and is referred to as the Yin method. This method is strong in assessing the depth of a student's knowledge but does not assess the structure of that knowledge. The second method is based on one described by Miller et al. (2009) and it is strong in assessing the quality and structure of a student's knowledge. The scoring procedure of each is described using an actual student map (Student 12) as an example.

The Yin method of scoring concept maps

In this method concept maps are scored simply as the sum of all the individual scores of single concept propositions. Each concept proposition was scored on a 1-5 scale with 1 being a slightly accurate proposition and five being a completely accurate proposition. This scoring technique is based on the Yin et al. (2005) 'S' technique where students select a linking phrase from a given list. This technique was chosen for a number of reasons which are discussed in Chapter 3, Section 3.5.2. The overall structure of the map was not considered; however, conceptual propositions were classified as either descriptive or theoretical. Descriptive conceptual propositions were those with observable exemplars and theoretical concept propositions were those with non-observable exemplars.

Extraction of concepts

The first step in the Yin method was to extract all the individual conceptual propositions, place them in a table, and rate each on a scale of 1 to 5. The table of propositions was then given to two expert markers (M1 and M2), experienced secondary physics teachers, so they could rate each proposition independently. Concepts that were clearly incorrect were not included in the table. Each concept was classified as descriptive or theoretical and this was done by consensus between M1 and M2. Marker 3 (M3), a non-teacher electronics expert, was used to mediate any differences in concept scores and that mediated score was taken as the final score used

for scoring the individual student concept maps. For example, for the concept proposition *Electricity measured in Voltage* M1 scored 2 and M2 scored 1. M3 decided that a score of 1 was more accurate. This total data set can be found in Appendix H and an extract is shown in Table 5.1. It should be noted that this total data set is based on all student maps and is not specific to a particular student.

Table 5. 1 The concept map scoring Table (Extract from Appendix H).

Concept	Link	Concept	Prop. Score m1 (1-5)	Prop. Score m2 (1-5)	Prop. Score M3 (1-5)	Type: Desc. Or theor.
Capacitors	store	Electric Charge	5	5	5	T
Electric or Electronic circuits	includes/needs a	diodes/resistor etc.	5	5	5	D
Electricity	measured in	Voltage	2	1	1	T
Electricity	runs in	Circuits	4	5	5	T
Electricity	measured in	Volts	2	1	2	T
Electronic Circuit	powers	LED	3	3	3	D

Note:

1. M1 is Marker 1 (assessed each proposition); M2 is Marker 2 (assessed each proposition); and M3 is Marker 3 (mediated differences between M1 and M2).
2. The scores in these tables are absolute values for each concept proposition.

Inter-rater reliability

All the propositional scores from the Concept Map Scoring Table (Appendix H) in the M1 column were correlated with all the scores in the M2 column. A Pearson product moment correlation, found in Table 5.2, was made to determine the inter-marker reliability between Marker 1 and Marker 2.

Table 5. 2 Descriptive statistics for inter-rater reliability

Marker	Mean	Standard Deviation	d.f.	Pearson r	Sig. (2 tailed)
Marker 1	2.93	1.45			
Marker 2	3.03	1.61			
Correlation			74	0.90	< 0.01

The means and standard deviations for Marker 1 and Marker 2 are very similar. When each rater's concept scores were correlated they produced a Pearson product moment coefficient of $r = 0.90$ and indicated a strong correlation between the two markers.

The concept proposition values from the concept map scoring table, mediated by M3, were then used to score each individual student concept map. As an example the student concept map for Student 12 in Figure 5.3 has been scored using the Yin method and later by the Miller method. The scoring templates are pasted onto the map for ease of scoring with the Yin method score on the bottom right corner and the Miller method score on the top left corner.

On the map in Figure 5.2, Student No.12 has stated that *LEDs-is a-diode*. From the *Concept Map Scoring Table* in Appendix H this single proposition is classified as descriptive (has an observable exemplar) and scores 5. Student 12 has four such propositions and therefore scores 20 for descriptive concepts. Similarly, the student states that *Voltage-measured in-Volts*, and from the *Concept Map Scoring Table*, this proposition is classified as theoretical (has a non-observable exemplar - *voltage*) and scores 5. Student No.12 scores 26 for theoretical concepts, making a total score of 46. While marking maps, the individual proposition scores are colour coded with a circle on each proposition for type (orange for descriptive and green for theoretical). Once the *concept map scoring table* is established, this process becomes an objective and reliable process. Duplicate propositions are not recorded and are marked on the map with a linking arrow. Student No.12 has two duplicate propositions, namely 'Electronic circuit includes resistors' and 'Electronic circuits include voltage'.

CONCEPT	SCORE
Descriptive (5)	20
Theoretical (11)	26
TOTAL	46

Figure 5. 2 Score sheet for Student No. 12 (Yin method)

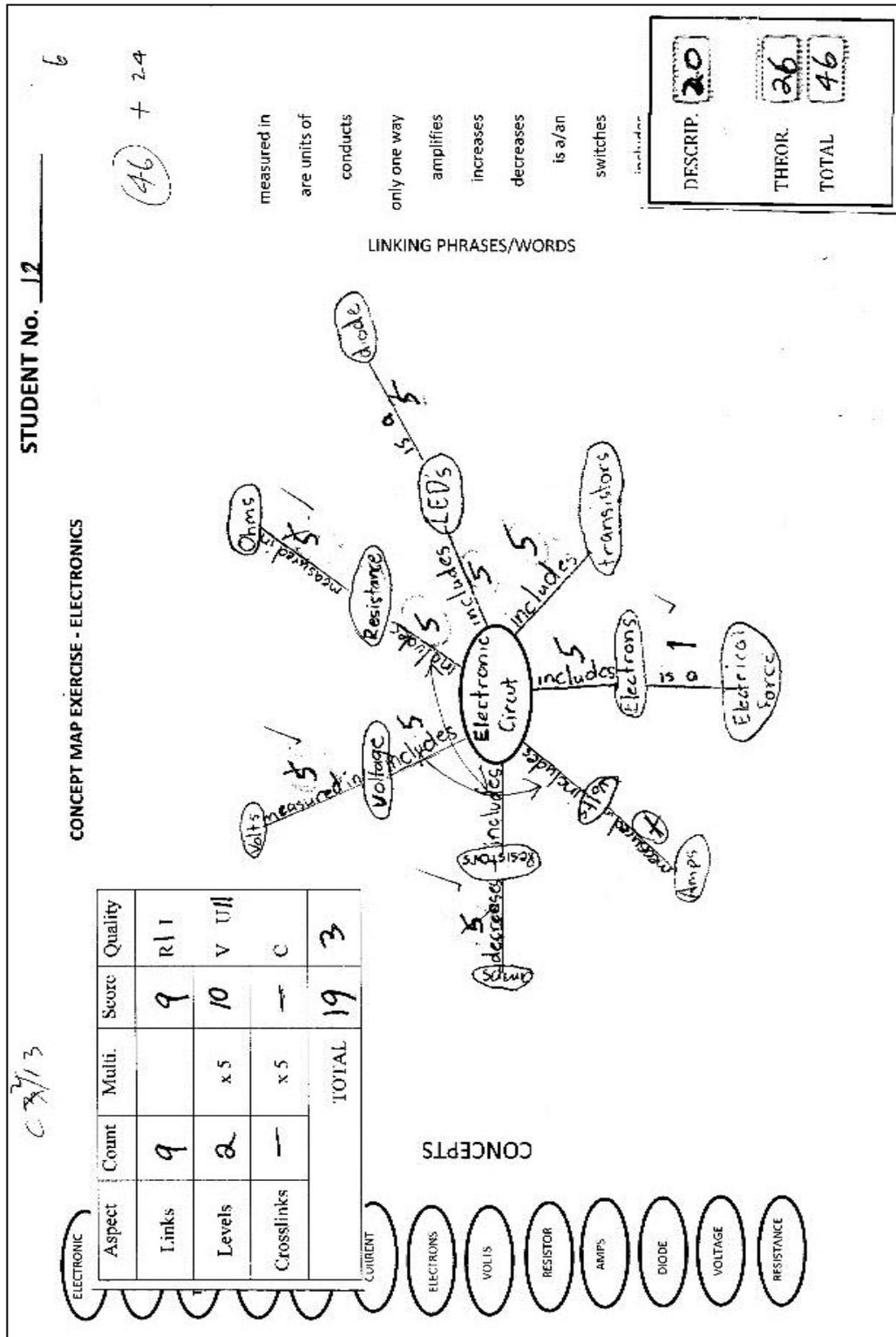


Figure 5. 3 Scored concept map for Student No.12

The Miller method of scoring concept maps

The Miller method of scoring concept maps, is discussed in Chapter 3 Section 3.5.2, takes into account map structure and quality. The Miller method scores map quality separately to the total map score. The quality score was determined using a concept

map quality scoring rubric: 0 if no key concepts present, 1 if one key concept present, and 2 if two key concepts are present in each of the concept areas of resistance (R), Current (I), voltage (V), units (U), and component function (C). A list of key concepts can be seen in Appendix J Raw scores of key concepts. This made a total possible quality score of 10. The scoring rubric is shown in Figure 3.8 in Chapter 3, Section 3.5.2 (p. 97).

Student No.12 can also be used to demonstrate this scoring method. For this method only strong concept links (single propositions) were considered, that is, concept links with a score of 3 or more based on the concept scoring table. Student No.12 has 9 concept links, scoring 9 for links. Levels are the number of concepts levels away from the central concept. The number of concept levels is weighted by a factor of 5. Student No.12's central concept is Electronic Circuit, and the highest number of levels is 2, therefore scores 10 for levels. However, Student No.12 has no cross links and therefore scores zero for cross links. Student No.12's total score for the map structure is 19. Generally map scores are lower for the Miller method, due largely to the fact that a single proposition only scores 1, whereas in the Yin method a single proposition can score up to 5.

Aspect	Count	Multiplier	Score	Quality
Links	9		9	R=1 I=0
Levels	2	x 5	10	V=0 U=2
Crosslinks	0	x 5	0	C=0
TOTALS			19	3

Figure 5. 4 Score sheet for Student No.12 (Miller method)

With respect to quality, Student No.12 had one concept proposition for resistance, *Resistors decrease Amps*, therefore scores 1 (R=1), and two for units, *Resistance measured in Ohms*, and *Voltage measured in Volts* (U=2), making a quality score of 3.

Concept map validity

The concept-mapping task consisted of a list of concepts and linking words or phrases associated with the PEAC electronics course that were given to the research

participants to construct a concept map. To ensure content validity, the task was given to two experts to firstly ensure that the concepts truly reflected the content of the course syllabus, and secondly, to use the concepts to construct an expert map as a scoring reference. The map was agreed by consensus. The expert map is shown in Appendix B and the expert concept scoring sheet is shown in Figure 5.5. The maximum scores possible on this map, using the Yin method, were 25 for descriptive concepts and 55 for theoretical concepts, making a total of 80. This expert map score only serves as a guide as there are many variations that can be made to achieve different scores. Nevertheless this exercise was useful in determining levels of complexity and quality that may be expected from the students.

CONCEPT	SCORE
Descriptive (5)	25
Theoretical (11)	55
TOTAL	80

Figure 5. 5 Score of expert concept map using Yin method

To further establish the validity of the concept mapping task, Pearson correlations were made between Yin method scores and Miller method quality scores. This was done separately for descriptive and theoretical concept scores (Yin). These correlations in Tables 5.3, 5.4, and 5.5 indicate a strong relationship between theoretical concepts scores (Yin method) and quality scores (Miller method). All these correlations have an ‘*r*’ value greater than 0.70. The theoretical concepts are similar to the key concepts used for determining quality under the Miller method and this is supported by the strong correlation between theoretical concepts and map quality for both pre and post-intervention, and difference scores. Of the three correlations for each treatment group, the theoretical concept (Yin) vs quality correlation (Miller) is the highest for pre, post, and pre-post difference scores (Tables 5.3, 5.4 and 5.5). It can also be noted that the descriptive concept correlations are quite low, sometimes negative, making them poor indicators of map quality.

Table 5. 3 Pearson correlations of Yin method scores and Miller method map quality scores (pre-intervention).

CORRELATION PAIR Yin method vs Miller method map quality scores.	ALL STUDENTS	DLC	HDLC
Descriptive concepts scores (Yin) vs Miller quality scores (pre intervention).	$r = 0.15$ Sig. = 0.293 $n = 51$	$r = 0.10$ Sig. = 0.626 $n = 25$	$r = 0.22$ Sig. = 0.273 $n = 26$
Theoretical concepts scores (Yin) vs Miller quality scores (pre intervention).	$r = 0.72$ Sig. = 0.000 $n = 51$	$r = 0.71$ Sig. = 0.000 $n = 25$	$r = 0.75$ Sig. = 0.000 $n = 26$
Total concepts scores (Yin) vs Miller quality scores (pre intervention).	$r = 0.63$ Sig. = 0.000 $n = 51$	$r = 0.65$ Sig. = 0.000 $n = 25$	$r = 0.59$ Sig. = 0.002 $n = 26$

Table 5. 4 Pearson correlations of Yin method scores and Miller method map quality scores (post-intervention)

CORRELATION PAIR Yin method v's Miller method map quality scores.	ALL STUDENTS	DLC	HDLC
Descriptive concepts scores (Yin) vs Miller quality scores (post intervention).	$r = 0.31$ Sig. = 0.013 $n = 51$	$r = 0.40$ Sig. = 0.051 $n = 25$	$r = 0.20$ Sig. = 0.338 $n = 26$
Theoretical concepts scores (Yin) vs Miller quality scores (post intervention).	$r = 0.77$ Sig. = 0.000 $n = 51$	$r = 0.75$ Sig. = 0.000 $n = 25$	$r = 0.80$ Sig. = 0.000 $n = 26$
Total concepts scores (Yin) vs Miller quality scores (post intervention).	$r = 0.67$ Sig. = 0.000 $n = 51$	$r = 0.72$ Sig. = 0.000 $n = 25$	$r = 0.64$ Sig. = 0.000 $n = 26$

Table 5.4 shows the correlations between post-intervention theoretical concepts and quality scores are higher than for pre-intervention and difference scores. In Table 5.5 the correlations for the difference scores for the descriptive concepts are mostly not significant and even negative, this may be noteworthy as it could indicate a movement away from descriptive concepts towards theoretical concepts as a result of the intervention. The correlations for theoretical concept difference scores and quality difference scores are high indicating strong relationships.

Table 5. 5 Pearson correlations of Yin method scores and Miller method map quality scores (pre-post difference scores)

CORRELATION PAIR Yin method v's Miller method map quality scores.	ALL STUDENTS	DLC	HDLC
Descriptive concepts scores (Yin) vs Miller quality scores.	$r = -0.09$ Sig. = 0.530 $n = 51$	$r = -0.08$ Sig. = 0.691 $n = 25$	$r = -0.10$ Sig. = 0.632 $n = 25$
Theoretical concepts scores (Yin) vs Miller quality scores.	$r = 0.75$ Sig. = 0.000 $n = 51$	$r = 0.79$ Sig. = 0.000 $n = 25$	$r = 0.73$ Sig. = 0.000 $n = 26$
Total concepts scores (Yin) v's Miller quality scores.	$r = 0.59$ Sig. = 0.000 $n = 51$	$r = 0.63$ Sig. = 0.000 $n = 25$	$r = 0.54$ Sig. = 0.000 $n = 26$

Concept map reliability

The inter-rater reliability of single proposition scores ($r = 0.90$) as described in the Yin method was found to be very high. However, to further determine the reliability of scoring concept maps, in particular the Miller method, a Pearson product moment correlation was made between scores obtained using the Yin method and those obtained using the Miller method. As shown in Table 5.6 the two methods correlated highly for all students, and for each treatment group, for both pre-intervention and post-intervention (i.e. $r = 0.80$ and 0.90 respectively).

Table 5. 6 Correlations coefficients between Yin method scores and Miller method scores.

CORRELATION PAIR Yin method v's Miller method map scores.	ALL STUDENTS	DLC	HDLC
Total map concepts scores: Yin vs Miller, pre intervention.	$r = 0.80$ Sig. = 0.000 $n = 51$	$r = 0.84$ Sig. = 0.000 $n = 25$	$r = 0.79$ Sig. = 0.000 $n = 26$
Total map concepts scores: Yin vs Miller, post intervention.	$r = 0.90$ Sig. = 0.000 $n = 51$	$r = 0.91$ Sig. = 0.000 $n = 25$	$r = 0.88$ Sig. = 0.000 $n = 26$

Note: significance levels are for 2 tailed.

The post-intervention correlations, $r = 0.90$ for all students, $r = 0.91$ for DLC students, and $r = 0.88$ for HDLC students are very strong and are all statistically significant results at greater than 0.01 level (2 tailed). The pre-intervention correlations are also strong: $r = 0.80$ for all students, $r = 0.84$ for DLC students, and $r = 0.79$ for HDLC students. The strength of the pre-intervention correlations is notable considering that most students had very little prior knowledge of the course concepts. These results would indicate a consistency in the two map scoring processes and not a consequence of the course itself.

5.2.2 Knowledge Test (two-tiered multiple choice test) reliability and validity

All the reliability estimates are based on the post-intervention scores as it was considered that the pre-intervention scores would be unreliable and lack content validity due to the lack of prior knowledge of the students.

Validity

To establish content validity the items in the Knowledge Test were designed specifically to test stated outcomes in the course description. The test was then given to three experienced physics teachers to complete and check the questions against the course description to verify that the questions truly reflected the stated outcomes. The physics teacher's results are summarized in Table 5.7.

Table 5. 7 Expert results for the Knowledge Test

Teacher	Score (20)	Comments
1	16	Q.1. - ambiguous and wording corrected. Q.9. - teacher error, forgot the resistor code.
2	18	Q.1 - teacher error (ambiguous question); considered the test difficult.
3	18	Q. 9 – teacher error, forgot the resistor code.

All questions, except Question 1 were found to be a true assessment of the Electronics course key concepts. Question 1 was found to have two possible answers resulting in the wording being changed to avoid the ambiguity. All other errors, such as forgetting the resistor code, were teacher errors which were determined by a post-test interview. One teacher commented that he thought the test difficult and was amazed that Year 6 students could understand the concepts being tested.

Reliability

The knowledge test created some problems with respect to determining its reliability. As stated in Chapter 3, the test did not satisfy the assumptions underlying the Cronbach's Alpha coefficient. That is, the items did not have similar difficulties, means and variances. It can be seen in Table 5.9 that item difficulties in the post intervention varied from $p_i = 0.99$, an easy item, to $p_i = 0.40$ a difficult item (p_i being proportion of students getting the item correct). Instead of using the Cronbach's Alpha, a matched split half correlation was made, and this result extrapolated to a 10 item test using a Spearman-Brown estimate.

Table 5. 8 Table of item difficulties for the Knowledge Test (pre-intervention)

Item:	1	2	3	4	5	6	7	8	9	10
p_i :	0.69	0.67	0.20	0.43	0.10	0.25	0.06	0.06	0.22	0.12

It can be seen from Table 4.8 that all items except Items 1 and 2, proved difficult for the students. It was possible to reason an answer for Items 1 and 2 without any prior knowledge. For example Item 2 (see Appendix D) asks what will happen to the speed of a fan when a resistance is added to the circuit. Students were able to reason that increased resistance reduces the speed of the fan. This item became even easier for the students after they learnt that resistance reduces current and reduced current reduces the performance of electrical devices such as electric motors. Item 5, on the other hand, could not be easily reasoned without a specific knowledge of the resistor colour code. The intervention gave the students this specific knowledge and consequently the item became relatively easy. A similar pattern can be seen in Items 3 to 10. All these items required specific knowledge contained in the intervention course.

Table 5. 9 Table of item difficulties for the Knowledge Test (post-intervention)

Item:	1	2	3	4	5	6	7	8	9	10
p_i :	0.78	0.99	0.58	0.68	0.77	0.73	0.40	0.48	0.77	0.55

After the intervention, Item 2, as discussed in the previous paragraph, turned out to be a very easy question with $p_i = 0.99$. However, Item 2 was included in the test as it assesses an important concept - the effect of resistance on current. The pre-

intervention difficulty value was $p_i = 0.67$ indicating the students could reason the answer reasonably well without prior knowledge. However, 33% of students still chose the wrong answer, and the intervention reduced this to 1%. This research was designed to look for conceptual growth and concept acquisition, not just the final score. A similar pattern to Item 2 can be seen with Item 4, which is concerned with the effect of voltage on current. Students were able to reason that increased voltage increased current. Item 1 had a similar difficulty level to Item 2 prior to the intervention; however, the change was very small for this item which involved synthesis of two pieces of knowledge and was therefore more challenging.

The first step in establishing the test reliability was to use a matched split-half correlation and Rulon's equation as described in Chapter 3, Section 3.5.1. Item matching was based on both content and difficulty, with priority given to content. The second step was to estimate the reliability of the full 10 item test using Spearman-Brown's prophecy formula. This formula assumes that when the five item test (split-half) is expanded to the full ten items it would have similar means and variances to the original test.

The correlation coefficient for the 10 item test using the Spearman-Brown estimate calculation was statistically significant at greater than 0.01. This would indicate a satisfactory reliability for the Knowledge Test using this method. However, care must be taken with this result as the item number and the sample sizes are small.

Table 5. 10 Knowledge Test reliability coefficients

Group	n	Split half correlation 5 items	Spearman-Brown estimate 10 items	Sig. (2 tailed) 10 items
All Students	51	0.48	0.65	>0.01

This method of determining reliability is partly dependent on matched pairs of items based on their difficulty, consequently in order to determine how stable the difficulty of each item was, a Pearson product moment correlation was made using SPSS between the DLC and the HDLC group for the total scores of each item. This was for both pre intervention and post intervention scores and the results are presented in Table 5.11.

Table 5. 11 Correlation of item scores between DLC and HDLC

Correlation Pair	Correlation	Sig. (2 tailed)
Pre DLC and HDLC	0.89	0.001
Post DLC and HDLC	0.80	0.006

It can be seen from Table 5.11 that the correlations are very high indicating the difficulty of the items remained stable for both pre-intervention and post-intervention test results.

5.2.3 Test of Science Related Attitudes (TOSRA)

Validity

The TOSRA is a well-established questionnaire hence its validity has been accepted for the purposes of this research. Only two subscales of the test were used for the test, Attitude towards scientific inquiry, and Enjoyment of science lessons.

Reliability

The Cronbach's Alpha reliability measures for the TOSRA for both pre and post intervention are shown in Table 5.12.

Table 5. 12 Reliability coefficients for the TOSRA

Group		Cronbach's Alpha Scientific inquiry	Cronbach's Alpha Enjoyment of lesson
DLC	Pre-intervention	0.87	0.85
	Post-intervention	0.85	0.96
HDLC	Pre-intervention	0.89	0.89
	Post-intervention	0.93	0.90

The Cronbach's Alpha values are all high indicating that the TOSRA demonstrated a high level of internal consistency for both pre and post measures for both groups.

5.3 Responses to Research Questions

A Q-Q plot for each data set was made to determine whether parametric statistics were suitable for data analysis. It was decided that when outliers were ignored, the degree of normality was sufficient in all cases to use parametric statistics. As mentioned in Chapter 3, an ANCOVA did not indicate any relationships, therefore ‘*t*’ tests were used as the main tool for data analysis.

5.3.1 Response to Research Questions – Cognitive Domain

The research results are presented as responses to the research questions. The quantitative data used to answer Research Questions 1 and 2, which are concerned with the cognitive domain, are based on the constrained concept mapping task and the two tiered multiple choice test (Knowledge Test). Data for these questions are presented in tables of descriptive statistics and column graphs. It should be noted that some standard deviations for the concept mapping task are unusually high. This is due to the open ended nature of the task and the small sample sizes making the data vulnerable to outlier influences. Quantitative data for Research Questions 3, 4, 5 and 6, which are concerned with the affective domain are based on the TOSRA and are presented in tables of descriptive statistics.

Response to Research Question 1:

Is a three phase learning cycle an effective teaching model for bringing about conceptual growth in PEAC students studying basic electronics?

Concept map scores using the Yin method

In the following graphs, scores for both learning cycles have been categorized to compress a wide range into a smaller range in order to make more meaningful graphs. The raw scores were processed using SPSS and the resulting data are shown in tables of descriptive statistics and graphs. Data from two methods of scoring concept maps are included. The Yin method which emphasizes depth of knowledge and the Miller method that emphasizes structure of a student’s knowledge. Each method is dealt with separately. Preceding each data set analysis is a Q-Q plot to indicate that the use of a ‘*t*’ test is appropriate. The Q-Q plot forms a part of the descriptive statistics.

Concept map scores for the Descriptive Learning Cycle (DLC)

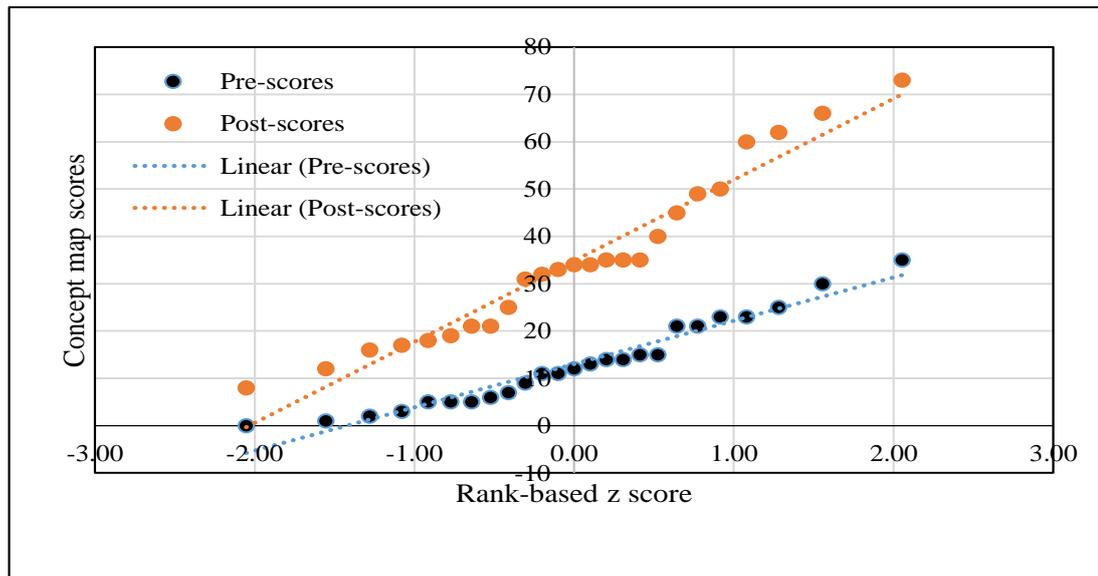


Figure 5. 6 Q-Q plot for DLC total concept scores (Yin Method).

The Q-Q plot indicates that the data set is sufficiently normal for the use of a ‘*t*’ test statistics to determine the significance of the difference of the respective means. The trend line gradient of the post-scores has increased indicating an increase in the range of scores as a result of the intervention. Four outliers in the post-scores appear to be partly responsible for this increase in the gradient.

Descriptive concepts scores

The intervention increased the descriptive concept mean score from 3.52 to 11.04 (Table 5.13). The standard deviation also increased and this is evident on the graph in Figure 5.7 where the scores span the complete range of possible scores for descriptive concepts based on the expert concept map (Appendix B). High standard deviations are a feature of the concept map data due to the open ended nature of the task. The ‘*t*’ value for the difference between the means was 3.76 which was significant at $p = 0.001$. The Cohen’s ‘*d*’ value of 1.08 indicates a large effect due to the intervention.

Table 5. 13 DLC group statistics for descriptive concept scores for Yin method (n=25).

Pre-test M (SD)	Post-test M (SD)	<i>t</i> -test (p)	Cohen’s <i>d</i>
3.52 (4.55)	11.04 (8.64)	3.76 (0.001)**	1.08

** $p < 0.001$

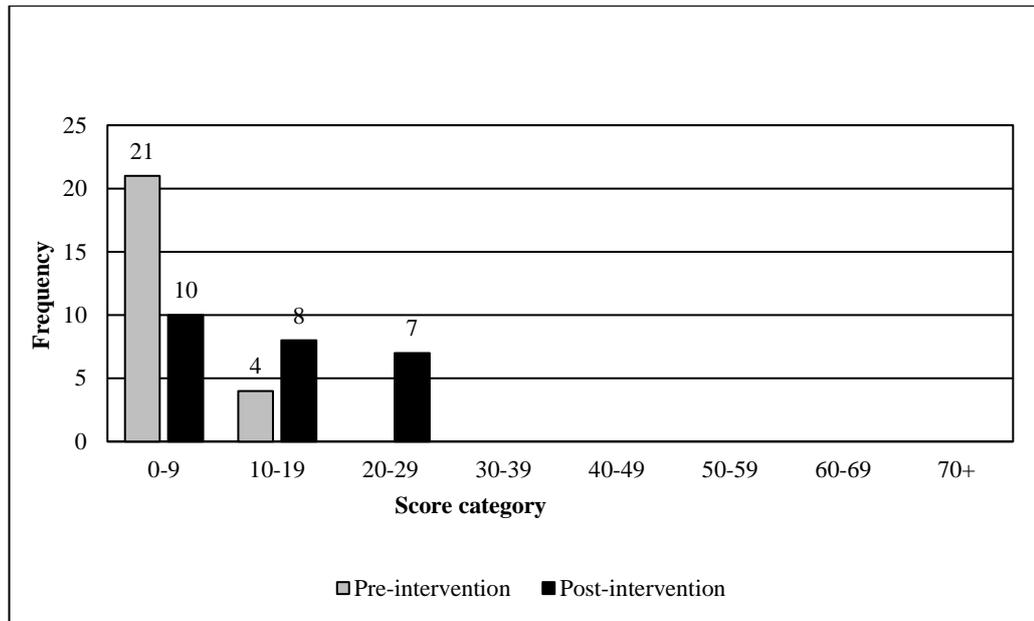


Figure 5.7 DLC group scores for descriptive concepts (Yin method).

It can be seen from the Figure 4.6 that few students had a strong prior knowledge of descriptive concepts related to electronics. These concepts were mostly regarding the functions of a variety of electronic components. The maximum score possible using the expert concept map was 25 for descriptive concepts and although some students went close to this score, nearly half of the group still remained in the 0-9 category.

Theoretical concepts scores

The means of both the pre and post course theoretical concepts were higher than for the descriptive concepts. However, this is just a reflection of the difference in the maximum scores available for descriptive and theoretical concepts respectively (25 compared to 55). The standard deviation also increased as is indicated in Figure 4.7. The t value of 7.05 was significant at $p < 0.001$ with an Cohen's d value of 1.42 indicating a very large effect size.

Table 5.14 DLC group statistics for theoretical concept scores for Yin method

($n = 25$).

Pre-test M (SD)	Post-test M (SD)	t -test (p)	Cohen's d
9.52 (7.29)	23.80 (12.20)	7.05 (0.000)**	1.42

** $p < 0.001$

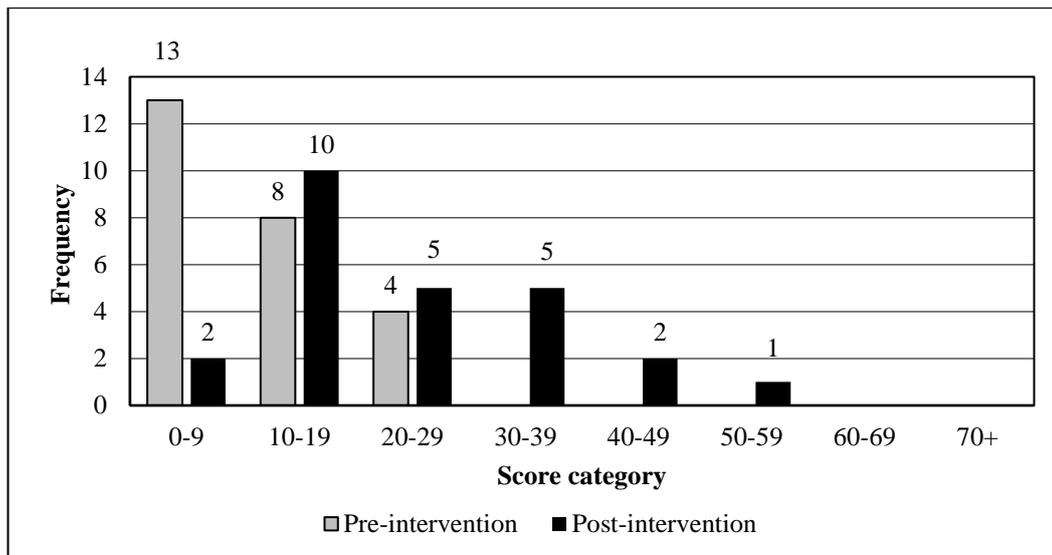


Figure 5. 8 DLC group scores for theoretical concepts (Yin method).

The theoretical concept scores before the intervention had a similar pattern to the descriptive concept scores in that the greatest number of students fell in the 0-9 category indicating little prior knowledge. The post intervention scores show a large drop in the 0-9 category (only two remaining) with most students falling in the 10-19 category. This would indicate that most students are beginning to understand some of the theoretical concepts. For comparison, the maximum score on the expert map for theoretical concepts was 55 and two students in the 40–49 category and one student in the 50-59 category came close to that score.

Total concepts scores

Table 5. 15 DLC group statistics for total concept scores for Yin method ($n=25$).

Pre-test M (SD)	Post-test M (SD)	t -test (p)	Cohen's d
13.03 (9.33)	34.84 (17.46)	7.94 (0.000)**	1.55

** $p < 0.001$

The post-intervention mean of 34.84 is almost three times that of the pre-intervention mean of 13.03. There is also a large increase in the standard deviation which is evident in Figure 4.8 with scores ranging from 0-9 to 70+. The ' t ' value of 7.94 was significant at $p < 0.001$ with an Cohen's ' d ' value of 1.55 indicating a very large effect size.

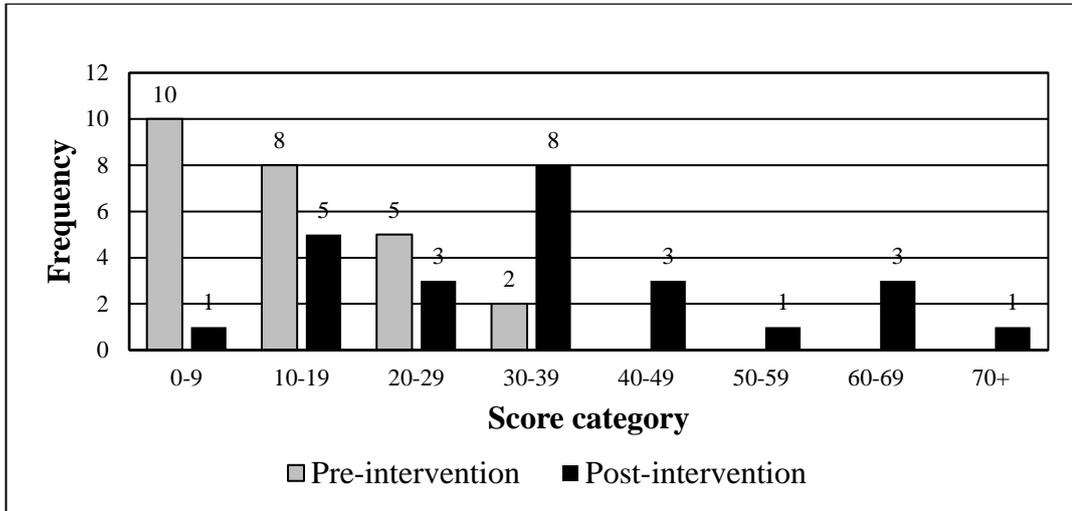


Figure 5. 9 DLC group scores for total concepts (Yin method).

An interesting feature of this graph is the linear fall in frequency of pre-intervention scores with the increase in the score category. However this does not occur for the post-intervention scores where the distribution of frequencies across the score categories seems to be random. It can be noted that one student, with a score of 73, approached the maximum score of 80 (based on the expert map). That student did have a high prior knowledge of electronics with the highest pre-course score of 35. This example highlights the need for a pre-course test to ascertain prior knowledge.

Concept map scores for the Hypothetical-Deductive Learning Cycle (HDLC)

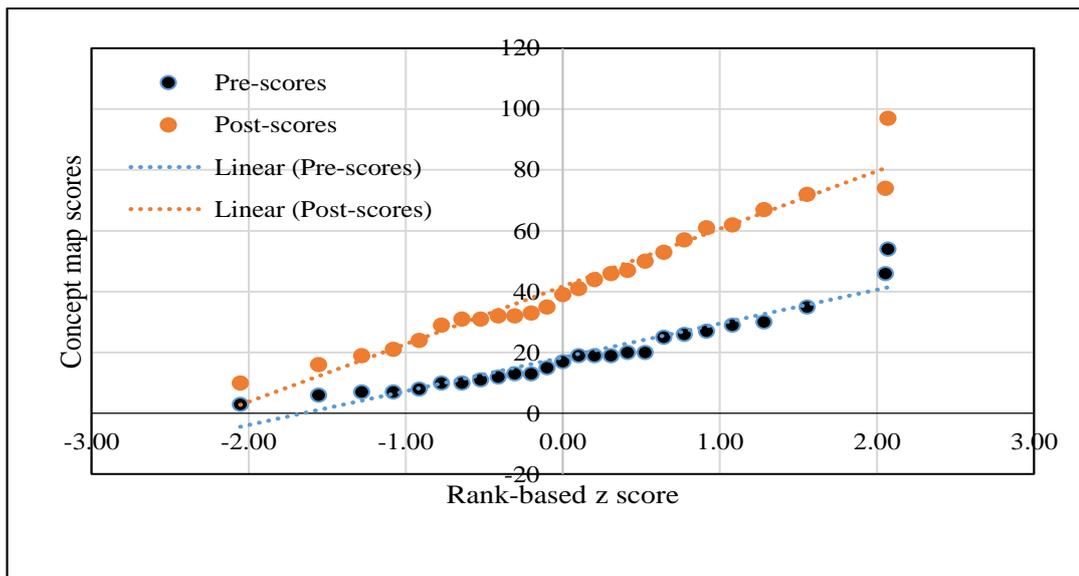


Figure 5. 10 Q-Q plot for HDLC total concept scores (Yin Method).

The Q-Q plot indicates that the data set is sufficiently normal for the use of a 't' test statistics to determine the significance of the difference of the respective means. The highest score in both the pre and post scores is an obvious outlier.

Descriptive concepts scores

Table 5. 16 HDLC group statistics for descriptive concept scores for Yin method
($n=26$).

Pre-test M (SD)	Post-test M (SD)	t-test (p)	Cohen's d
9.96 (9.04)	17.38 (11.65)	3.86 (0.001)**	0.71

** $p < 0.001$

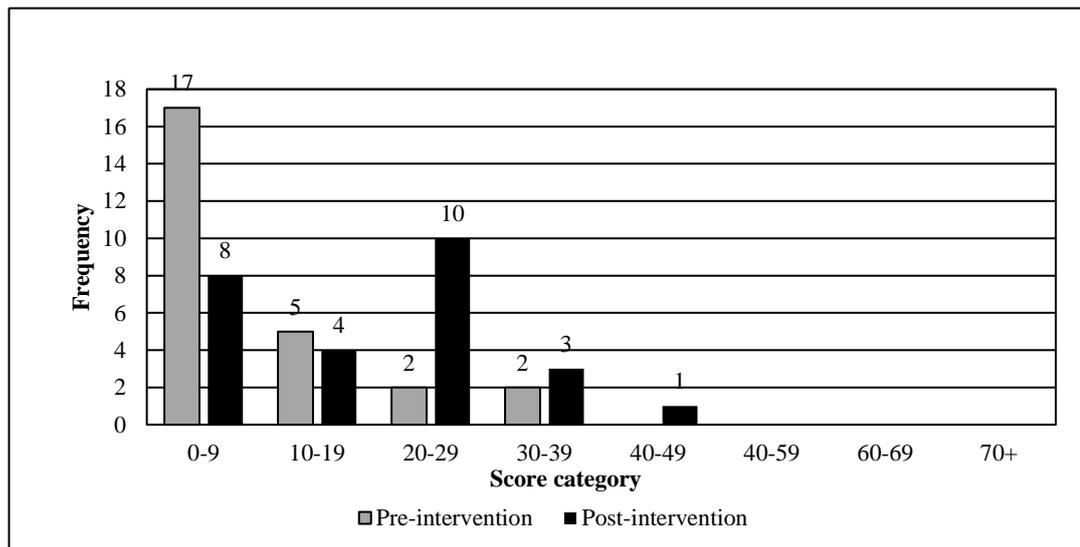


Figure 5. 11 HDLC group scores for descriptive concepts (Yin method).

The HDLC group is clearly a higher achieving group with respect to descriptive concepts, and this is indicated by the higher pre-intervention means of 9.96 compared to 3.52 (Table 5.13) for the DLC and post-intervention means of 17.38 compared to 11.04 (Tables 5.13) for the DLC. As with the DLC group the large range (see Figure 5.10) has created a large standard deviation. There is a statistically significant difference between the pre-intervention scores and the post-intervention scores for descriptive concepts with a 't' value of 3.86, and there is a large effect size.

If Figure 5.11 (HDLC descriptive concept scores) is compared with Figure 5.7 (DLC descriptive concept scores) the HDLC group contained two high achievers in both the pre-intervention and the post-intervention scores who had a large effect on the HDLC

means due to the small sample size. However the same basic pattern in the pre-intervention scores is evident, that is, the largest frequency is in the 0-9 category indicating little prior knowledge for the group as a whole. It should also be noted that the mean difference of descriptive concept scores for the DLC and the HDLC changed little as a result of the intervention.

Theoretical concepts scores

With respect to theoretical concepts, the HDLC group pre-intervention scores and post-intervention scores are remarkably similar to those of the DLC group (9.52 compared to 9.31 and 23.80 compared to 25.81 respectively). The increase in the mean and standard deviation as a result of the intervention is very similar to the DLC group with a *t* value of 7.72 (DLC = 7.05) which was statistically significant at $p < 0.001$ and an effect size of 1.53 (DLC = 1.42) which is considered very large.

Table 5. 17 HDLC group statistics for theoretical concept scores for Yin method ($n=26$).

Pre-test M (SD)	Post-test M (SD)	<i>t</i> -test (p)	Cohen's <i>d</i>
9.31 (6.88)	25.81 (13.56)	7.72 (0.000)**	1.53

** $p < 0.001$

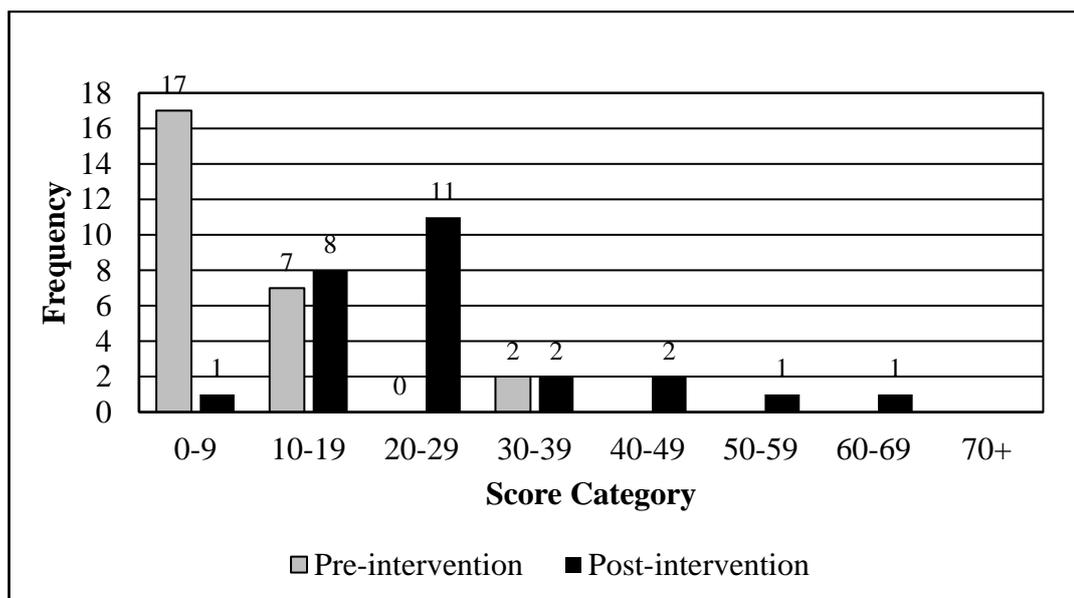


Figure 5. 12 HDLC group scores for theoretical concepts.

Figure 5.12 graph shows a similar pre-intervention score pattern to all the previous graphs in that the largest frequency is in the 0-9 score category. The post-intervention score for the 0-9 category reduced from 17 - indicating little prior knowledge, to 1 - indicating considerable acquisition of theoretical concepts. The same trend can be seen in the DLC theoretical concept graph. The pre-intervention mean scores for the DLC and the HDLC are similar for theoretical concepts. It appears that the superior prior knowledge of the HDLC was only for descriptive concepts.

Total concepts scores

The relatively high mean scores for the total concepts of the HDLC group, compared to the DLC group, can be partially explained by the relatively high pre-intervention scores for the descriptive concepts, indicating a high level of prior knowledge for those concepts. This high pre-intervention score for descriptive concepts, as was discussed in the comments relating to Figure 4.9, was influenced by two students who achieved a high score for those concepts. However, this was not the case with the theoretical concepts.

The 't' value of 9.39 was statistically significant at $p < 0.001$ and an effect size of 1.41 which is considered very large and is similar to the DLC group's 'd' of 1.55. Similar to the DLC group statistics, the large standard deviations can be explained by the large range of the student scores due to the open-ended nature of the concept mapping task.

Table 5. 18 HDLC group statistics for total concept scores for Yin method (n=26).

Pre-test M (SD)	Post-test M (SD)	t-test (p)	Cohen's d
19.27 (12.30)	43.19 (20.50)	9.39 (0.000)**	1.41

** $p < 0.001$

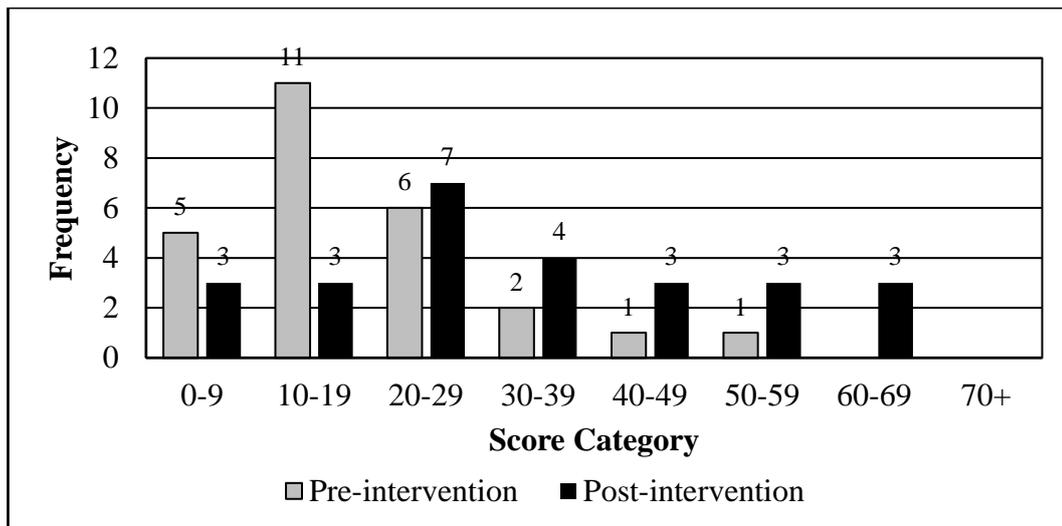


Figure 5. 13 HDLC group scores for total concepts.

The relatively low frequency (5) compared to the DLC group for the 0-9 category indicates a higher prior knowledge in the HDLC group when all concepts are considered.

Concept map scores using the Miller method

Concept map scores for the DLC.

As mentioned in Section 5.2.1, the Miller method of scoring concept maps takes into consideration the structure of the map which can give an indication of the structure of the student’s knowledge, compared to the Yin method which only considers the depth of knowledge. The Miller method of scoring addresses Research Question 1 with respect to the structure and quality of the student’s knowledge rather than the depth.

Table 5. 19 DLC group statistics for total concept map scores for Miller method. ($n= 25$).

Pre-test M (SD)	Post-test M (SD)	<i>t</i> -test (p)	Cohen’s <i>d</i>
8.68 (5.43)	19.76 (9.80)	7.25 (0.000)**	1.40

** $p < 0.001$

The means of the concept map total Score for the DLC group using the Miller method of scoring, shown in Table 5.19, increased by more than a factor of two as a result of the intervention, with a ‘*t*’ value of 7.25 which was statistically significant at $p < 0.001$. The effect size of 1.40 is considered very large. The range of the scores also increased,

but the range is less than that produced by the Yin method, resulting in lower standard deviations.

Figure 5.14 shows similar characteristics to the DLC total concept scores using the Yin method (Figure 5.9) in that the pre-intervention scores are highest in the 0-9 score category and then decline linearly. The post-intervention scores show a tendency toward a normal distribution.

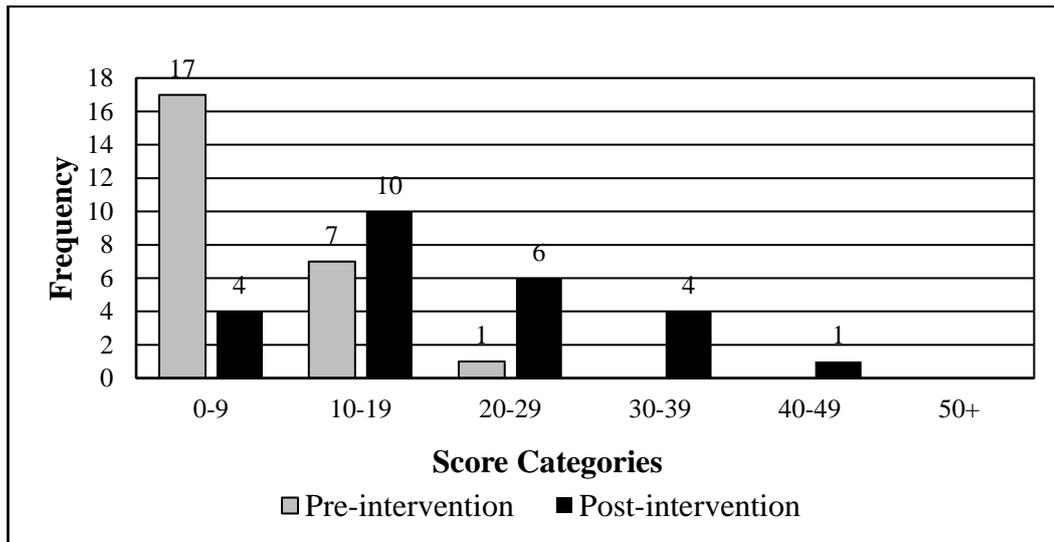


Figure 5. 14 DLC group concept map scores for Miller method.

Concept map quality scores for DLC

Quality scores are indicate the extent to which students understand the relationships between the key concepts in the electronics course. This is discussed in Section 5.2.1.

Table 5. 20 DLC group statistics for concept map quality scores for Miller method (n=25).

Pre-test M (SD)	Post-test M (SD)	<i>t</i> -test (p)	Cohen's <i>d</i>
0.92 (1.26)	3.68 (1.65)	8.17 (0.000)**	1.88

** $p < 0.001$

The spread of the map quality scores only increased slightly as indicated by the standard deviations (1.26 to 1.65). However, the map quality score mean for the DLC group increased by a factor of four as a result of the intervention, with a '*t*' value of 8.17 being statistically significant at $p < 0.001$. The effect size '*d*' of 1.88 is considered

very large. These results indicate a substantial increase in the student map quality as a result of the intervention.

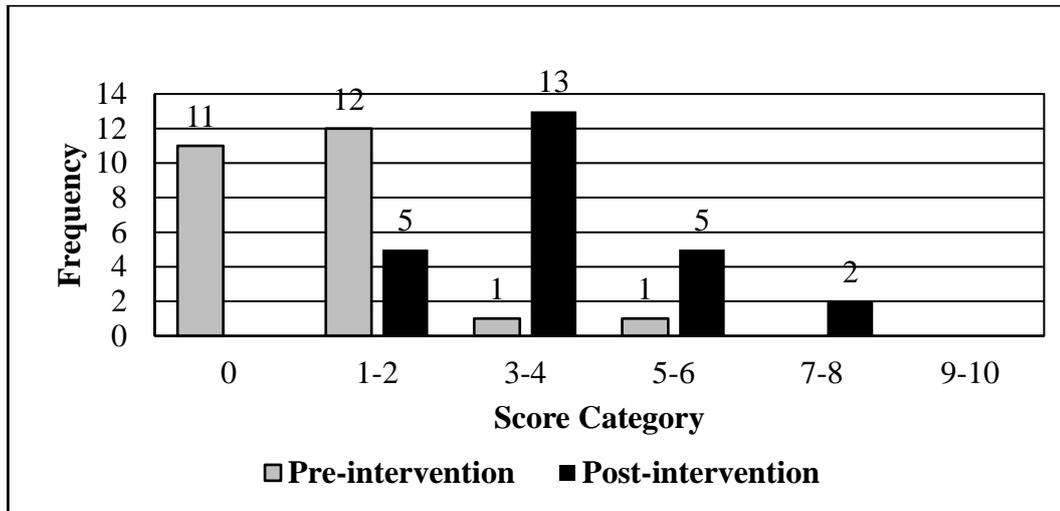


Figure 5. 15 DLC group concept map quality scores for Miller method.

From data in Figure 5.15 it can be seen that there was a large increase in the quality of the student's concept maps and this is evident with the effect size '*d*' of 1.88 in Table 5.20.

Concept map scores for the HDLC

Table 5. 21 HDLC group statistics for concept map scores for Miller method (n=26).

Pre-test M (SD)	Post-test M (SD)	<i>t</i> -test (p)	Cohen's <i>d</i>
12.69 (6.11)	21.35 (12.28)	4.69 (0.000)**	0.89

** $p < 0.001$

The mean increased by slightly less than a factor of 2 with a '*t*' value of 4.69 which was statistically significant with $p < 0.001$ and the effect size '*d*' of 0.89 is considered large. The effect size even though large was not as large as that for the DLC group. This can be attributed to the HDLC group's higher prior knowledge as discussed earlier. The large increase in the standard deviation can be explained partly by the one outlier with a score of 50+. With the exception of the outlier (50+) the graph for HDLC group concept scores (Miller method) has a very similar pattern to the DLC group's distribution of scores.

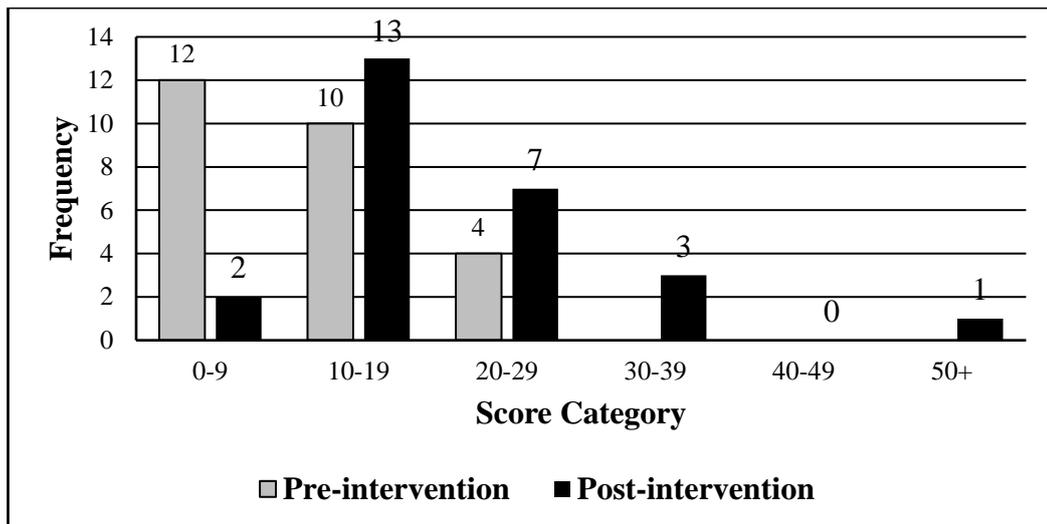


Figure 5. 16 HDLC group concept map scores (Miller method).

Map quality scores for the HDLC

The Map Quality score mean for the HDLC group increased by more than a factor of three, and there was a relatively large increase in the standard deviation as a result of the intervention. The bimodal nature of the distribution is one reason for the relatively large standard deviation. The *t* value of 6.78 was statistically significant at $p < 0.001$. The effect size *d* of 1.45 is considered very large and this is similar to the DLC group increase.

Table 5. 22 HDLC group statistics for map quality scores for Miller method (n=26).

Pre-test M (SD)	Post-test M (SD)	<i>t</i> -test (p)	Cohen's <i>d</i>
1.04 (1.31)	3.54 (2.06)	6.78 (0.000)**	1.45

** $p < 0.001$

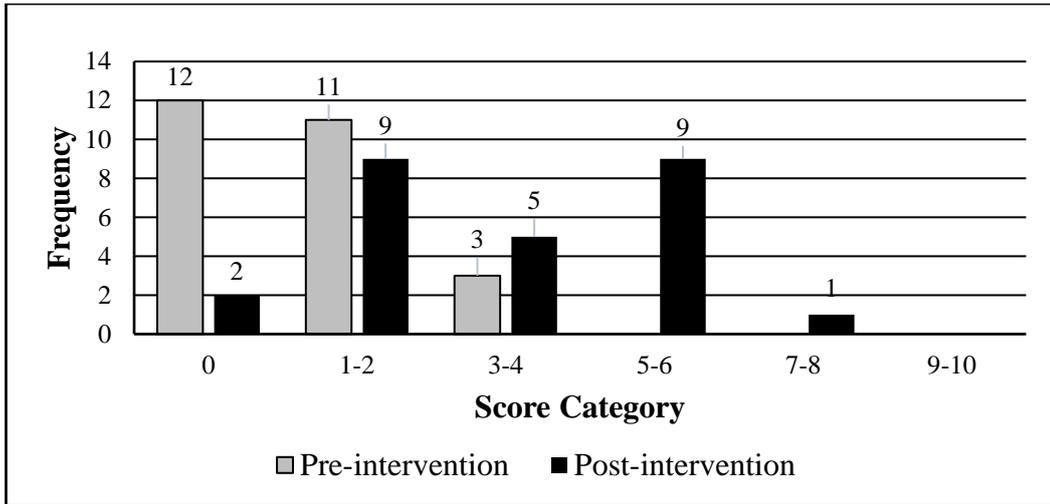


Figure 5. 17 HDLC group concept map quality scores for Miller method.

Map quality scores for the HDLC group increased similarly to the DLC group with the exception that the post-intervention distribution appears to be bi-modal. The two students in the 0-9 category, whose scores did not increase, also contributed to the high standard deviation.

Knowledge Test scores.

The data from previous sections, concerning the concept mapping task, examined the depth and quality of student knowledge. The data from the Knowledge Test in the next sections examine the student’s ability to apply that knowledge to answer 10 two-tiered multiple choice questions.

DLC Knowledge Test scores

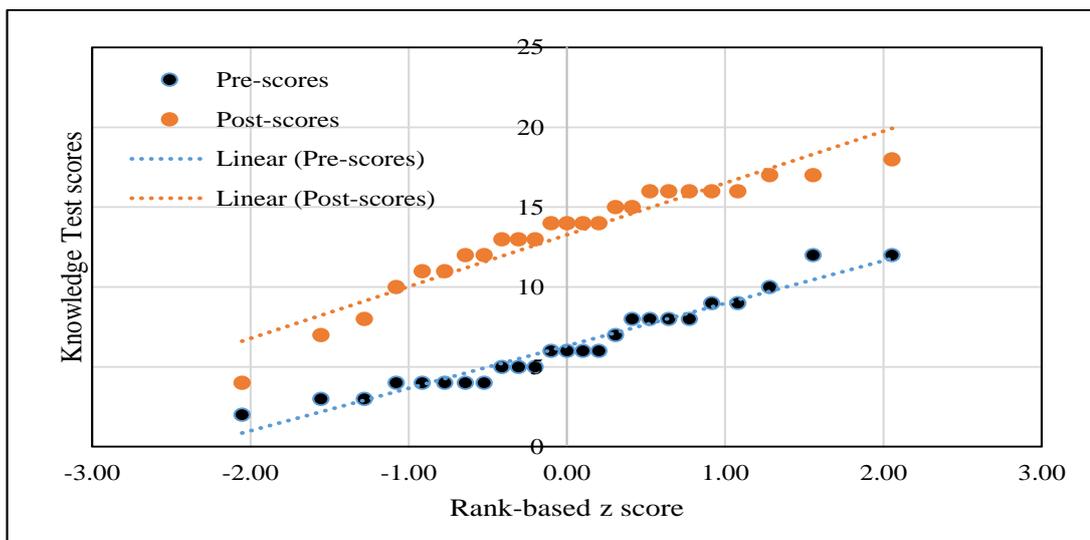


Figure 5. 18 Q-Q plot for DLC Knowledge Test scores.

The Q-Q plot indicates that the data set is sufficiently normal for the use of a 't' test statistics to determine the significance of the difference of the respective means. The pre-test scores have a slight downward curve indicating a skewness towards the lower scores. The post-test scores have an upward curve indicating a skewness towards the higher scores. This skewness is also evident on the histogram of the data in Figure 5.19. The Knowledge Test score mean for the DLC group increased from 6.32 to 13.28. This was an increase of more than a factor of two as a result of the intervention. The 't' value of 7.63 was significant at $p < 0.001$. The effect size of 'd' 2.27 is considered very large.

Table 5. 23 DLC Group statistics for the Knowledge Test
($n=25$).

Pre-test M (SD)	Post-test M (SD)	t-test (p)	Cohen's d
6.32 (2.72)	13.28 (3.37)	7.63 (0.000)**	2.27

** $p < 0.001$

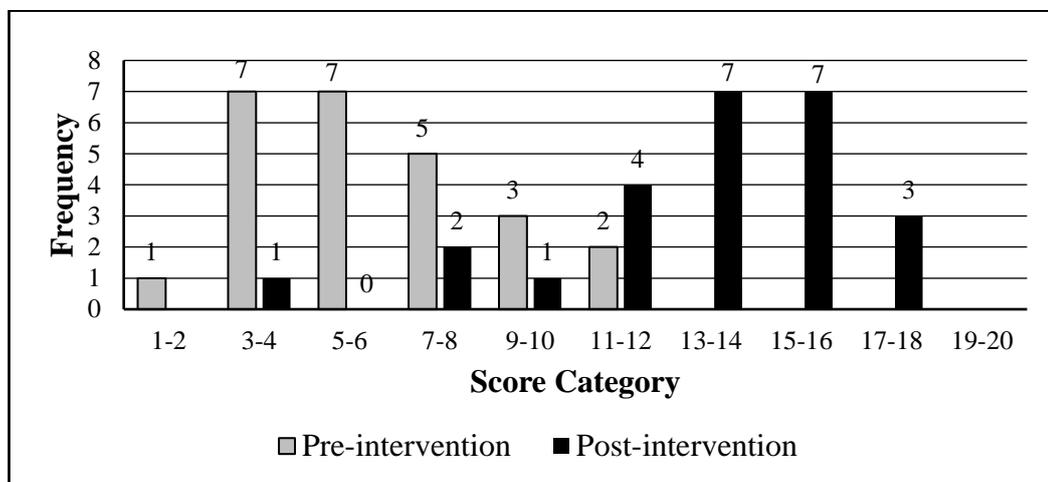


Figure 5. 19 Pre and post intervention DLC Knowledge Test scores.

Figure 5.19 shows that the pre- intervention scores are skewed to the low end and the post-intervention scores are skewed toward the high end with both score distributions tending towards normality. There appears to be only one outlier (post-intervention, score 3-4).

HDLC Knowledge Test scores

The Q-Q plot (Figure 5.20) indicates that the data set is sufficiently normal for the use of a 't' test statistics to determine the significance of the difference of the respective means. Multiple scores of the same value make this graph appear more scattered than it actually is. There appears to be no outliers or indication of significant skewness in either data sets. The Knowledge Test score mean for the HDLC group increased from 7.12 to 13.15. This increase is by nearly a factor of two as a result of the intervention, with a 't' value of 10.04 which was significant with a $p < 0.001$. The effect size 'd' of 2.21 is considered very large.

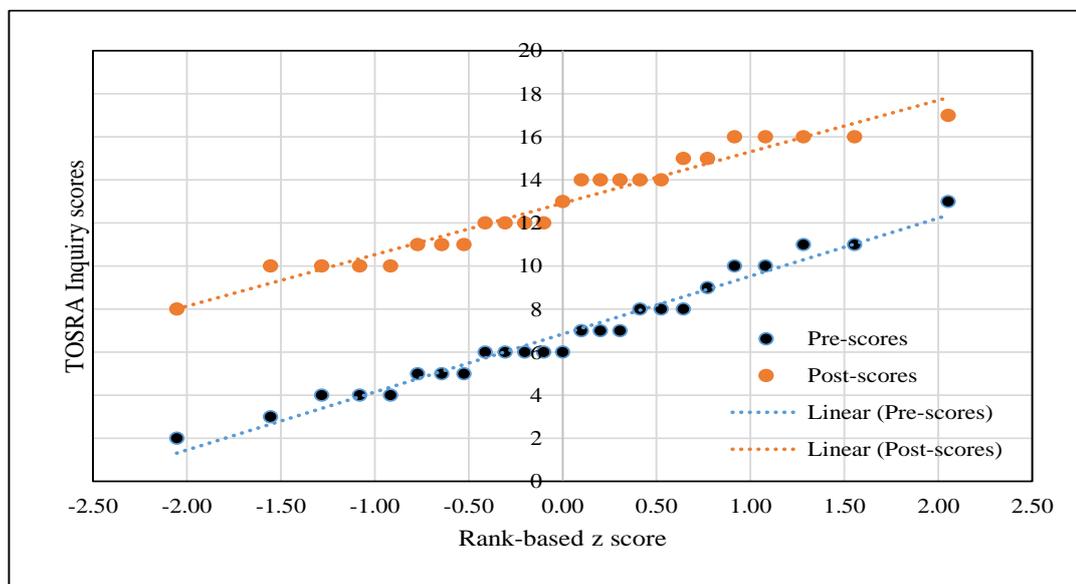


Figure 5. 20 Q-Q plot for HDLC Knowledge Test scores.

Table 5. 24 HDLC Group statistics for the Knowledge Test (n=26)

Pre-test M (SD)	Post-test M (SD)	t-test (p)	Cohen's d
7.12 (3.01)	13.15 (2.66)	10.04 (0.000)**	2.21

** $p < 0.001$

The histogram for the HDLC group appears similar to the DLC group in that both the pre-intervention and the post-intervention scores seem to be normally distributed. There appear to be no outliers.

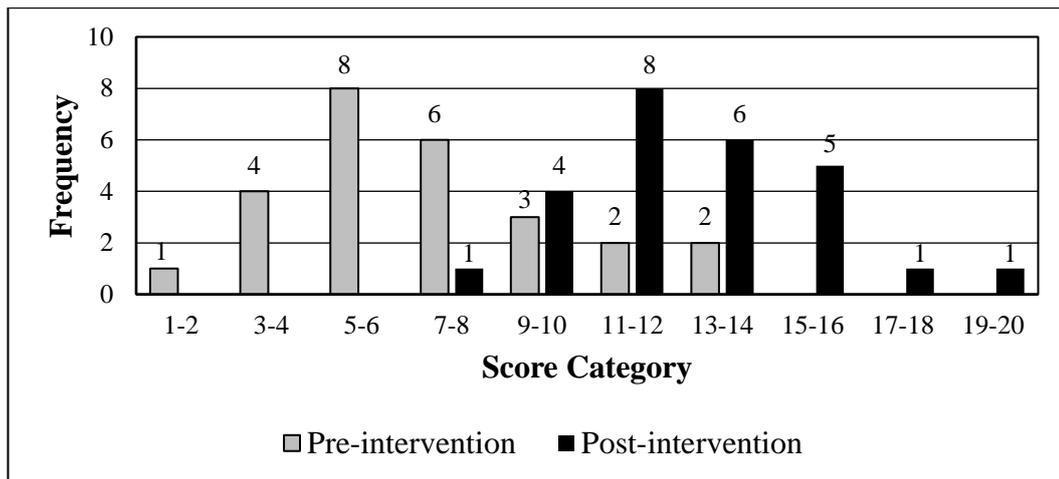


Figure 5. 21 Pre and post intervention HDLC Knowledge Test scores

Response to Research Question 2:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in bringing about conceptual growth in PEAC students studying basic electronics?

Comparison of the effectiveness of the DLC and HDLC

To answer Research Question 2, an independent samples test analysis was performed between the DLC and the HDLC group results for the concept mapping task and the knowledge test.

Concept map differences for the DLC and HDLC groups (Yin method)

Table 5. 25 Differences between means of the DLC and HDLC groups (Yin method)

Concept Type	Group	Pre Mean	Post Mean	Mean diff. (SD)	n.	df	t' value	Sig. (2 tailed)
Descriptive	DLC	3.52	11.04	7.52 (10.00)	25	49	-0.04	0.97
	HDLC	9.96	17.38	7.42 (9.80)	26	49		
Theoretical	DLC	9.52	23.80	14.28 (10.14)	25	49	0.75	0.46
	HDLC	9.31	25.81	16.50 (10.90)	26	49		
Total	DLC	13.03	34.84	21.80 (13.74)	25	49	0.57	0.57
	HDLC	19.27	43.19	23.92 (13.00)	26	49		

The very high standard deviations in Table 5.25 for the pre and post intervention difference scores are due to the large range in the student scores based on the open

ended nature of the concept mapping task. Table 5.25 shows that the descriptive concept difference of means for the DLC and the HDLC groups, differed by only 0.10 giving a *t* value of 0.035 which was not statistically significant. The means for the theoretical concepts and total concepts were higher for the HDLC group, giving a *t* value of 0.75 and 0.57 respectively, but these were not significant at the 0.05 level of significance. These results indicate there is no difference in the descriptive, theoretical and total concept score means as a result of the DLC and the HDLC interventions. Effect sizes (Cohen's *d*) for descriptive, theoretical and total scores of 0.01, 0.21, and 0.16 respectively are small.

Concept map differences for the DLC and HDLC groups (Miller method)

As shown in Table 5.26, using the Miller method of scoring, the DLC produced a higher mean difference than the HDLC; however this only produced a *t* value of 1.03 which is not statistically significant at the 0.05 level. Similarly the *t* value of 0.52 for the map quality difference of means was not significant at the 0.05 level of significance. These results indicate there is no difference in the concept score means (Miller method) when comparing the DLC and the HDLC interventions. Similarly the DLC and the HDLC interventions did not produce a difference in the map quality score means.

Table 5. 26 Differences between means of the DLC and HDLC groups (Miller method)

Concept Map	Group	Pre Mean	Post Mean	Mean diff. (SD)	n.	df	<i>t</i> value	Sig. (2 tailed)
Concept scores	DLC	8.68	19.76	11.08 (7.25)	25	49	1.03	0.309
	HDLC	12.69	21.35	8.65 (9.42)	26	49		
Quality scores	DLC	0.92	3.68	2.76 (1.69)	25	49	0.52	0.606
	HDLC	1.04	3.54	2.50 (1.88)	26	49		

The effect size (Cohen's *d*) for concept scores is 0.29 and for quality scores is 0.15 and both are considered small.

Knowledge Test differences between DLC and HDLC groups

An independent samples test analysis was performed on the Knowledge Test scores to determine if there was any difference between the means of the DLC group and the HDLC group as a result of the intervention. The maximum score possible on this test was 20.

Table 5. 27 Group statistics for the Knowledge Test

Group	Pre Mean	Post Mean	Diff of Means (SD)	<i>n</i>	df	' <i>t</i> ' value	Sig. (2 tailed)	Cohen's <i>d</i>
DLC	6.32	13.28	6.96 (4.56)	25	49	0.85	0.40	0.24
HDLC	7.12	13.15	6.04 (3.07)	26				

Table 5.27 shows that The DLC pre-post difference of means is slightly higher than that for the HDLC, however with a '*t*' value of 0.85 the difference is not statistically significant at $p < 0.05$. The effect size of '*d*' = 0.24 was small.

Scoring of key concepts

This section closely examines the data for each key concept from both the Concept Mapping Task and the Knowledge Test, rather than student scores, in order to more meaningfully interpret the responses to Research Question 2.

Key concept scores

In addition to student scores, the total score was made for each key concept using the Yin scoring method. The raw scores are in Table 5.27. Figure 5.22 presents the change in key concept scores for each group as percentages of the total conceptual growth scores for all students in each concept. Percentages were used for this chart as a means of placing the changes on a common scale for easier comparison.

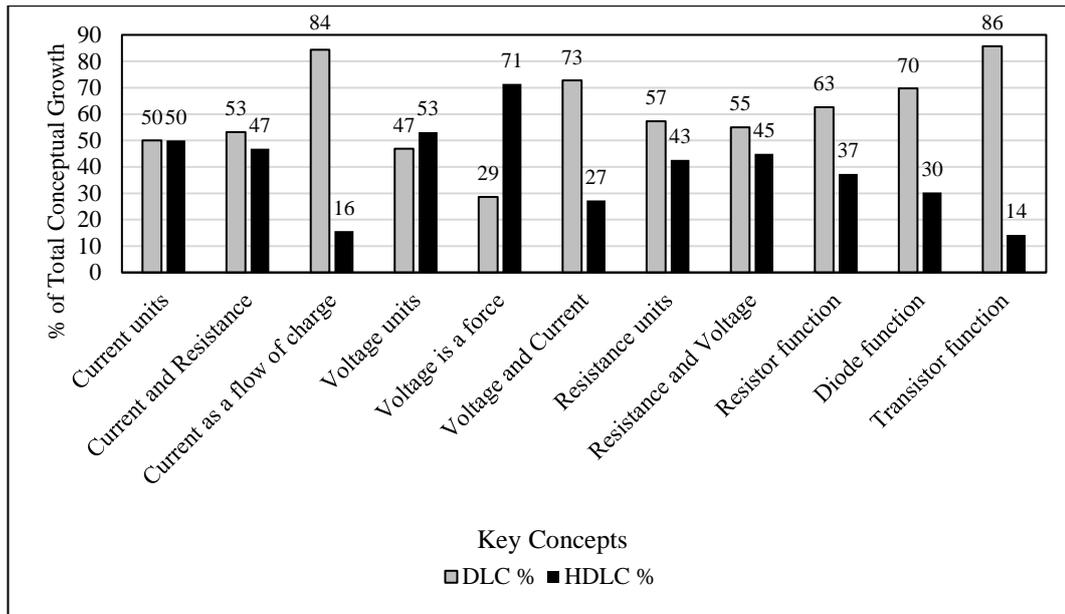


Figure 5. 22 Group percentage differences for Key Concepts for concept mapping task ($n_{DLC} = 25$; $n_{HDLC} = 26$).

Table 5.27 contains the total raw scores for each key concept in each group. Based on the expert map (Appendix B), the total possible score for each concept would be 125 for the DLC group ($n = 25$) and 130 for the HDLC group ($n = 26$). The data in Table 5.28 has two basic aspects. Firstly the pre-intervention scores indicate the degree of prior knowledge students have before starting the electronics course, and secondly the difference in scores indicate the degree the concept has been acquired by the students. A concept mapping task which is relatively open-ended does not necessarily indicate what each student understands. Being an open format task, the concept mapping task only records what the student recalls at the time of the test, prioritizes for the map, or was able to record in the time available. In other words, if a student omits to record a concept, it does not mean the concept is not understood. For these reasons analysis of the key concept scores is done on a qualitative basis only.

Table 5. 28 Raw scores of Key Concepts on Concept Maps
($n_{DLC} = 25$; $n_{HDLC} = 26$).

CONCEPT	DLC Pre	DLC Post	DLC Diff.	HDLC Pre	HDLC Post	HDLC Diff
Current is measured in Amps	5	42	37	5	42	37
Current is reduced by resistance or resistance reduces current	11	45	34	5	35	30
Current is a flow of charge/electrons	6	33	27	11	16	5
Voltage or electric force is measured in Volts	51	66	15	25	42	17
Voltage is a force	10	20	10	0	25	25
Voltage causes current to flow	11	19	8	10	13	3
Resistance is measured in Ohms	5	60	55	0	41	41
Resistance reduces voltage or electric force in a circuit	4	15	11	20	29	9
Resistor increases resistance (or any function)	0	52	52	7	38	31
Diode function - directs current in one direction (or any function)	0	23	23	8	18	8
Transistor function - amplifies current or acts as a switch	10	28	18	5	8	3

Key: Pre = pre intervention concept score.
 Post = post intervention concept score.
 Diff = difference between Pre and Post concept scores.

An examination of these scores indicates that there is no clear pattern. For example, *Current is measured in Amps*, has an equal score for each group, whereas *Voltage is a force* scores higher for the HDLC group, and *Current is a flow of charge* scores

higher for the DLC group. Also, some concepts score very high in the pre-test, such as “*Voltage is measured in Volts*’ and some score very low such as ‘*Resistor increases resistance*’. In order to interpret these results it was necessary to examine them in conjunction with the teacher reflections. For example, did the exact manner in which the concepts were presented in the teaching-learning situation influence the degree of acquisition by the students? Quotations in this section are from Chapter 5, teacher reflections. Each concept difference score is also discussed in conjunction with the Knowledge Test results for related concepts. Table 4.29 contains results for the key concepts from the Knowledge test (KT) which consists of 10 question with two questions based on the same concept. The full test can be seen in Appendix D. In Table 4.29 the questions are paired by common concept and the two item scores are averaged and expressed as a percentage of a perfect score. The difference scores are also expressed as a percentage. This differs from the concept mapping data (Table 4.28) because the Knowledge Test was not an open ended task.

Key concept analysis

The key concept analysis is based on the key concepts from the student concept maps of both groups as shown in Table 5.28 and Figure 5.22. Concepts that are also assessed in the Knowledge Test are indicated as follows: (KT, Items 1 and 2)

Table 5. 29 Knowledge Test concept results grouped by common concept.

Question	DLC Pre Av. %	DLC Post Av. %	DLC Diff %	HDLC Pre Av. %	HDLC Post Av. %	HDLC Diff %
1 and 2 – <i>Current and Resistance.</i>	67	90	23	75	86	11
3 and 4 – <i>Voltage and Current.</i>	36	67	31	50	58	8
5 and 9 – <i>Resistance Units and Resistor Code</i>	32	75	43	16	78	52
6 and 10 – <i>Circuits and Continuity.</i>	21	56	24	23	70	47
7 and 8 – <i>Component Function.</i>	14	44	40	16	43	27

Key: Pre = pre intervention; Post = post intervention; Diff = difference between Pre and Post.

Concept: *Current is measured in Amps* (no KT items – concept map only).

Both groups scored equally for this concept with only one student in each group having any prior knowledge of current being measured in Amps. Each group improved their score by 37 (Table 5.28: *Current is measured in Amps*; DLC, 37; HDLC, 37). which was fourth largest improvement of any concept. The concept of a unit of measure does not require a deep understanding of electricity and was relatively easily acquired by the students. In a study by Psillos, Tiberghien, and Koumaras (1988) on the voltage concept in secondary students, they asked 66 students the following question: ‘Which of the following units are familiar to you and give examples on where you have noted the term volt?’ (p. 31). They reported the following results (percentage of students who found the term familiar): Volt, 58%; Kilowatt, 35%; KWh, 3%; **Ampere, 3%**, and Coulomb, 1%. Examples on where they noted the term volt were: Batteries, 53%; household machinery, 12%; bulbs, 9%; others, 14% (Psillos et al., p 31). These results indicate that the unit ampere is not very familiar to secondary students and would most likely be less familiar to primary students, hence the low pre-test score for this concept. These results will also be discussed under the concept *Voltage is measured in volts*.

Concept: *Current is reduced by resistance* (KT, Items 1 and 2).

There is very little difference between pre-test and post-test percentage differences for this concept based on the concept mapping task (Figure 5.22) for either group (DLC 53%; HDLC 47%), but the change in score for each group was quite strong (Table 5.27; DLC 34; HDLC 30). It appears from these results that neither learning cycle had an advantage in teaching this concept. The Knowledge Test post-test results for Questions 1 and 2 (current and resistance) in Table 5.29, indicate that this concept was well understood and well applied in a problem situation (DLC 90%; HDLC 86%).

Concept: *Current is a flow of charge* (no KT items – concept map only).

Again students demonstrated little prior knowledge of a concept involving current. However the pre-test post-test difference percentages were very large for the DLC group namely 84%. The HDLC group’s difference was 16%. This was the largest group percentage difference for all the key concepts. In the DLC group the concept of current was explained using the analogy of water in a pipe.

In the HDLC group the definition of current and the ampere was assigned for homework after a short class discussion, which did not include an analogy, and the exact value of the ampere in electrons per second was also assigned for homework. The homework was discussed the following lesson. It appears from the results that the approach used for the DLC group was more effective than that used for the HDLC group. The scaffolding given the DLC group in the form of analogies and facts presented in an interesting way appears to be very successful, more successful than assigning individual research in the form of homework.

Concept: *Voltage is measured in Volts* (no KT items – concept map only).

Although the percentage difference scores for this concept are similar (Figure 5.22; DLC 47%; HDLC 53%) the pre-test scores are very high for each group indicating a strong prior knowledge. The largest pre-intervention scores for any concept was for the concept *Voltage is measured in volts* (Table 5.28; DLC 51; HDLC 25). The word voltage is commonly the first word a child hears in connection with electrical devices which is indicated by the Psillos et al. (1988) study mentioned in the discussion of the concept *Current is measured in amps*. It is a logical assumption from these early experiences, particularly for a gifted student, that voltage is measured in volts given the word *volt* is obviously derived from the word *voltage* and an easy guess for an intelligent child. The degree of score improvement for this concept was not as high as for *amps* because of the high prior knowledge but the post-test scores were correspondingly also the highest. The type of learning cycle used did not favour either group.

Concept: *Voltage is a force* (no KT items– concept map only).

The concept ‘voltage is a force’ is arguably the most difficult of all the concepts in the PEAC Electronics course. It is also the only key concept the HDLC group achieved a significantly higher difference score than the DLC group (Table 5.28); DLC, 10; HDLC, 25) although neither group achieved a very high post-intervention score on this concept. Because the scores are small the percentage differences shown in Figure 5.22 (DLC, 29%; HDLC, 71%) are exaggerated and should be considered with caution. The concept that voltage is a force was given to the DLC students after a short question time in which no student was able to give the correct answer.

A transcript of the DLC lesson recording from Chapter 4 is (T = teacher; S = student):

- T:** *What do you think voltage is?*
- S:** *It's a unit of power.*
- T:** *It's not power.*
- S:** *Its electrons.*
- T:** *No it's not electrons*
- S:** *It's electricity.*
- T:** *No, that word is too general. Now watch this. (Teacher hold up a duster).
What happens when I let it go?*
- S:** *It falls.*
- T:** *Correct (lets duster drop) – what caused it to fall.*
- S:** *Gravity.*
- T:** *Voltage is a force like gravity.*

The equivalent discussion in the HDLC group was similar. However the discussion was preceded with a thinking time where students could discuss the concept with their partner and write down their thoughts. The students had to arrive at the conclusion that voltage was a force. The teacher did not give the definition of voltage as in the DLC group which had to come from the students' discussion. From the following transcript it can be seen that the HDLC students could not arrive at the correct answer until an analogy was used:

- T:** *Now I want you to think about what voltage actually is and write your thoughts on your worksheet. [Students write responses on worksheet; T checks student responses]. Everyone has written an answer but I have not seen the correct answer yet, although some are getting close.*
- S:** *Gives power to the circuit and voltage is more electricity.*
- T:** *Change the word power and you will be getting close.*
- S:** *Voltage is energy.*
- T:** *Not exactly, but can be considered a type of potential energy.*
- S:** *Voltage is current.*

T: *No, voltage is not current. I will have to give you a clue. Voltage is like gravity.*

Now if I put this object up here [on the desk] and push it over the edge, what made it fall?

S's: *Gravity.*

T: *What is gravity?*

S's: *A force [class in unison!]*

T: *Now let me ask again – What is voltage?*

S's: *It's a force! [class in unison!].*

It is interesting to note that the concept of 'voltage is a force' was arrived at immediately the gravity analogy was used. The analogy was only used as a last resort. Even after discussion with their partner and group discussion the students could not arrive at the answer therefore an analogy was used. The concept that gravity is a force is well established in most children (Vosniadou, 1994). It is a concept they have experienced since a very early age. Relating gravity to voltage led to an immediate understanding in most students. A young child develops a naïve framework theory about gravity through simple experiences such as dropping objects, and by using the analogy (mental model) of gravity to explain voltage, an existing structure has been enriched leading to conceptual change (Vosniadou, 1994). The HDLC voltage lesson and discussion also satisfies Ausubel's (1963) criteria for meaningful learning, where the learner needs (a) a framework of understanding to draw on (prior knowledge of gravity); (b) to relate new ideas (voltage) to what they already know; and (c) meaningful tasks to give direct experience (concept exploration). Ausubel considers prior knowledge as the most critical.

The HDLC (41 minutes) lesson took a longer time to complete than the DLC lesson (30 minutes) due to the time given to discussion between the teacher and class and between the students. The HDLC students needed to develop their own definition and understanding of voltage.

Concept: *Voltage and current* (KT, Items 3 and 4)

Lesson 5 dealt with voltage and current and dealt with the most difficult concept in the whole electronics course. Post-intervention concept map scores only improved marginally for this concept. The DLC group only improving by 8 raw score points

and the HDLC by 3 points (Table 5.28). Questions 3 and 4 of the Knowledge Test indicate a better student understanding of this concept. The DLC group post-test for the knowledge test improved by 31%, and the HDLC by only 8% (Table 5.29). This supports the scores for the concept map. In Lesson 5, DLC students were carefully guided through what was a complex lesson whereas HDLC students needed to set hypotheses and plan experiments with less teacher support on the actual concept. Most student support given by the teacher for the HDLC was for the ‘scientific process’. It appears the concept may have been lost in the lesson process in the case of the HDLC group.

Concept: *Resistance is measured in ohms* (KT, Items 5 and 9)

This concept, which is quite a simple one, produced the best result in terms of improved concept raw scores between the pre-test and post-test on both the concept map task (Table 5.28: DLC, 55; HDLC, 41) which gave a conceptual growth of 57% and 43%, respectively (Figure 4.22) and the relevant Knowledge Test items (Table 5.28: DLC, 43%; HDLC, 52%). The concept map scores indicate that only one student had prior knowledge of the ohm as a unit of resistance. During the course of the electronics course, students were continually dealing with resistors and those resistors were always named by their value. For example in their exploration phase of a lesson they used 5 and 20 ohm resistors, and in their projects a variety of resistors ranging from 390 ohm to 100k ohm. DLC students were slowly guided through the colour code and then given several resistors with which to practice. The procedure was mastered by most students in the first or second attempt. The HDLC students were given a set of cards with resistors on them and a sheet describing how to use the code. Students were asked to ‘crack the code’ with their partner. Some students were able to use the code within a few minutes.

All student projects contained resistors and each had to be placed correctly into their respective circuits. Students needed to use the colour code sheet to determine the correct resistor, however there were many mistakes. If a DLC student placed a resistor in the incorrect place he or she was advised of the error and asked to read the code to the teacher. HDLC students were simply told that their resistors were in the wrong position and to go back to their workstation to determine which one. Some students struggled with this procedure and asked other students or compared their circuit board

with another. If they could not solve the problem independently they were advised in the same way as the DLC students.

Neither the DLC nor the HDLC gave a clear advantage in the acquisition of this concept. However, continually using the word ohm in the context of their projects produced a very good result in both groups.

Concept: *Resistance and voltage* (no KT items).

This concept was not directly dealt with in a lesson. It was dealt with during the project constructions. Most projects contained a 390 ohm resistor to reduce 9 volts to 3 volts for use with LEDs. This was explained to students but there was no lesson to explore the concept, and consequently little gains were made (Table 5.28: *Resistance reduces voltage*; DLC, 11; HDLC, 9).

Concept: *Resistors function* (KT, Items 1 and 2)

The effect of resistance on current and the function of globes was dealt with in Lessons 1 and 2 when students were able to see the effect of a large resistor on the brightness of a globe. They were able to observe that an increased resistance, as indicated by the value marked on the resistors, reduced the brightness of the globe in the circuit, and all the student projects contained resistors and students needed to know their values and functions in the circuit. Consequently, students in both groups were able understand that *resistors increase resistance*. The increase in concept scores in the concept mapping task were relatively high for each group ((DLC 52; HDLC 31). These raw score changes represented 63% for the DLC and 43% for the HDLC groups. Much of the *Exploration* and *Concept Development* time in Lesson 3 (Resistance) for the HDLC group centred on hypothesis setting and designing experiments to test the hypotheses. Discussion on the nature of resistance was mostly student-centred. Students discussed with their partners a possible reason for the light being dimmer with increased resistance. No analogies were used by the teacher and students had to research definitions for resistance and resistors for homework. The use of an analogy, water in a pipe with a tap as a resistor, and the teacher-centred discussion in the DLC group clearly produced a better result for this concept than for the HDLC group which had less scaffolding and was more student-centred. The lack of prior knowledge indicated that this concept was new to the students, therefore a high degree of scaffolding seemed necessary.

Concept: Diode function (KT, Items 7 and 8)

With respect to the concept mapping task, the DLC group scored 0 on the pre-test and 23 on the post-test giving a difference of 23 (70%). The HDLC group had some prior knowledge with a pre-test of 8 and a score of 18 on the post-test with a score difference of 10 (30%). This result is consistent with the knowledge test result of 40% and 27% improvement, respectively. The *Exploration* phase was identical for both groups in this lesson (Lesson 6 Diode Function). However after class discussion regarding difficulties in connecting diodes and during the *Concept Development* phase, the DLC group were given two facts about diodes: diodes have a positive (anode, A) and a negative (cathode, K) side; and diodes only conduct a current in one direction. These rules were written on their worksheets. These rules were not given to the HDLC group. They needed to design, with the help of their partner, a set of instructions for correctly connecting diodes in a circuit. This set of instructions led to the rule for diode connection. The function of diodes and the rule for their connection was assigned for homework ready for discussion next lesson.

Diodes featured prominently in the student projects. All projects contained at least one diode, and the incorrect connection of diodes was the most common fault in student circuits. When this happened, DLC students were told by the teacher how to correct the problem by reminding them of the rule for diode connection. The rule was constantly being reinforced. HDLC students were given a list of common faults in student circuits and told to isolate the fault for themselves by working through the list. It appears that the strategy of clearly defining the characteristics of diodes for the students and reinforcing the rule of connection when problem solving their faulty projects produced the better result.

Concept: Transistor function (no KT items).

Transistors are more complex than diodes and both groups needed help in connecting them into a circuit. When explaining the function of a transistor, the water and tap analogy is ideal. A tap has an inlet (collector) and an outlet (emitter) with the tap handle (base) used to regulate the flow of water. This analogy was used to describe the function of the transistor to the DLC group. The HDLC group were given a circuit diagram of their water indicator project (a one transistor amplifier) and were asked to try and describe the function of the transistor in the circuit. This exercise required a

lot of scaffolding by the teacher. In both groups, the transistor function was demonstrated as a class activity with the class being the base resistor (Lesson 7).

The water analogy in conjunction with the teacher defining the function of transistors seemed to achieve a better result. The DLC group achieved 86% of the total transistor function concepts on the mapping task, and the HDLC only 14%.

5.3.2 Response to Research Questions - Affective Domain.

Two scales of the seven that make up the TOSRA were used for this study – ‘*Attitude to Scientific Inquiry*’ and ‘*Enjoyment of Science Lessons*’. Only two dimensions were chosen due to the time constraint of the student contact time within this study and the full test was considered too long for Year 6 students.

The Q-Q plots indicate that the data sets for ‘*Enjoyment of science lessons*’ do not seem sufficiently normal for the use of a ‘*t*’ test statistics to determine the significance of the difference of the respective means. The data sets for *Attitude towards scientific inquiry* seem more normal and suitable for a ‘*t*’ test. Levene’s test for equality of variance is $p = 0.90$ for *Attitude towards scientific inquiry* and $p = 0.30$ for *Enjoyment of science lessons*. These values allow the assumption of equal variance for the two groups. Also the data sets both appear to be skewed towards the high scores. The robustness of the ‘*t*’ test is able to allow for this if the skewness is in the same direction, which it is, and if the sample size is not very small. The sample size for the Levene’s test was 51 (df = 49) which is not very small.

Response to Research Question 3:

Does a three phase learning cycle change PEAC students’ attitude toward scientific inquiry?

This scale was chosen because the study was using inquiry learning strategies and therefore it seemed appropriate to determine whether this had an effect on their attitude to scientific inquiry. The Cronbach’s Alpha coefficient in both groups was high (DLC; 0.87 and HDLC; 0.89) and compares favourably with those quoted in the TOSRA Handbook (Fraser, 1981, p. 6) for Australia (0.69 to 0.81). More recent studies by Wong and Fraser (1996) and Lowe (2004) give values of 0.86 and 0.83, respectively. It should also be noted that the means in all cases were high for both pre- and post-intervention scores. This indicates a generally high positive attitude in most students towards scientific inquiry.

Results for Descriptive Learning Cycle (DLC)

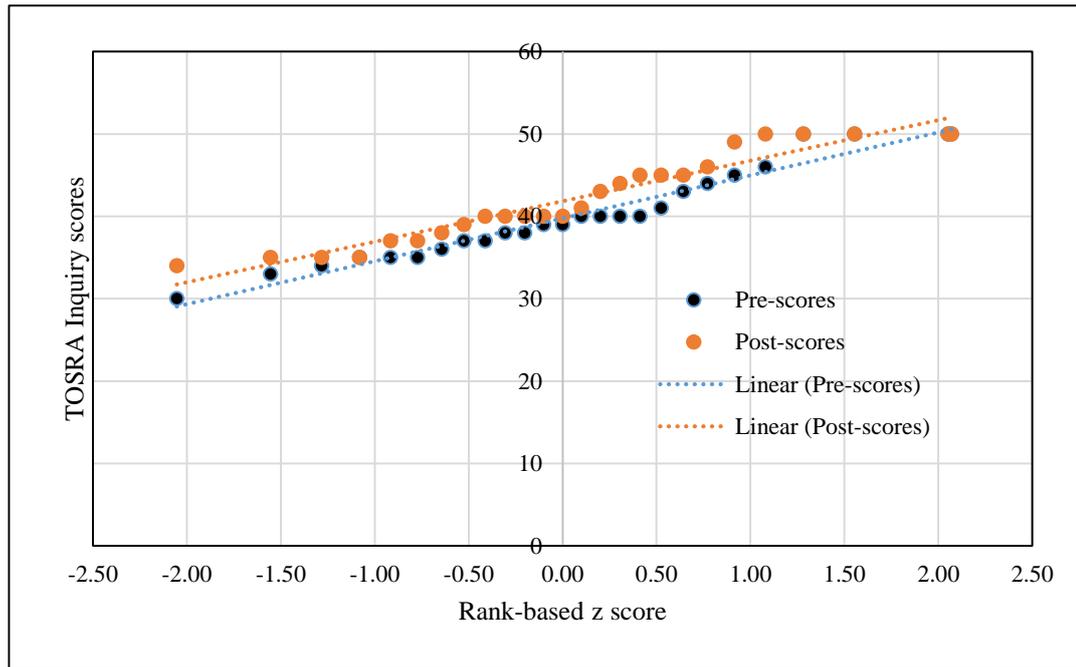


Figure 5. 23 Q-Q plot for DLC student's 'Attitude toward scientific inquiry' scores.

The Q-Q plot indicates that the data set is sufficiently normal for the use of a 't' test statistics to determine the significance of the difference of the respective means. No outliers are apparent in this plot. It can be seen from Table 5.30 that the DLC had a positive effect on students' attitude towards scientific inquiry as indicated by the mean score increasing from 39.80 to 41.92. The 't' value of 2.46 was statistically significant at $p < 0.05$. The effect size using Cohen's 'd' was 0.40 and is considered moderate.

Table 5. 30 DLC results for Pre-Post Mean differences for 'Attitude to Scientific Inquiry' ($n=25$)

DLC Group	Mean (SD)	Cronbach's Alpha	't' value	Effect size 'd'
Pre-Intervention.	39.80 (5.24)	0.87	2.46 (0.021)*	0.40
Post-Intervention.	41.92 (5.36)	0.85		

* $p < 0.05$

Results for Hypothetical Deductive Learning Cycle (HDLC)

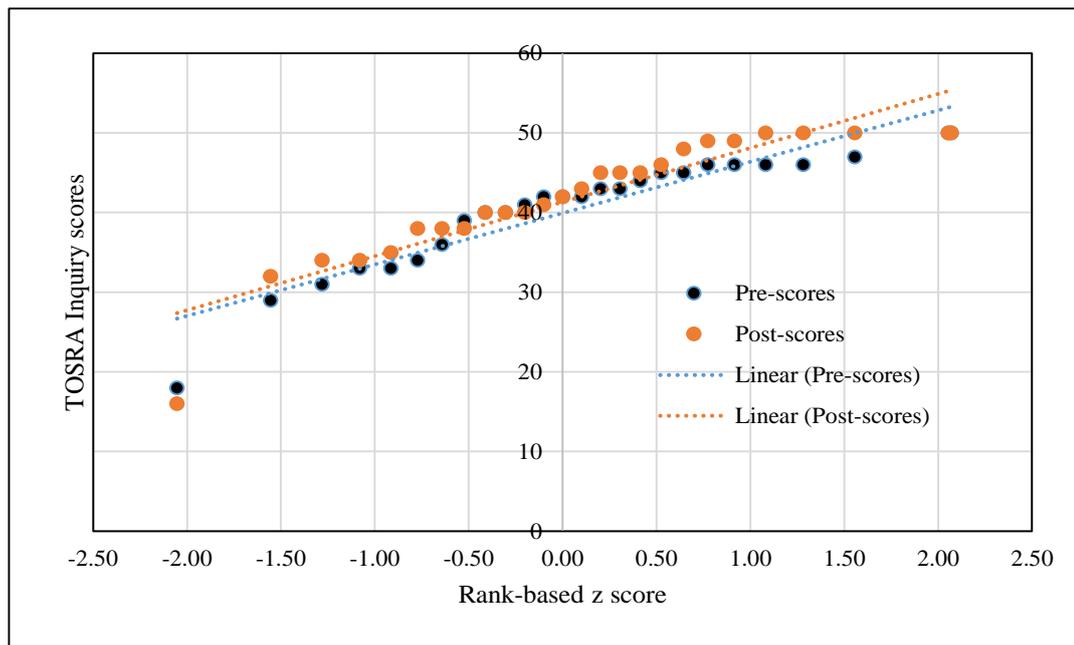


Figure 5. 24 Q-Q plot for HDLC student's 'Attitude toward scientific inquiry' scores. The Q-Q plot indicates that the data set is sufficiently normal for the use of a 't' test statistics to determine the significance of the difference of the respective means. The plot also indicates both data sets are skewed towards the high end. Two outliers are evident in both the pre and post-test scores.

Table 5. 31 HDLC results for Pre-Post Mean differences for 'Attitude to Scientific Inquiry' (n=26).

HDLC Group	Mean (SD)	Cronbach's Alpha	't' value (Sig)	Effect size 'd'
Pre-Intervention.	40.42 (7.27)	0.89	1.69 (0.104)	0.19
Post-Intervention.	41.85 (7.78)	0.93		

The pre-intervention mean for *Attitude to Scientific Inquiry* of 40.42 was high indicating that students started the course with a strong positive attitude towards scientific inquiry. This relatively high mean reduced the amount of improvement the students could make. The mean score did increase to 41.85. This increase in the mean for *Attitude to Scientific Inquiry* is small and the 't' value of 1.687 was not statistically

significant at $p < 0.05$ (Table 4.31). The effect size using Cohen's 'd' was 0.19 and is considered small.

Response to Research Question 4:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing PEAC students' attitude toward scientific inquiry?

The DLC students had a slightly higher positive difference mean than the HDLC students but the difference between the means of both groups was not statistically significant.

Table 5. 32 Pre and Post Mean group differences for 'Attitude to Scientific Inquiry'

Group	Pre Mean	Post Mean	Mean Diff.	n	't' value	Cohen's 'd'
DLC	39.80 (5.36)	41.92 (5.24)	2.12 (4.30)	25	0.58 (0.566)	0.16
HDLC	40.42 (7.28)	41.85 (7.78)	1.43 (4.30)	26		

Although there is a very small effect ($d = 0.16$) in favour of the DLC group as a consequence of their respective learning strategies, the 't' value of 0.58 is not statistically significant at $p < 0.05$. The effect size using Cohen's 'd' was 0.16 and is considered small.

Response to Research Question 5:

Does a three phase learning cycle change PEAC students' enjoyment of science lessons?

Establishing a strong interest in science during a student's primary education years is important for their future secondary education motivation and interest, consequently this scale was chosen to determine the effect of learning cycles on the enjoyment of science lessons.

The scatter of post-test scores in the Q-Q plot (Figure 5.25) is confused by the representation of multiple scores of the same value. The distribution is highly skewed towards the high score end. Half the scores are in the range 48 to 50. It was however considered that the data sets were suitable for the use of a 't' test as discussed in the introduction at the beginning of Section 5.3.2. This decision was based on the fact that

the ‘*t*’ test is robust if skewness of the two samples are in the same direction, the sample size is not very small, and equal variances are assumed. The data satisfies these assumptions.

Results for Descriptive Learning Cycle.

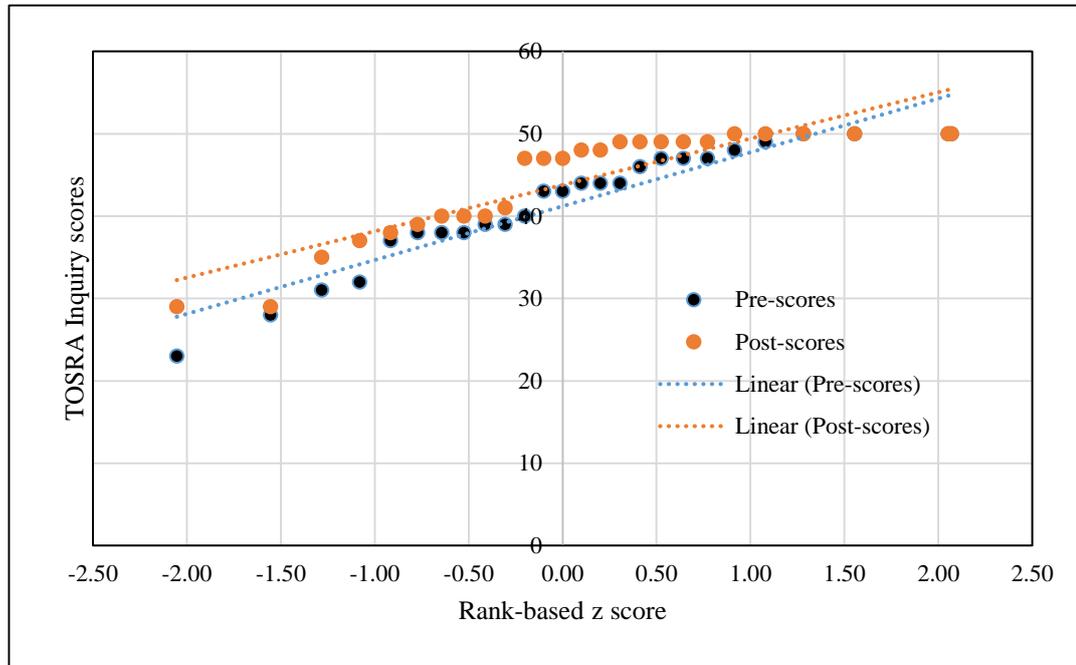


Figure 5. 25 Q-Q plot for DLC student’s ‘*Enjoyment of science lessons*’ scores.

Students commenced the PEAC Electronics course with a strong sense of enjoyment towards science with a mean score of 41.40 out of a possible 50. This mean increased to 44.00 as a result of the course. The Cronbach’s Alpha values for this scale of 0.85 and 0.96 for the DLC group are very high and are similar to the value quoted by Fraser of 0.91 for Australian students (1981, p. 6). Similar values are given by Wong and Fraser (1996), Lowe (2004) and Martin-Dunlop and Fraser (2008) of 0.97, 0.88, and 0.98, respectively.

The *Enjoyment of Science Lessons* mean score for the DLC group increased as a result of the intervention, with a ‘*t*’ value of 2.463 which was statistically significant at $p < 0.05$. The effect size ‘*d*’ of 0.22 is considered small.

Table 5. 33 DLC results for Pre-Post Mean differences for ‘Enjoyment of Science Lessons’
($n=25$).

DLC Group	Mean (SD)	Cronbach’s Alpha	‘ t ’ value	Cohen’s ‘ d ’
Pre-Intervention.	41.40 (7.21)	0.85	2.463 (0.02)*	0.22
Post-Intervention.	44.0 (6.65)	0.96		

* $p < 0.05$

Results for Hypothetical Deductive Learning Cycle

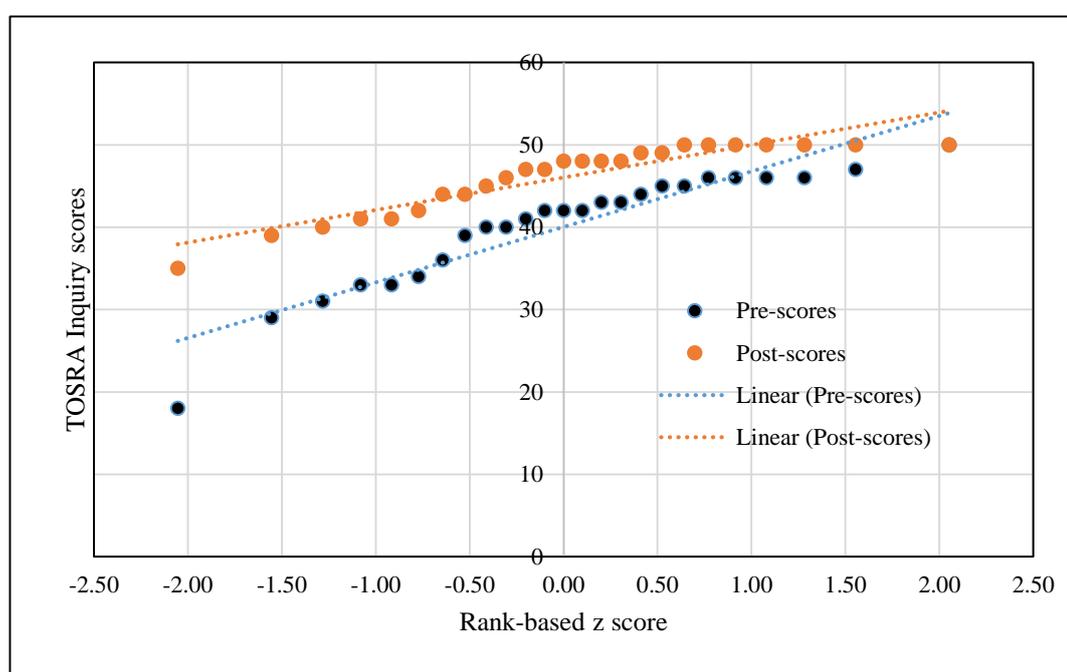


Figure 5. 26 Q-Q plot for HDLC student’s ‘Enjoyment of science lessons’ scores.

The Q-Q plot indicates that the data set is sufficiently normal for the use of a ‘ t ’ test statistics to determine the significance of the difference of the respective means. The plots indicate that both data sets are skewed to the high scores. One pair of scores at the low score end appear to be outliers. Inspection of the raw data indicated that these scores were from the same student, indicating this students made the biggest improvement in attitude. These results follow a similar pattern to the DLC group in that the students commenced the course with a strong sense of enjoyment towards science and this further improved as a result of the intervention.

Table 5. 34 HDLC results for Pre-Post Mean differences for ‘*Enjoyment of Science Lessons*’ (n=26).

HDLC Group	Mean (SD)	Cronbach’s Alpha	‘t’ value (Sig)	Cohen’s ‘d’
Pre-Intervention.	45.77 (4.47)	0.89	0.35 (>0.200)	0.01
Post-Intervention.	46.19 (4.21)	0.90		

The *Enjoyment of Science Lessons* mean score for the HDLC group increased from 45.77 to 46.19 as a result of the intervention. The ‘t’ value of 0.35 for the two means was not statistically significant at $p < 0.05$. The effect size of 0.01 is considered small. The Cronbach’s Alpha values of 0.89 and 0.90 are very high and are consistent with the values for the DLC group.

Response to Research Question 6:

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing PEAC students’ enjoyment of science lessons?

The DLC group produced a statistically significant better improvement in the enjoyment of science lessons than the HDLC group as a result of the intervention. This result is partly due to the high pre-intervention score of the HDLC group giving a pre-post mean difference of only 0.42. It should be noted that both groups exhibited a high level of enjoyment of the PEAC Electronics lessons on completion of the course with post-intervention mean scores of 44.00 for the DLC group and 46.19 for the HDLC group out of a possible 50. The high pre-intervention scores (41.40 and 45.77) left little room for improvement in either group.

Table 5. 35 Group Pre-Post Mean differences for ‘*Enjoyment of Science lessons*’.

Group	Pre Mean	Post Mean	Mean Diff.	n	‘t’ value	Cohen’s ‘d’
DLC	41.40 (7.21)	44.00 (6.65)	2.60 (4.20)	25	2.29 (0.026)*	0.64
HDLC	45.77 (4.47)	46.19 (4.21)	0.42 (2.33)	26		

* $p < 0.05$

There is a large effect size '*d*' of 0.64 in favour of the DLC group as a consequence of the intervention, and the '*t*' value of 2.29 is statistically significant at $p < 0.05$.

5.4 The Classroom Test of Scientific Reasoning

Lawson's (1995) Classroom Test of Scientific Reasoning (LCTSR) was administered to an independent group of 50 Year 6 PEAC students in order to ascertain their general level of cognitive development with respect to scientific reasoning. It was not administered to the research subjects due to the time constraints of the research and the small numbers of students available. Results of this test were considered useful in the general interpretation of the research results.

Table 5. 36 Year 6 student scores on Lawson's Classroom Test of Scientific Thinking

Total Score	1	2	3	4	5	6	7	8	9	10	11	12
Frequency	0	2	6	2	15	8	9	4	2	2	0	0

(n=50)

The student scores in Table 5.36 had a mean of 4.17 which indicated that the students found this test difficult. There is also a large range in scores (from 2 – 10) and this is reflected in the large standard deviation (4.57). The large range in scores would suggest that there is a large range of developmental levels with respect to scientific thinking in this representative group of Year 6 PEAC students. Table 5.37 and Figure 5.27 indicate the developmental stage of the students as measured by the test.

Table 5. 37 Developmental level of thinking of Year 6 PEAC students as measured by the LCTSR.

Level of Thinking	Score category (Lawson, 1995, p. 445)	Students achieving this level
Empirical-inductive	0 – 4	10
Transitional	5 - 8	36
Hypothetical-deductive	9 - 12	4

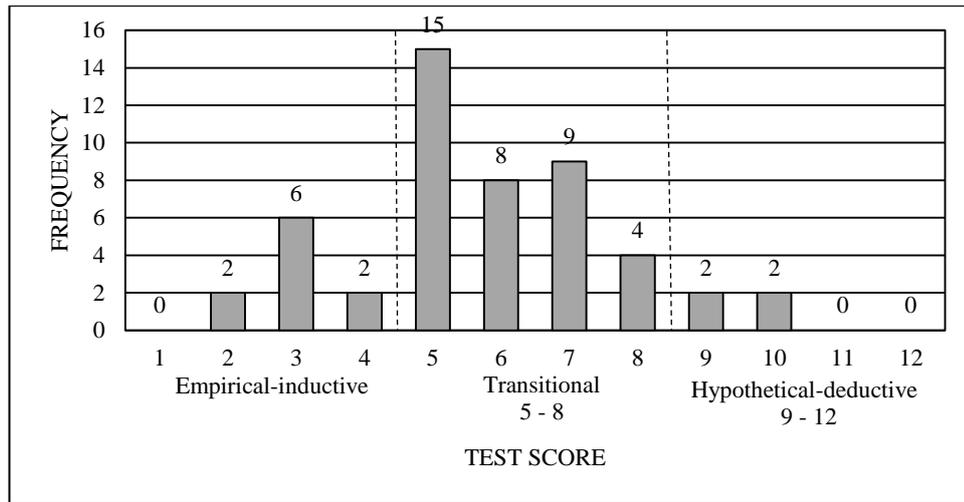


Figure 5. 27 Year 6 PEAC scores and frequencies for LCTSR.

It can be seen from Table 5.36 and Figure 5.27 that most Year 6 students are in the transitional category (Score of 5 – 8) with regards to their level of scientific thinking. This information is useful for interpreting whether the type of learning cycle to be used for teaching PEAC students is appropriate. For example, does a HDLC use strategies beyond the developmental level of these students? From these results it would appear that a HDLC is not inappropriate. Year 6 PEAC students are mostly in a transitional stage, therefore development of hypothetical-deductive thinking skills would be very important at this stage of their education. However, a high degree of scaffolding would be required to develop those skills.

5.5 Concluding Comments

Responses to the Research Questions are summarized in the following paragraphs.

Research Question 1 *Is a three phase learning cycle an effective teaching model for bringing about conceptual growth in PEAC students studying basic electronics?* Statistically significant improvement was found in both depth, quality and application of knowledge assessment scores in both learning cycles as a result of the intervention.

Research Question 2 *Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in bringing about conceptual growth in PEAC students studying basic electronics?* No statistically significant difference was found between the DLC and the HDLC.

Research Question. 3 *Does a three phase learning cycle change PEAC students' attitude toward scientific inquiry?* It was found that the DLC gave a statistically significant improvement as a result of the intervention but the HDLC did not.

Research Question 4 *Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing PEAC students' attitude toward scientific inquiry?* No statistically significant difference was found between the DLC and the HDLC as a result of the intervention.

Research Question 5 *Does a three phase learning cycle change PEAC students' enjoyment of science lessons?* No statistically significant difference was found for either DLC or the HDLC as a result of the intervention.

Research Question 6 *Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing PEAC students' enjoyment of science lessons?* It was found that the DLC gave a statistically significant improvement as a result of the intervention but the HDLC did not.

CHAPTER 6 Discussion and Conclusions.

6.1 Introduction

Chapter 6 has six sections: 6.1 Introduction; 6.2 Thesis Overview; 6.3 Research Findings; 6.4 Overview of this study in the context of the reviewed literature; 6.5 Limitations of the Research; 6.6 Significance and Recommendations; 6.7 Chapter Summary. The chapter is written from my point of view as the researcher and the teacher. Conclusions are based on the quantitative data and qualitative data based on my experience as the teacher/researcher. The conclusions based on my experiences are important as the recommendation of this research relate directly to teacher preparation and the implementation of the learning cycles as a teaching model for the use in the PEAC program in Western Australia.

6.2 Thesis Overview

Chapter 1 described my personal journey that led to this research. At the end of 2004 I took early retirement from full time teaching and accepted a part time position teaching gifted primary students. This research resulted from my desire to find a simple and effective teaching model for teaching science to gifted primary students. Professional development supplied by the Western Australian Department of Education (DoE) dealt mainly with general aspects of giftedness but not specific models for classroom practice. I was looking for a teaching model that was simple to implement, effective in bringing about conceptual growth, and motivating for students.

Chapter 2 reviewed the literature regarding learning cycles, inquiry learning, and the nature of giftedness. The history and underlying educational theory of learning cycles is discussed. Learning cycles are a form of inquiry learning, thus aspects of inquiry learning are also discussed. The research concerns the effectiveness of learning cycles in bringing about conceptual growth and concept acquisition, therefore various theories relating to learning and conceptual change are discussed. This research is conducted with gifted primary students, therefore it was necessary to review the literature on the general nature of giftedness, giftedness in science, and gifted pedagogy. A review of differentiated curricula for gifted students in Australia and some other major countries is made. Three research instruments were used in this research: a constrained concept mapping task; a two-tiered multiple choice knowledge

test; and an attitude questionnaire (TOSRA). Literature relevant to these instruments is reviewed.

Chapter 3 is structured in seven sections: Research questions; Research Design; Curriculum; Research instruments; Teacher as the researcher; Data collection and analysis; and Ethical issues. The research used a quasi-experimental design to compare the effectiveness of a descriptive learning cycles and a hypothetical-deductive learning cycle for teaching basic electronics to gifted Year 6 students. Quantitative data was collected using a constrained concept mapping task, a two-tiered multiple choice test, and an attitude questionnaire using a pre-intervention and post-intervention testing method. Additional quantitative data was collected using Lawson's Classroom Test of Scientific Reasoning (LCTSR) to ascertain the developmental level of a representative sample of Year 6 PEAC students. Qualitative data consisting of teacher reflections was used to help interpret the quantitative data.

Chapter 4 describes my experiences as the teacher-researcher in the preparation and implementation of the PEAC Electronics course. At the end of each lesson I recorded my reflections on the lesson and described any specific strategies I used to teach particular concepts. The strategies varied for each type of learning cycle. A summary of these reflections is presented for each lesson.

Chapter 5 is structured in two basic parts: firstly the descriptive statistics for the testing instruments and secondly the data analysis in response to the research questions. All three instruments proved satisfactory with respect to validity and reliability. Statistically significant pre-post changes with respect to conceptual growth and attitudinal change were evident for each type of learning cycle, but there were no statistically significant differences between the two types of learning cycles. The LCTSR indicated that representative Year 6 PEAC students were in a transitional developmental stage rather than a hypothetical-deductive stage, indicating that a hypothetical-deductive learning cycle necessitated a high degree of student scaffolding. An analysis of key concepts in conjunction with the teacher reflections indicated that the manner in which concepts were presented was important for concept acquisition.

Chapter 6 discusses the research findings in the context of the research questions and the literature review. It also discusses the limitations and significance of the research.

6.3 Research Findings

Due to the small sample sizes in the research, care should be made in making generalizations from the research findings. Several factors such as class size and frequency of class meetings were major limitations of this study, and these led to small sample sizes. The results relevant to Research Questions 1 and 2 are presented in Chapter 5: Section 5.3.1 Response to Research Questions – Cognitive Domain. The results relevant to Research Questions 3 to 6 are present in Section 5.3.2 Response to Research Questions - Affective Domain.

6.3.1. Research Questions 1

Is a three phase learning cycle an effective teaching model for bringing about conceptual growth in PEAC students studying basic electronics?

The conceptual growth of the PEAC students as a result of using learning cycles was assessed using a constrained concept mapping task and a two-tiered multiple choice test. The student concept maps were analysed firstly using a method that assessed the depth of student knowledge (Yin et al., 2005) and secondly using a method that assessed the structure and quality of student knowledge (Miller et al., 2009). The concept mapping task indicated that both the Descriptive Learning Cycle (DLC) and the Hypothetical-Deductive Learning Cycle (HDLC) produced statistically significant improvements, with very large effect sizes, in both depth and quality of student knowledge (Section 5.3.1., p. 139). Similarly, the two-tiered multiple choice knowledge test, which assessed a student's ability to apply acquired concepts, indicated a statistically significant improvement in scores with very large effect sizes for both learning cycles (Section 5.3.1, p. 151). It can be concluded therefore that a three phase learning cycle is effective in bringing about conceptual growth in the PEAC students studying basic electronics.

This finding is consistent with a statement made by Hmelo-Silver et al. (2007) that “Most proponents of inquiry learning are in favour of structured guidance in an environment that affords choice, hands-on experiences, and rich student collaborations” (p. 104). Learning cycles as used in this research are an inquiry learning strategy that provides considerable scaffolding to students which is important in providing opportunities for students to deal with tasks that lie in their zone of proximal development (Vygotsky, 1978).

6.3.2. Research Questions 2

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in bringing about conceptual growth in PEAC students studying basic electronics?

The research findings indicate there is no statistically significant difference between the DLC and the HDLC in bringing about conceptual growth of PEAC students studying basic electronics (Section 5.3.1. p. 154). Kirschner et al. (2006) argued that minimally guided instruction can inhibit learning due to the relationship between working memory and long term memory. They stated that working memory is limited to about 30 seconds with a capacity of four to seven elements. Minimally guided instruction places a heavy load on working memory with novice learners because of their lack of prior knowledge (long term memory). Problem solving tasks, such as in the HDLC, require a high degree of long term memory. In the PEAC electronics course, most students were novice learners and still in the process of establishing long term memory with respect to electronics. I experienced this problem with the HDLC while teaching the theoretical concept of voltage. The students needed to establish that voltage was a force. They could not do this until a comparison was made with the force of gravity, a concept that was in their long term memory. This analogy was a form of scaffolding and enabled all the students to grasp the fact that voltage was an invisible force. This example supports Ausubel's (1963) concept of meaningful learning in which students related a new idea to what they already knew. The example is also consistent with Vosniadou's (1994) approach to conceptual change, whereby students can understand the concept of voltage by adding additional information (concept of voltage) into an existing theoretical framework (framework theory of gravity).

Analogies, or mental models (Vosniadou, 1994), such as the water analogy for electric current, were used frequently in the DLC as a means of explaining theoretical concepts, whereas HDLC students were given student centred research assignments instead. It appears from the research findings that the effectiveness of analogies by the teacher was as effective as a student-centred research assignment. The effectiveness of analogies with the DLC may have cancelled out any advantage gained from the more student centred activities of the HDLC. Specific examples for each key concept are discussed in Chapter 5.

The results of the Classroom Test of Scientific Reasoning (LCTSR) indicate that most Year 6 PEAC students are in the transitional developmental stage with respect to scientific reasoning. Only 4 students in a sample of 50 achieved a score that placed them in the hypothetical-deductive category. This results indicates that a HDLC learning cycle might be considered not suitable for their developmental level. This was also apparent in lessons that involved difficult theoretical concepts such as voltage. Considerable scaffolding in the form of analogies was required in many cases. Even though the HDLC did not produce a statistically significantly better result, the result was equal to the DLC, and therefore I would recommend that the HDLC be used in preference to the DLC for two reasons. Firstly, the HDLC results were equivalent to the DLC with respect to conceptual growth, and secondly, the HDLC enabled students to learn the scientific processes of hypothesis setting, testing and experimental design. It is most important to develop these skills particularly considering that most Year 6 PEAC students are in the transitional stage. I found that the students were very quick in learning the procedures. The transitional stage is an ideal stage in which to develop hypothetical-deductive thinking skills, enabling students to move to the next stage. Due to time constraints this study did not measure procedural knowledge. However I would hypothesise that if procedural knowledge was assessed then the HDLC would be far superior to the DLC. I recommend that future studies should compare the two learning cycles with respect to the development of procedural knowledge and scientific reasoning.

6.3.3. Research Questions 3

Does a three phase learning cycle change PEAC students' attitude toward scientific inquiry?

A gifted child has an inquiring mind and '*seeks meaning and explanation of phenomena*' (Watters, 2004). Watters (1997) previously stated that teachers need to create environments that enable the gifted child to express his or her gifts. The learning cycle needs to foster that inquiring mind and improve a student's attitude towards science. Student interest and motivation need to be considered as crucial to conceptual change (Treagust & Duit, 2008).

In the DLC there was a statistically significant improvement in attitude towards scientific inquiry with an effect size '*d*' of 0.40. It can be concluded therefore that the DLC improves a PEAC student's attitude towards scientific inquiry. There was an

improvement in the HDLC (effect size *d* of 0.19) but it was not statistically significant (Section 5.3.2. p. 167). The pre-intervention mean score for the HDLC on the *Attitude toward Scientific Inquiry* scale was very high (40.4/50) and this left little room for improvement. Even though the improvement was not statistically significant, the post-intervention mean score was very high (41.8/50), which indicates that the HDLC maintained a very good attitude towards scientific inquiry.

6.3.4. Research Questions 4

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing a PEAC student's attitude toward scientific inquiry?

From the research results it can be concluded that there is no statistically significant difference between the DLC and the HDLC in changing these PEAC students' attitudes to scientific inquiry (Section 5.3.2, p. 170). However, as stated in the conclusion to Research Question 3, both groups commenced the electronics course with a relatively good attitude to scientific inquiry which allowed little scope for improvement. The strongly positive attitude was maintained in both groups as a result of the intervention.

6.3.5. Research Questions 5

Does a three phase learning cycle change PEAC students' enjoyment of science lessons?

An important aspect of the PEAC extension program in Western Australia is to expose primary students to various academic disciplines in order for them to make reasoned choices regarding their secondary education and possible careers. Kelbe et al. (1994) and Watters (2004) stated that gifted students often make career choices in their primary years. It is logical to say therefore that it is important to maintain the student's interest within an extension program, which in turn implies the student needs to enjoy their lesson time. This is particularly important for those gifted in science. For example, to foster two of the characteristics of students gifted in science stated by Watters (2004): "Often exhibit an intense interest in a particular area of science and persistent in exploring these areas for understanding"; and "A passionate interest in the origin of things" (p. 4). would be difficult to achieve without creating enjoyable science lessons.

Although both groups produced an improvement in enjoyment of science lessons, only the DLC group produced a statistically significant improvement. The HDLC group improved slightly but the result was not statistically significant (Section 5.3.2., p. 170). The pre-intervention mean for the HDLC group was 45.77 out of a possible 50. This high pre-intervention mean left little room for improvement. The post-intervention mean scores of 44.00 (DLC) and 46.19 (HDLC) indicate a very high level of enjoyment of science in both groups as a result of the intervention. This result is supported by my recollection of the lessons – the students always seemed to be totally focussed during the lessons. I recorded no incidence of lack of attention amongst the students. The learning cycle format enabled students to explore a concept and discuss it with their partners. During this research all students worked in pairs and were encouraged to discuss their work with each other. All exploration phases included hands-on activities and the concept application phase included project work where students could develop psychomotor skills in the construction of their own electronic circuits. This blend of activities and social interaction created very enjoyable lessons for the students. Although only the DLC resulted in a statistically significant improvement in the enjoyment of science lessons, they both maintained a very high level of enjoyment as is indicated by the post-intervention scores.

6.3.6. Research Questions 6

Which of the two learning cycles, a descriptive learning cycle or a hypothetical-deductive learning cycle, is the most effective in changing PEAC students' enjoyment of science lessons?

The DLC group produced a statistically significant better improvement than the HDLC group with respect to enjoyment of science lessons as a result of their respective interventions (Section 5.3.2., p. 173). This result is due in part to the HDLC group's high pre-intervention mean. As mentioned in the conclusion to Research Question 5, the HDLC group had a pre-intervention mean score of 45.77 which was very high and left little room for improvement. Both the DLC and the HDLC intervention maintained a high level of enjoyment of science lessons.

6.4 Overview of this study in the context of the reviewed literature.

6.4.1 The Learning Cycle as an inquiry teaching-learning strategy

In this study, my aim was to investigate the suitability of a three phase learning cycle for use as a teaching-learning model for the PEAC program in Western Australian state schools. Teaching-learning models in the PEAC program need to be efficient in both planning and delivery for two reasons: firstly, because of the rigid time constraint of 20 hours; and secondly because of the fact that most science teachers in the program were untrained in gifted education and would benefit from a structured model that would provide the basis of a differentiated curriculum for gifted primary students.

The characteristics of a gifted child are discussed in Chapter 2 and include: rapid learning; good attention control; memory efficiency; commitment to task (Heller et al., 2005); an intense and persistent interest and a need to apply assimilated knowledge quickly (Watters, 2004). I found all of these characteristics present during the teaching phase of this study and the learning cycles were able to complement these characteristics in all cases. Many of the concepts in the electronics course, such as voltage and current, were theoretical and required a deep level of understanding. The learning cycle enabled students to explore the concepts in a circuit situation and then apply the concept in a problem solving application such as their projects. Scaffolding was necessary, but this was minimal. Students were quick to grasp a concept and apply it.

The HDLC learning cycle allows students to apply the scientific process of hypothesis setting and experimental design in a practical situation. Watters (2004) considers this should be considered before facts. He also considers that open inquiry should be used as a learning strategy. However, as was found in this research, inquiry needs to be associated with varying degrees of scaffolding. This is consistent with statements made by Kirschner et al. (2006), and Helmo-Silver et al. (2007) who both state that scaffolding is critical to the process of inquiry. The PEAC students had little prior knowledge of electrical concepts, as indicated by the pre-intervention assessments, before commencing the electronics course. Consequently a pure open inquiry strategy was deemed not appropriate. The students did not have enough prior knowledge or a framework of understanding to draw upon in an open inquiry situation. According to Ausubel (1963) prior knowledge is critical to meaningful learning and Posner et al.

(1982) state that without existing knowledge it is impossible for a learner to inquire about a new concept. The lessons used in this research commenced by reviewing a student's existing knowledge and the review of previous lessons. Scaffolding was given where necessary for particular students and particular concepts.

6.4.2 The Learning Cycle and learning theory.

Meaningful learning

Ausubel (1963) stated that three criteria were necessary for meaningful learning: a framework of understanding, ability to relate new ideas to existing conceptual frameworks, and meaningful tasks that gave direct experience with physical objects. The learning cycle satisfied all three criteria. First, the PEAC students commenced the course with a little knowledge of '*electricity*'. For example, they were able to state in the early stages of the course, that it was '*electricity*' that caused observed phenomena in the exploration phase. The framework of '*electricity*' was modified later in the course to more specific concepts of resistance, current and voltage, satisfying Ausubel's second criteria. With respect to the third criteria of meaningful tasks, students were given laboratory apparatus in hands-on situations to explore electrical phenomena and electronic projects to construct as an application of newly acquired concepts.

Conceptual change

Most of the PEAC students in this study had little prior knowledge of the nature of current, voltage and resistance. This is evident in Table 5.27 in Chapter 5. However they did have some naïve understandings of electricity and the aim of the electronics course was to change these naïve understandings to more theoretical understandings of voltage, current and resistance. For example, in the *exploration phase* discussion of Lesson 5 (Chapter 4 Section 4.3.5) of the HDLC group, a student stated that the globe became brighter because '*There will be more voltage through the globe*'. This is a naïve understanding that requires restructuring. In Lesson 5, students learned that voltage is a force that increases current and it is the current that causes the globe to glow brighter. This point was clarified after students conducted more experiments and made further observations. Class discussion with the teacher enabled the nature of voltage to be clarified. The transcript of this discussion can be found in Section 4.3.5 *Lesson 5 – Voltage* of Chapter 5.

The discussion in Lesson 5 is consistent with the process of conceptual change stated in Driver's Model: elicitation of ideas, restructuring of ideas (*cause of globe brightness*), clarification and exchange (*nature of voltage*), and construction of new ideas (*voltage is force causing current to flow*). In the process of clarifying a concept I found that using an analogy such as gravity for an unseen force and the water analogy for current flow was very effective. The use of analogies or mental models to change a student's conceptual framework is consistent with Vosniadou's (1994) view of conceptual change. However, for this to be successful I had to first ascertain that the students understood how water flowed in a pipe. I did this by demonstrating water flow in the laboratory. The transfer of the concept of water flow to electricity flow appeared to be successful. For example, analogies were used early in discussions with the DLC group to explain electrical concepts. In the HDLC group analogies were only used if student could not reach an understanding from their own discussion and observations. For example, the water analogy for current was not used in the HDLC group and the effectiveness of the analogy is demonstrated by the Key Concept Score for *current is a flow of electrons/charge* (Chapter 4, Section 4.3.1 Figure 4.27): the DLC score changed from 6 (pre-intervention) to 33 (post-intervention) and the HDLC score was from 11 (pre) to 16 (post). Similar result occurred for other concepts that were clarified using analogies.

6.4.3 The Learning Cycle and attitudinal change.

It is clear from the literature that if a student is to reach his or her full potential a high degree of motivation is required (Pintrich & Groote, 1990a; Pintrich et al., 1993), and Gagné (2013) states that research in the area of giftedness indicates the importance of creating a stimulating environment. This is important to foster areas of passion which is so important for the gifted student (Watters, 2004).

It is clear from the results of this study that students commenced the PEAC electronics course with a good attitude towards both scientific inquiry and an expectation they would enjoy the lessons. In both the DLC and the HDLC these high levels of attitude were maintained. The enjoyment of the lessons were evidenced by the continual high degree of engagement of the students in all activities. The hands-on activities in the exploration phases, the discussion in small groups (pairs), and the construction of projects as an application were key features leading to this enjoyment. The excitement

a student displayed on the successful completion of a project (an electronic circuit) clearly led to an improved self-efficacy.

With respect to the social/affective aspect of conceptual change, I can conclude that the three phase learning cycle using either the DLC or the HDLC as used in this research is an ideal model for use in PEAC courses for gifted primary students.

6.5 Limitations of the Research

6.5.1. Sample Size

Three factors contributed to the small sample sizes in this research: firstly there was only one class at any one time; secondly there were only three classes per year; and thirdly all classes contained mixed grades making obtaining a large homogeneous sample, with respect to developmental level, quite difficult. These constraints meant that sample sizes were quite small – 25 Year 6 students for the DLC and 26 for the HDLC. Unfortunately this was an unavoidable constraint as the research was conducted in the specific context of the PEAC program. Due to the small sample sizes care must be taken in generalizing the research findings beyond the PEAC program.

6.5.2. Instruments

Three instruments were used in this study: a constrained concept mapping task; a two-tiered multiple choice test (TMCT); and the TOSRA questionnaire. Of these three the TMCT needed more development. Ideally a TMCT is a diagnostics instrument (Treagust, 1986), but in this case it was used as a knowledge application test. Due to the low frequency of PEAC electronics classes, three classes of 22 students per year, extensive trials to develop a diagnostic instrument specifically for this group of students were not possible within the time frame of the research.

6.5.3. Data Analysis

The data analysis of the concept mapping task and the TOSRA was well supported by strategies described in the literature (Yin et al., 2005; Miler et al., 2009) and no difficulties were experienced. However, the TMCT presented difficulties in establishing reliability. Due to the limited number of trials for the TMCT, it was not possible to establish an instrument with items of similar difficulty, thus making the Cronbach's Alpha coefficient inappropriate. In anticipation of this, the TMCT was

constructed with parallel items so that a split half reliability test could be made. This strategy produced a satisfactory result.

6.5.4 Teacher as Researcher

Being the researcher and the teacher in this study had the potential to create a problem in bias particularly in the administration of the intervention. This was overcome, as mentioned in Chapter 3 (Section 3.4.2), by carefully scripting each lesson. Each script was in the form of a student worksheet. To avoid bias in the presentation of each type of learning cycle I kept strictly to each script. This worked very well after I rehearsed the procedures in the initial trial of each learning cycle. Keeping to the scripted lesson also made keeping to a tight time schedule much easier. The worksheet also enabled students to work at their own pace, enabling the faster students to work ahead. They also had a permanent record of each lesson.

The teacher as the researcher also raised various ethical issues and these are discussed in Chapter 3, Section 3.6.1. Before commencing this research, I needed to obtain ethics approval from both Curtin University and the Western Australian Department of Education (DoE). The requirements for approval from DoE were rigorous and included that at no stage must I compel the students to be part of the study. Each student and one of their parents signed a form agreeing to participate in the study. The study was done in the context of a normal PEAC program and therefore compulsion to participate was never an issue. Only one student declined to take part in my research. He did, however need to participate in all activities as the Electronics course was a part of his PEAC program. Only his results were not used. The ethical procedures used in the research addressed all the issues raised by Nolen and Puten (2007) that are associated with action research in education.

6.6 Significance and Recommendations

I conducted this study in order to investigate whether a three phase learning cycle is an effective model for teaching PEAC students. As discussed in Chapter 1, many PEAC teachers are not specifically trained in gifted education (Plunkett and Kronborg, 2011) or science education. My research findings indicate that the learning cycle provides a simple and effective teaching model that is both appropriate and effective for teaching science to gifted primary students. Although the learning cycle may

appear quite simple in structure, it should be remembered it is based on sound educational theory (Lawson, 1995).

The simple structure of a three phase learning cycle makes it relatively easy for teachers to prepare lessons. This is an important attribute considering that many PEAC teachers are not trained in science teaching or gifted education. Ease of preparation leads to more confidence in teaching. For example, many primary trained teachers have a limited background in science inquiry and teaching science, which leads to a lack of confidence in that area (Kelble et al., 1994; Hackling et al., 2007; Ireland et al., 2014). An alternative model, the IMSTRA, for example, has three main stages with two sub-stages in each for the teacher and two for the student making a total of 12 stages. Due to its relative complexity this model can appear daunting from a preparation aspect. A series of three phase learning cycles can be programmed into a spiral curriculum to give continuity of lessons within a curriculum. This aspect makes the learning cycle and the spiral curriculum powerful programming tools. For example, when I was preparing the electronics course I programmed each lesson so that the key concept from one lesson became background for the key concept of the next lesson. This enabled me to use the previous lesson's concept as an engagement leading into the exploration phase of the next lesson.

My recommendation as a result of the findings of this study would be that the learning cycle and the spiral curriculum should be considered as an essential tool available to teachers for curriculum programming and a model for teaching science in both primary and secondary schools. I know from my own experience as a science teacher, and ten years as a PEAC teacher, I never experienced the learning cycle in in-service professional development sessions. Professional development sessions only addressed general aspects of gifted education. My aim in this study has been to address this problem and give my colleagues strategies that are based on original research in the PEAC context. It is difficult to 'sell' an idea without some form of solid evidence. I believe this study will provide that evidence. Although this study uses an established teaching/learning model in the form of the learning cycles, it contributes original research in the context of PEAC science teaching and learning. In a profession that is becoming increasingly more difficult with time being consumed with administrative matters, an efficient and effective teaching strategy such as the three phase learning

cycle would be very valuable and should be included in both pre-service training and in-service training of science teachers in both primary and secondary education.

Any future study in the context of Western Australia education would need to consider repeating this study using larger samples and in different contexts, to enable more general conclusions to be made. This study was essentially a case study in the context of a small gifted education program. The strategies outlined in this study need to be tested in a larger context such as the GATE programs in large secondary schools. This would enable sound recommendations to be made to educational policy makers and teacher training institutions.

If this study was repeated in a larger context, I recommend that a robust two-tiered multiple choice instrument be developed that would investigate not only any conceptual growth that takes place in the students, but also the existence of misconceptions that they may have. This would provide valuable feedback to teachers to enable them to modify lessons or curricula.

6.7 Chapter Summary

Chapter 6 provides a brief overview of each chapter in this thesis and answers the research questions with reference to the research findings and the relevant literature. The research found that a three phase learning cycle is an effective teaching model for changing conceptual structures and attitudes in gifted primary students. However there was no statistically significant difference between a Descriptive Learning Cycle and a Hypothetical Deductive Learning Cycle when used for teaching basic electronics to Year 6 PEAC students. It was concluded that this was possibly due to the extra scaffolding needed for the Year 6 students in the Hypothetical Deductive Learning Cycle when confronted with a more student centred learning cycle.

Care must be taken in generalizing the findings of this research due to the constraints and the narrow context under which the research was conducted. It is recommended that further research needs to be conducted with larger groups and in wider contexts.

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APPENDICES.

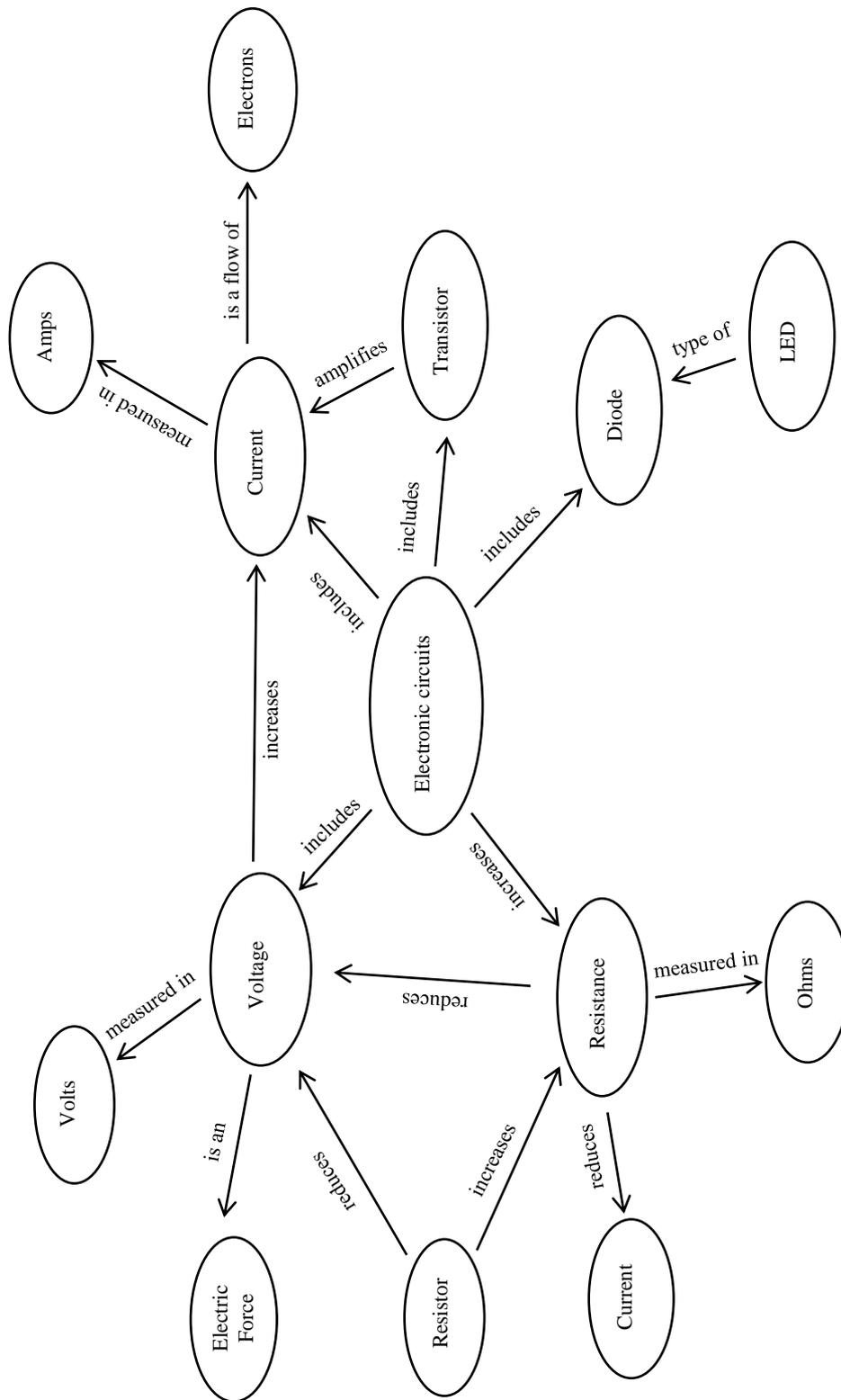
Appendix A PEAC Electronics Student Outcomes

Table of Specific Student Outcomes for the PEAC Electronics Course

At the completion of the course students should be able to demonstrate the following skills, knowledge and attitudes:

Psychomotor Domain	Cognitive Domain	Affective Domain
<ul style="list-style-type: none"> • Construction of a printed circuit board (PCB). • Drilling holes in a PCB. • Soldering of components onto a PCB. • Correct layout of components on a PCB. • Use a multimeter. 	<p><i>Knowledge of concepts:</i></p> <ul style="list-style-type: none"> • simple circuitry. • circuit diagrams and use of circuit symbols. • the function of a switch. • concept of resistance, its effects and measurement. • the resistor colour code • concept of voltage, its effects and measurement. • concept of current, its effects and measurement. • function of diodes in a circuit. • function of transistors in a circuit. <p><i>Procedural skills:</i></p> <p>To develop the science process skills of observing, measuring, interpreting, experimenting, model building, and predicting.</p>	<ul style="list-style-type: none"> • An appreciation for the science of electronics. • An increased enjoyment of science through construction of projects. • An appreciation for the role of inquiry in science investigations.

Appendix B Expert Concept Map



Appendix C Lesson Worksheets Examples

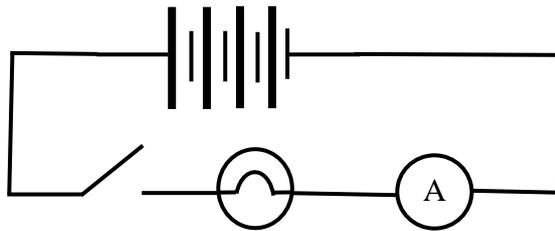
A Descriptive Learning Cycle Lesson

LESSON 5 (DLC)

Lesson 5 will explore the concept of voltage.

CONCEPT EXPLORATION

Task 1: Set up a circuit with a 6V battery pack, switch, and ammeter as drawn below.



1. Connect the leads to the 1.5 volt plug and:
 - a. Describe the brightness of the globe _____
 - b. Record the reading on the ammeter _____
2. Predict any changes to the above observations if you changed the lead to the 3 volt plug. Give a reason for each prediction:
 - a. Brightness of the globe _____
Reason _____
 - b. Ammeter reading _____
Reason _____
3. Change the lead to the 3 volt plug and:
 - a. Describe the brightness of the globe _____
 - b. Record the reading on the ammeter _____

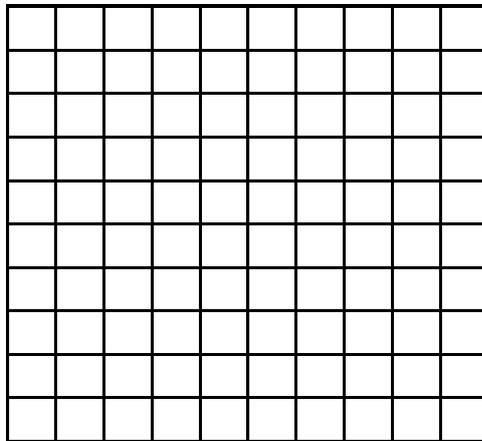
How accurate was your prediction? _____

CONCEPT DEVELOPMENT

Task 2: In the table below record the current (amps) for all the voltages 1.5, 3.0, 4.5, and 6.0.

Voltage	1.5 V	3.0 V	4.5 V	6.0 V
Current				

Draw a graph of your results on the graph paper below.



New Terms:

Voltage is ... _____

Units of voltage are ... _____

CONCEPT APPLICATION

1. What is the relationship between the voltage and the current in your circuit?

2. Using your graph to predict the current for 10 volts.

3. Predict what would happen to a 6V globe if connected to a 12V power source.

Why? _____

4. Your teacher will demonstrate what does happen!
Observation:

5. When you buy an electrical appliance such as a light globe, a voltage is written on it. For example the globes you are using are 6V globes. Why do you think this voltage is written on the globe?

A Hypothetical-Deductive Learning Cycle Lesson

LESSON 5 (H)

Lesson 5 will explore the concept of voltage.

CONCEPT EXPLORATION

Task 1:

(a) Set up a circuit with a 6V battery pack, switch, and ammeter. Draw your circuit using circuit symbols.

(b) Connect the leads to the 1.5 volt plug and:

Describe the brightness of the globe _____

Record the reading on the ammeter _____

(c) Predict any changes to the above observations if you changed the lead to the 3 volt plug. Give a reason for each prediction:

Brightness of the globe _____

Reason _____

Ammeter reading _____

Reason _____

(d) Change the lead to the 3 volt plug and:

Describe the brightness of the globe _____

Record the reading on the ammeter _____

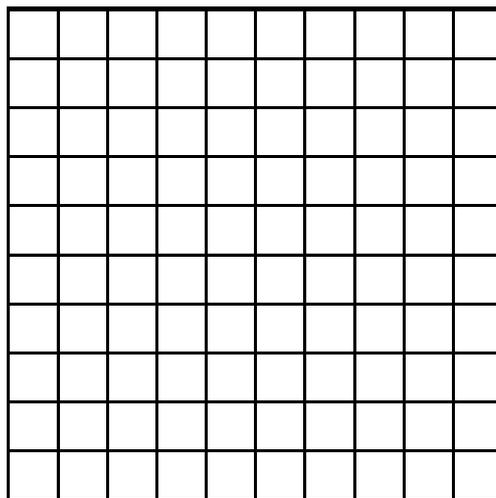
How accurate was your prediction? _____

Thinking Time: What do you think voltage does in your circuit?

Task 2:

(a) How could you further test your idea (hypothesis) about what voltage does in the circuit.

(b) You may want to use the graph paper below to display any results you may have.



CONCEPT DEVELOPMENT

New Term:

Write down what you think *voltage* might be

Voltage is _____

After discuss with the teacher, write down the correct meaning of voltage

Voltage is _____

Units of Voltage are: _____

CONCEPT APPLICATION

3. What is the relationship between the voltage and the current in your circuit?

4. Using your graph predict the current for 10 volts. _____

5. When you buy an electrical appliance such as a light globe, a voltage is written on it. For example the globes you are using are 6V globes. Why do you think this voltage is written on the appliance?

6. Predict what would happen to a 6V globe if connected to a 12V power source.

Why? _____

Your teacher will demonstrate what does happen!!

Observation _____

Appendix D PEAC Electronics Test

PEAC Electronics Test

Instructions:

Each question has two parts. The first part is your answer to the question, and the second part is the reason for your answer.

In both parts you choose the correct answer by marking (a), (b), or (c) with an X.

You must answer both parts of the question.

Practice Example:

Practice Question:

A dog has very large and pointed canine teeth. This is useful for:

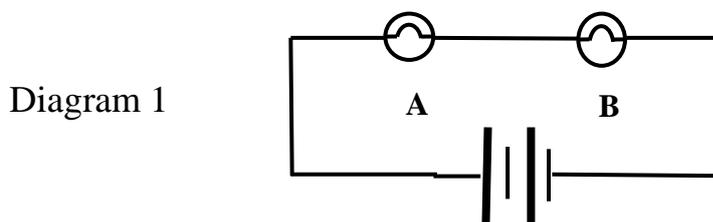
- (a) Chasing cats.
- (b) Eating meat.
- (c) Barking.

Choose the **best** alternative below as a reason for your above answer:

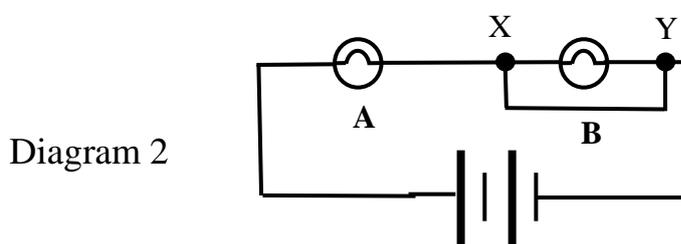
- (a) Large canine teeth are good for tearing meat.
- (b) Large canine teeth make a loud bark.
- (c) Large canine teeth make the dog run fast.

Question 1.

In Diagram 1, two globes A and B are connected as shown and each shines equally bright.



What would happen to the brightness of each globe when a wire is connected between points X and Y as shown in Diagram 2?



- (a) Globe A and B would shine with the same brightness.
- (b) Both would shine, but globe A would be brighter than Globe B.
- (c) Globe A would shine brighter and Globe B would not shine.

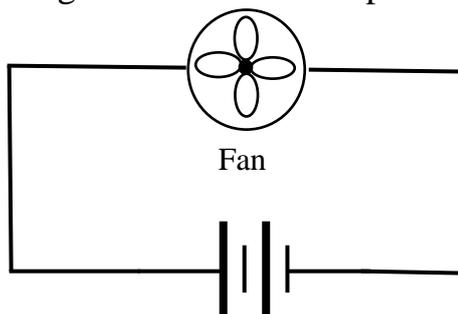
Choose the **best** alternative below as a reason for your above answer:

- (a) The wire takes half the energy from Globe B.
- (b) The wire from X-Y is a short circuit.
- (c) The wire has low resistance and does not affect the globes.

Question 2.

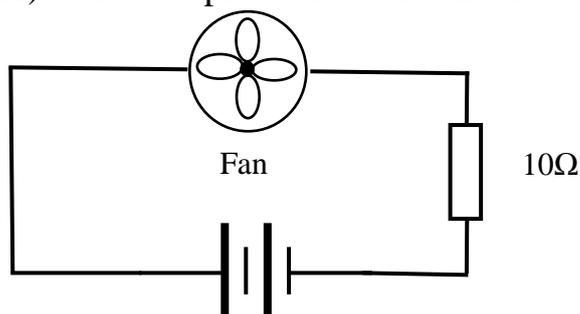
In Diagram 1 the fan is turning at 200 revolutions per minute.

Diagram 1



In Diagram 2 a 10 ohm (Ω) resistor is placed into the circuit.

Diagram 2



What would happen to the speed of the fan when the 10 ohm resistor is added?

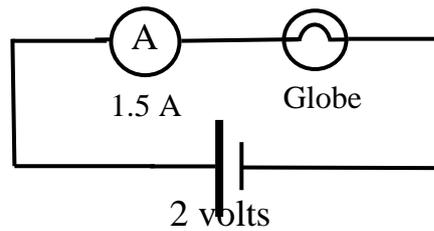
- (a) It will slow down.
- (b) It will stay at the same speed.
- (c) It will speed up.

Choose the **best** alternative below as a reason for your above answer:

- (a) The 10Ω resistor will direct more current to the fan causing it to speed up.
- (b) The 10Ω resistor increases the resistance of the circuit, therefore reduces the current (amps) to the fan.
- (c) The 10Ω resistor does not change the voltage of the battery therefore the fan will stay at the same speed.

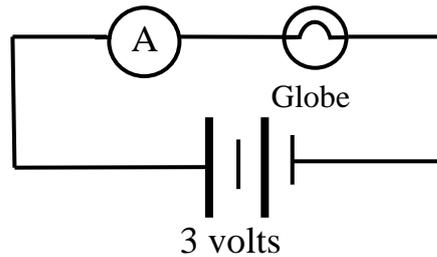
Question 3.

Circuit 1.



The reading on the ammeter in the Circuit 1 is 1.5 amps.

Circuit 2.



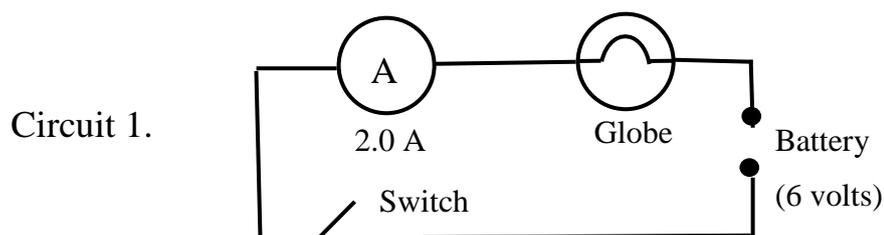
In Circuit 2 the voltage is increased to 3 volts. Which reading below would be **closest** to the ammeter reading in Circuit 2.

- (a) 1.8 amps
- (b) 2.0 amps
- (c) 2.2 amps

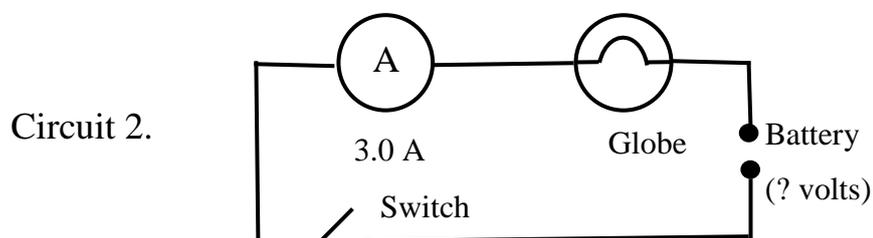
Choose the **best** alternative below as a reason for your above answer:

- (a) When the voltage increases, the globe will get a lot brighter because the current increases.
- (b) The voltage increase is not enough to affect the current (amps) or the globe's brightness.
- (c) If you increase the voltage, the current (amps) will increase in proportion.

Question 4.



When the switch in Circuit 1 is closed, the globe lights up and the ammeter shows a reading of 2.0 amps.



In Circuit 2 the ammeter shows a reading of 3.0 amps when the switch is closed. What do you think the voltage of the battery is in Circuit 2?

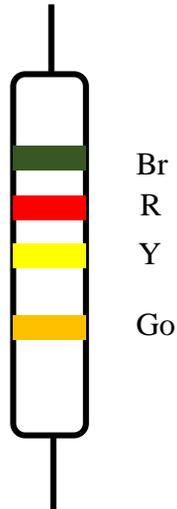
- (a) 7 volts.
- (b) 8 volts.
- (c) 9 volts.

Choose the **best** alternative below as a reason for your above answer:

- (a) A 50% increase in voltage (an increase of 3 volts), will cause a 50% increase in current (an increase of 1 amp).
- (b) The voltage increases 1 volt therefore the current increases by 1 amp.
- (c) A 2 volt increase in the battery will cause a 1 amp increase in current.

Question 5.

Use the colour code on the right hand side to determine the value of the resistor shown below.



Bl = Black	= 0
Br = Brown	= 1
R = Red	= 2
O = Orange	= 3
Y = Yellow	= 4
G = Green	= 5
B = Blue	= 6
V = Violet	= 7
Gr = Grey	= 8
W = White	= 9
Go = Gold	= 5%

The resistor is:

- (a) 124 ohms.
- (b) 120,000 ohms.
- (c) 1,200 ohms.

Choose the **best** alternative below as a reason for your above answer:

- (a) Band 1 is 1; Band 2 is 2; Band 3 is 4, making 124 ohms
- (b) Band 1 is 1; Band 2 is 2; Band 3 is for 4 numbers making 1,200 ohms.
- (c) Band 1 is 1; Band 2 is 2; Band 3 is for 4 zeros making 120,000 ohms.

Question 6.

When an electronic circuit does not work properly there could be one or more faults. How would you find the fault? Choose the quickest sequence from the four sequences shown below. I would look for:

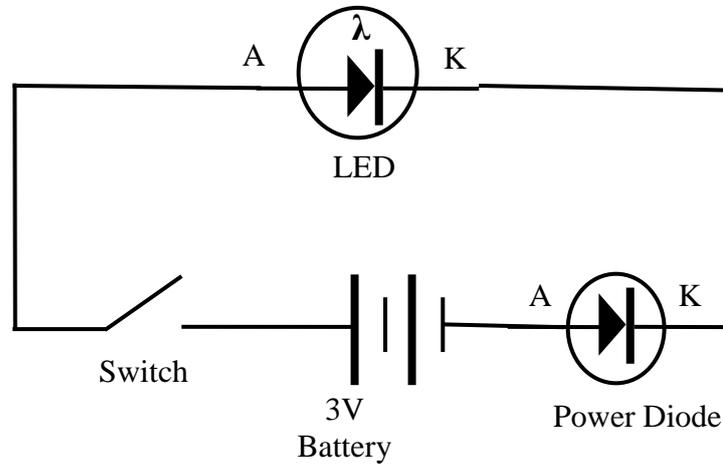
- (a) Components reversed (e.g. diodes) or battery leads reversed.
Scratches on the printed circuit (broken circuit).
Poor soldering.
Correct resistor values.
A faulty component, remove and check.
- (b) A faulty component, remove and check.
Components reversed (e.g. diodes) or battery leads reversed.
Correct resistor values.
Scratches on the printed circuit (broken circuit).
Poor soldering.
- (c) Poor soldering.
A faulty component, remove and check.
Components reversed (e.g. diodes) or battery leads reversed.
Correct resistor values.
Scratches on the printed circuit (broken circuit).

Choose the **best** alternative below as a reason for your above answer:

- (a) If there is a faulty component it will not work.
- (b) It is quicker to check the visible faults first.
- (c) Poor soldering is a common fault.

Question 7.

When Siobhan switched on the circuit below, it did not work. That is the LED did not light up.



Why do you think the LED (Light Emitting Diode) did not light up?

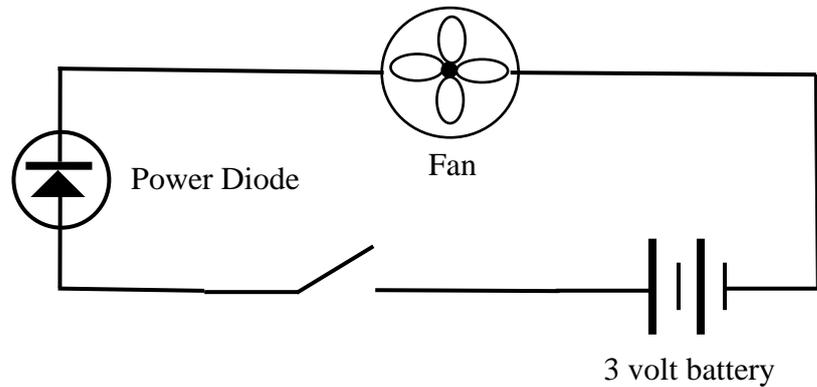
- (a) The LED is connected in reverse.
- (b) The power diode is connected in reverse.
- (c) Both the LED and the diode are connected in reverse.

Choose the **best** alternative below as a reason for your above answer:

- (a) A in any diode is the anode and must be connected to the positive side of the battery.
- (b) K in any diode is the cathode and must be connected to the positive side of the battery.
- (c) The power diode should be between the switch and the LED.

Question 8.

Alex made up a simple circuit for a battery driven electric fan for use when he was walking on hot days. In the circuit he placed a power diode. The circuit is shown below:



Why do you think he placed the diode in the circuit?

- (a) To protect the fan from too high a voltage.
- (b) To protect the fan motor from going in the reverse direction.
- (c) To protect the fan from too high a current (amps).

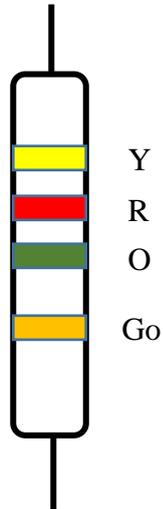
Choose the **best** alternative below as a reason for your above answer:

- (a) Fans do not work properly if turning in a reverse direction.
- (b) To reduce the speed of the fan to conserve the battery.
- (c) Too much current will burn out the fan motor.

Question 9.

When asked to find the value of the resistor shown below, Fred worked it out to be 434 ohms, however this was incorrect.

Note: Band 1 is at the top.



Bl = Black	= 0
Br = Brown	= 1
R = Red	= 2
O = Orange	= 3
Y = Yellow	= 4
G = Green	= 5
B = Blue	= 6
V = Violet	= 7
Gr = Grey	= 8
W = White	= 9
Go = Gold	= 5%

What should his answer be?

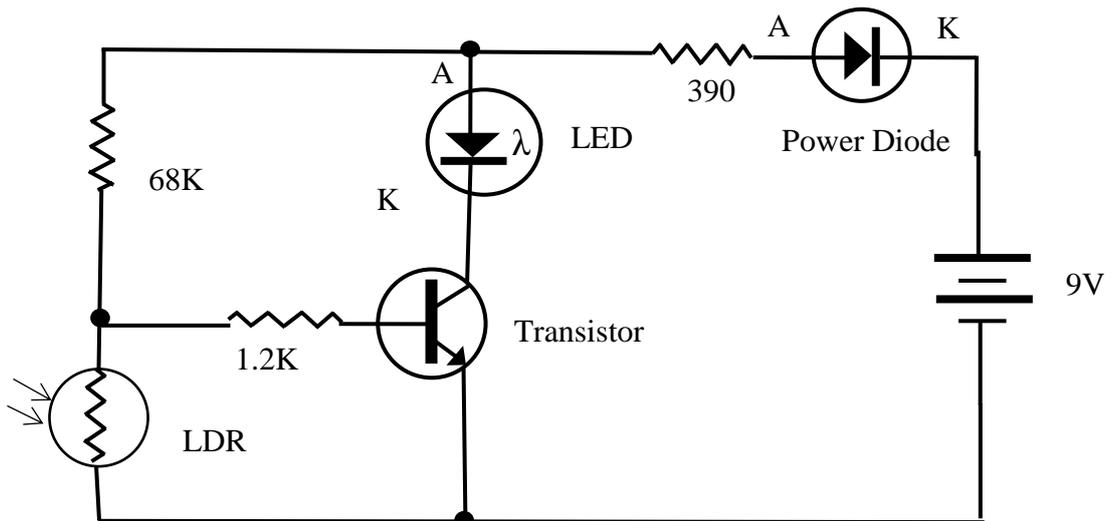
- (a) 423 ohms
- (b) 42000 ohms
- (c) 42K ohms

Choose the **best** alternative below as a reason for your above answer:

- (a) He only got Band 2 incorrect (R=2).
- (b) He got Band 2 incorrect (R=2) and Band 3 should read 000 but written as K.
- (c) He got Band 2 incorrect (R=2) and Band 3 should be 000 and written as 000.

Question 10.

The circuit shown below includes a transistor, a light emitting diode (LED), a power diode, a light dependent resistor (LDR), and three fixed resistors. The circuit is used to switch on lights when it gets dark. The circuit however does not work.



The circuit does not work because:

- (a) The power diode is incorrectly connected.
- (b) The LED is connected in reverse.
- (c) The battery is connected incorrectly.

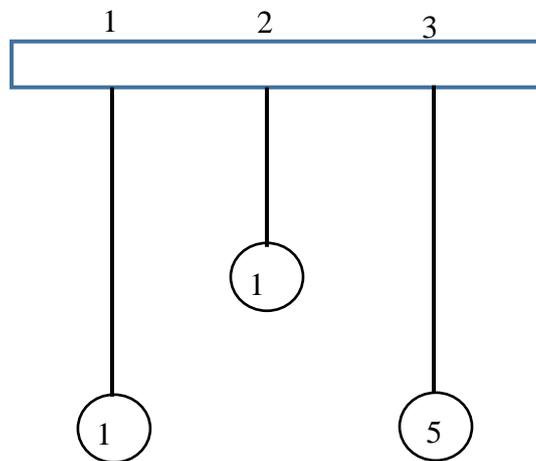
Choose the **best** alternative below as a reason for your above answer:

- (a) The LED must be connected with K (cathode) to the positive terminal of the battery.
- (b) The battery needs to be connected with the negative side to the K (cathode) of the power diode.
- (c) The power diode must be connected with A (anode) to the positive side of the battery.

Appendix E Sample questions from Lawson's Classroom Test of Scientific Reasoning (Lawson, 1995, p. 439)

Item 5

The drawing below shows three strings hanging from a bar. The strings have metal weights attached to their ends. String 1 and string 3 are the same length. String 2 is shorter. A 10-unit weight is attached to the end of string 1. A 10-unit weight is also attached to the end of String 2. A 5-unit weight is attached to String 3. The strings (and attached weights) can be swung back and forth, and the time it takes for the strings and weights to make a complete swing can be timed. Suppose you wanted to find out whether length has an effect on the time it takes to swing back. Which strings would you use to find out?



Answer:

Please explain why you chose those strings.

Item 6

Suppose you wanted to find out whether the amount of weight attached to the end of a string has an effect on the time it takes for a string to swing back and forth. Which of the strings in Item 5 above would you use to find out?

Answer:

Please explain why you chose those strings.

Appendix F Test of Science Related Attitudes answer sheet

STUDENT No: _____

Test of Science Related Attitudes (TOSRA) (Fraser, 1981)

Directions:

1. This test contains a number of statements about science. You will be asked what you think about these statements. There are no “right” or “wrong” answers. Your opinion is what is wanted.
2. For each statement, draw a circle around the specific numeric value corresponding to how you feel about each statement. **Please circle only ONE value per statement.**

5 = Strongly Agree (SA)

4 = Agree (A)

3 = Uncertain (U)

2 = Disagree (D)

1 = Strongly Disagree (SD)

Statement	SA	A	U	D	SD
1. I would prefer to find out why something happens by doing an experiment than be being told.	5	4	3	2	1
2. Science lessons are fun.	5	4	3	2	1
3. Doing experiments is not as good as finding out information from teachers.	5	4	3	2	1
4. I dislike science lessons.	5	4	3	2	1
5. I would prefer to do experiments rather than to read about them.	5	4	3	2	1
6. School should have more science lessons each week.	5	4	3	2	1
7. I would rather agree with other people than do an experiment to find out for myself.	5	4	3	2	1
8. Science lessons bore me.	5	4	3	2	1
9. I would prefer to do my own experiments than to find out information from a teacher.	5	4	3	2	1
10. Science is one of the most interesting school subjects.	5	4	3	2	1

Statement	SA	A	U	D	SD
11. I would rather find out things by asking an expert than by doing an experiment.	5	4	3	2	1
12. Science lessons are a waste of time.	5	4	3	2	1
13. I would rather solve a problem by doing an experiment than be told the answer.	5	4	3	2	1
14. I really enjoy going to science lessons.	5	4	3	2	1
15. It is better to ask a teacher the answer than to find it out by doing experiments.	5	4	3	2	1
16. The material covered in science lessons is uninteresting.	5	4	3	2	1
17. I would prefer to do an experiment on a topic than to read about it in science magazines.	5	4	3	2	1
18. I look forward to science lessons.	5	4	3	2	1
19. It is better to be told scientific facts than to find them out from experiments.	5	4	3	2	1
20. I would enjoy school more if there were no science lessons.	5	4	3	2	1

Appendix G Ethics Matters

G (I) Western Australian Department of Education research approval



Government of **Western Australia**
Department of **Education**

Your ref :
Our ref : D12/0412742
Enquiries :

Mr Graham Lake
52 Descanso Loop
AUBIN GROVE WA 6164

Dear Mr Lake

Thank you for your completed application received 21 May 2012 to conduct research on Department of Education sites.

The focus and outcomes of your research project, *The effect of teaching and learning strategies on conceptual and attitudinal change of gifted primary students*, are of interest to the Department. I give permission for you to approach site managers to invite their participation in the project as outlined in your application. It is a condition of approval, however, that upon conclusion the results of this study are forwarded to the Department at the email address below.

Consistent with Department policy, participation in your research project will be the decision of the schools invited to participate, individual staff members, the children in those schools and their parents. A copy of this letter must be provided to site managers when requesting their participation in the research. Researchers are required to sign a confidential declaration and provide a current Working with Children Check upon arrival at the Department of Education site.

Responsibility for quality control of ethics and methodology of the proposed research resides with the institution supervising the research. The Department notes a copy of a letter confirming that you have received ethical approval of your research protocol from the Curtin University Human Research Ethics Committee.

Any proposed changes to the research project will need to be submitted for Department approval prior to implementation.

Please contact Ms Allison McLaren, A/Evaluation Officer, on (08) 9264 5512 or researchandpolicy@education.wa.edu.au if you have further enquiries.

Very best wishes for the successful completion of your project.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Alan Dodson'.

ALAN DODSON
DIRECTOR
EVALUATION AND ACCOUNTABILITY

27 June 2012

151 Royal Street, East Perth Western Australia 6004

G (II) Curtin University research approval



Memorandum

To	Graham Lake, SMEC
From	Pauline Howat, Administrator, Human Research Ethics Science and Mathematics Education Centre
Subject	Protocol Approval SMEC-12-12
Date	2 March 2012
Copy	David Treagust, SMEC

Office of Research and Development
Human Research Ethics Committee
Telephone 9266 2784
Facsimile 9266 3793
Email hrec@curtin.edu.au

Thank you for your "Form C Application for Approval of Research with Low Risk (Ethical Requirements)" for the project titled "*The effect of teaching and learning strategies on conceptual and attitudinal change of gifted primary students*". On behalf of the Human Research Ethics Committee, I am authorised to inform you that the project is approved.

Approval of this project is for a period of twelve months **2nd March 2012 to 1st March 2013**.

The approval number for your project is **SMEC-12-12**. *Please quote this number in any future correspondence*. If at any time during the twelve months changes/amendments occur, or if a serious or unexpected adverse event occurs, please advise me immediately.

PAULINE HOWAT
Administrator
Human Research Ethics
Science and Mathematics Education Centre

Please Note: The following standard statement must be included in the information sheet to participants:
This study has been approved under Curtin University's process for lower-risk Studies (Approval Number SMEC-12-12). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21).
For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

G (III) Research information and consent forms

Principals consent



Curtin University of Technology
Science and Mathematics Education Centre

Participant Information Sheet

The Principal

My name is Graham Lake. I am currently completing a piece of research for my Doctor of Philosophy – Science and Mathematics Education at Curtin University.

Purpose of Research

I am investigating the research topic: "*The effect of Teaching and Learning Strategies on Conceptual and Attitudinal Change by Gifted Primary Students*" It is hoped that this research will give teachers a better understanding of teaching and learning strategies for gifted students.

Your Role

I am seeking your permission to conduct research by asking for students to take part in short diagnostic tests on electronics that will complement their learning. All testing will be done within the students' normal PEAC class time. Students involved will undertake a number of short tests. The results of the tests will be given back to the students after the completion of the test. I will also ask for the student's participation in a short questionnaire about their attitudes and opinions about science. Again this participation will be voluntary and of short duration (10-15 mins). As this research is conducted by me as the student's teacher in the context of a normal PEAC class, it presents no risk to your child.

Consent to Participate

The students and your school's involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form I will assume that you have agreed to participate and allow me to use the students' data in this research.

Confidentiality

The information provided will be kept separate from the students' personal details, and only myself and my supervisor, Professor David Treagust, will have access to this. The test scripts will not have student names or any other directly identifying information on them and in adherence to university policy, the information will be kept in a locked cabinet for at least five years, before a decision is made as to whether they should be destroyed.

Further Information

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number SMEC-12-12). If you would like further information about the study, please feel free to contact me on (08) 9439 2794 or by email graham.lake@postgrad.curtin.edu.au. Alternatively, you can contact my supervisor Professor David Treagust on (08) 9266 7924 or email D.Treagust@curtin.edu.au.

**Thank you very much for your involvement in this research.
Your participation is greatly appreciated.**

Principals consent (cont.)



PRINCIPAL'S CONSENT FORM

- I understand the purpose and procedures of the study.
 - I have been provided with the participation information sheet.
 - I understand that the procedure itself may not benefit me.
 - I understand that my schools involvement is voluntary and I can withdraw at any time without problem.
 - I understand that no personal identifying information will be used in any published materials.
 - I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
 - I have been given the opportunity to ask questions about this research.
 - I agree to allow students from my school to participate in the study outlined to me.
-

Name: _____

Signature: _____

Date: 16/5/2012

Parent information and consent form



Curtin University

Science and Mathematics Education Centre

PARENT Information Sheet

My name is Graham Lake. I am currently completing a piece of research for my Doctor of Philosophy – Science and Mathematics Education at Curtin University.

Purpose of Research

I am investigating the research topic: *”The effect of Teaching and Learning Strategies on Conceptual and Attitudinal Change by Gifted Primary Students”*. It is hoped that this research will give teachers a better understanding of teaching and learning strategies for gifted students.

Your Role

I will conduct research by asking your child to take part in short diagnostic tests on electronics that will complement their learning. The school principal has already been contacted and has agreed in principle to the project. Students involved will undertake a number of short tests to ascertain any change in learning and attitude toward science. All testing will be done within the students’ normal PEAC class time. The results of the tests will be given back to your child after the completion of the tests. As this research is conducted by me as your child’s teacher in the context of a normal PEAC class, it presents no risk to your child.

Consent to Participate

Your child’s involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your child’s rights or my responsibilities. When you have signed the consent form I will assume that you have agreed to allow your child to participate and allow me to use the data in this research.

Confidentiality

The information your child provides will be kept separate from his or her personal details, and only myself and my supervisor, Professor David Treagust, will have access to this. The test transcripts will not have any names or any other directly identifying information on them and in adherence to university policy, the information will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed.

Further Information

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number SMEC-12-12). If you would like further information about the study, please feel free to contact me on (08) 9439 2794 or by email graham.lake@postgrad.curtin.edu.au. Alternatively, you can contact my supervisor Professor David Treagust on (08) 9266 7924 or email D.Treagust@curtin.edu.au.

**Thank you very much for your involvement in this research.
Your participation is greatly appreciated.**

PARENT CONSENT FORM

-
- I understand the purpose and procedures of the study.
 - I have been provided with the participation information sheet.
 - I understand that the procedure itself may not benefit my child.
 - I understand that my and my child’s involvement is voluntary and I can withdraw at any time without problem.
 - I understand that no personal identifying information like my name and address will be used in any published materials.
 - I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
 - I have been given the opportunity to ask questions about this research.
 - I agree to allow my child to participate in the study outlined to me.
-

Name: _____

Student Name: _____

Signature: _____

Date: _____

Student information and consent form



Curtin University of Technology Science and Mathematics Education Centre

STUDENT Information Sheet

My name is Graham Lake. I am currently completing a piece of research for my Doctor of Philosophy – Science and Mathematics Education at Curtin University.

Purpose of Research

I am investigating the research topic :”*The effect of Teaching and Learning Strategies on Conceptual and Attitudinal Change by Gifted Primary Students*” It is hoped that this research will give teachers a better understanding of teaching and learning strategies for gifted students.

Your Role

I will conduct research by asking for you to take part in short diagnostic tests on electronics that will complement your learning. Your teachers and the school principal have already been contacted and have agreed in principle to the project. You will undertake a number of short tests. The results of the tests will be given back to you after the completion of the test. I will also ask for your participation in a short questionnaire about your attitudes and opinions about science. All testing will be done within your normal PEAC class time and there will be no change in the nature of the PEAC course you chose. Again this participation will be voluntary and of short duration.

Consent to Participate

Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form I will assume that you have agreed to participate and allow me to use your test results in this research.

Confidentiality

The information you provide will be kept separate from your personal details, and only myself and my supervisor, Professor David Treagust, will have access to this. The tests and questionnaire will not have your name or any other directly identifying information on them and in adherence to university policy, the information will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed.

Further Information

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number SMEC-12-12). If you would like further information about the study, please feel free to contact me on (08) 9439 2794 or by email graham.lake@postgrad.curtin.edu.au. Alternatively, you can contact my supervisor Professor David Treagust on (08) 9266 7924 or email D.Treagust@curtin.edu.au.

**Thank you very much for your involvement in this research.
Your participation is greatly appreciated.**

STUDENT CONSENT FORM

-
- I understand the purpose and procedures of the study.
 - I have been provided with the participation information sheet.
 - I understand that the procedure itself may not benefit me.
 - I understand that my involvement is voluntary and I can withdraw at any time without problem.
 - I understand that no personal identifying information like my name and address will be used in any published materials.
 - I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
 - I have been given the opportunity to ask questions about this research.
 - I agree to participate in the study outlined to me.
-

Name: _____

Signature: _____

Date: _____

Appendix H Concept Map Scoring Table

CONCEPT	LINK	CONCEPT	M1 (1-5)	M2 (1-5)	M3 (1-5)	Type D/T
Amps	are measured in	Electrons	1	2	2	T
Capacitors	store	Electric Charge	5	5	5	T
Current	increases	Amps	2	3	2	T
Current	of	Amps	1	1	1	T
Current	can light up	LED	5	4	5	T
Current	is measured in	amps	5	5	5	T
Currents	includes	Electrons	3	4	4	T
Currents	are used for	Diodes	2	3	3	T
Diodes	only one way	Electrons	4	4	4	T
Electric Charge	increases	LED	0	1	0	T
Electric Charge	is measured in	Volts	0	1	0	T
Electric Charge	is a	Volt	1	1	1	T
Electric Charge	is an	Electric Force	2	1	1	T
Electric Charge	increases	Current/Amps	2	1	1	T
Electric Charge	is a	Current	2	2	2	T
Electric Charge	can be called	Electrons	3	3	3	T
Electric Force	is part of an	Electronic Circuit	3	2	3	T
Electric Force	amplifies	Volts	1	1	1	T
Electric Force	increases	Volts	2	1	2	T
Electric Force	is measured in	Volts	5	4	5	T
Electric Force	is a	Volt	2	1	2	T
Electric force	increases	amps	3	2	2	T
Electric Force	includes	Voltage	4	3	4	T
Electric Force	conducts one way	Current	1	1	1	T
Electric Force	comes from an	Electric Charge	5	5	5	T
Electric Force	moves in	Currents	1	0	0	T
Electric force	increases	Electrons	2	1	2	T
Electric force	made by	Electrons	2	1	1	T
Electric/electronic circuits	includes/needs a	diodes/resistor/etc.	5	5	5	D
Electricity	is measured in	Voltage	2	1	1	T
Electricity	runs in	Circuits	4	5	5	T
Electricity	is measured in	Volts	2	1	2	T
Electricity	includes	Electric Charge	4	5	4	T
Electricity	includes	Electrons	4	5	5	T
Electricity	runs in	Currents	3	2	3	T
Electricity	has an	Electric Force	4	3	4	T
Electricity	has a	Electric charge	3	4	4	T
Electricity	is	Electrons	1	2	2	T
Electricity	is an	Electric force	4	3	3	T
Electronic Charge	is a	Current	0	0	0	T
Electronic Circuit	powers	LED	3	3	3	D
Electronic Circuit	uses	Volts	3	3	3	D
Electronic Circuit	includes/ involves	Resistance	4	5	5	T
Electronic Circuit	switches on	Electric Force/volts	1	1	1	T
Electronic Circuit	includes	Currents/ Voltage	4	5	5	T
Electronic Circuit	has	Electric Charge	4	5	5	T

Appendix H Concept Map Scoring Table (cont.)

CONCEPT	LINK	CONCEPT	M1 (1-5)	M2 (1-5)	M3 (1-5)	Type D/T
Electronic Circuit	creates	Electric force	3	3	3	T
Electronics	includes	Electronic Circuit	3	5	4	D
Electronics	includes	Electronic Circuit	3	4	4	D
Electronics	includes	Voltage	3	4	4	T
Electronics	includes	Resistance	3	4	4	T
Electronics	includes	Electrons	3	5	4	T
Electrons	measured in	Volts	2	1	1	T
Electrons	measured in	Amps	3	2	2	T
Electrons	amplifies	LED	1	1	1	T
Electrons	power	LED	4	5	4	T
Electrons	are units of	Current	2	2	2	T
Electrons	are units of	Electric force	0	1	0	T
Electrons	make up a	Current	5	5	5	T
LED	only one way	Current	3	3	3	T
LED	need	Electric Force	2	2	2	T
LED	is powered by	Volts	2	3	3	T
LED	conducts only one way	Diode	3	2	2	D
LED	is a	Diode	5	5	5	D
Resistance	is created when elect. flows thru	Resistor	2	1	1	T
Resistance	is measured in	Ohms	5	5	5	T
Resistance	uses	Resistors	1	1	1	T
Resistance	decreases	Electric Force/ Voltage	4	4	4	T
Resistance	decreases	Current	5	5	5	T
Resistance	is something that decreases	Volts	4	4	4	T
Resistor	Increases/creates	Resistance	2	4	2	T
Resistor	decreases	Electric Charge	2	4	2	T
Resistors	decreases	Volts	4	3	4	T
Transistor	conducts only one way	Current	3	2	3	T
Voltage	increases	Amps	3	4	4	T
Voltage	which can light up	LED	1	2	2	T
Voltage	amplifies	Amps	3	3	3	T
Voltage	is measured in	Volts	5	5	5	T

Appendix I Concept Map Worksheet

STUDENT No. _____

CONCEPT MAP EXERCISE - ELECTRONICS

- CONCEPTS
- ELECTRONIC CIRCUIT
 - LED
 - TRANSISTOR
 - OHMS
 - ELECTRIC FORCE
 - CURRENT
 - ELECTRONS
 - VOLTS
 - RESISTOR
 - AMPS
 - DIODE
 - VOLTAGE
 - RESISTANCE

LINKING PHRASES/WORDS

- measured in
- are units of
- conducts
- only one way
- amplifies
- increases
- decreases
- is a/an
- switches
- includes



Appendix J Raw scores of Key Concepts

Table of Raw scores of Key Concepts on Concept Maps.

CONCEPT	DLC Pre	DLC Post	DLC Diff.	HDLC Pre	HDLC Post	HDLC Diff
Current is measured in Amps	5	42	37	5	42	37
Current is reduced by resistance or resistance reduces current	11	45	34	5	35	30
Current is a flow of charge/electrons	6	33	27	11	16	5
Voltage or electric force is measured in Volts	51	66	15	25	42	17
Voltage is a force	10	20	10	0	25	25
Voltage causes current to flow	11	19	8	10	13	3
Resistance is measured in Ohms	5	60	55	0	41	41
Resistance reduces voltage or electric force in a circuit	4	15	11	20	29	9
Resistor increases resistance (or any function)	0	52	52	7	38	31
Diode function - directs current in one direction (or any function)	0	23	23	8	18	8
Transistor function - amplifies current or acts as a switch	10	28	18	5	8	3

Key: Pre = pre intervention concept score.

Post = post intervention concept score.

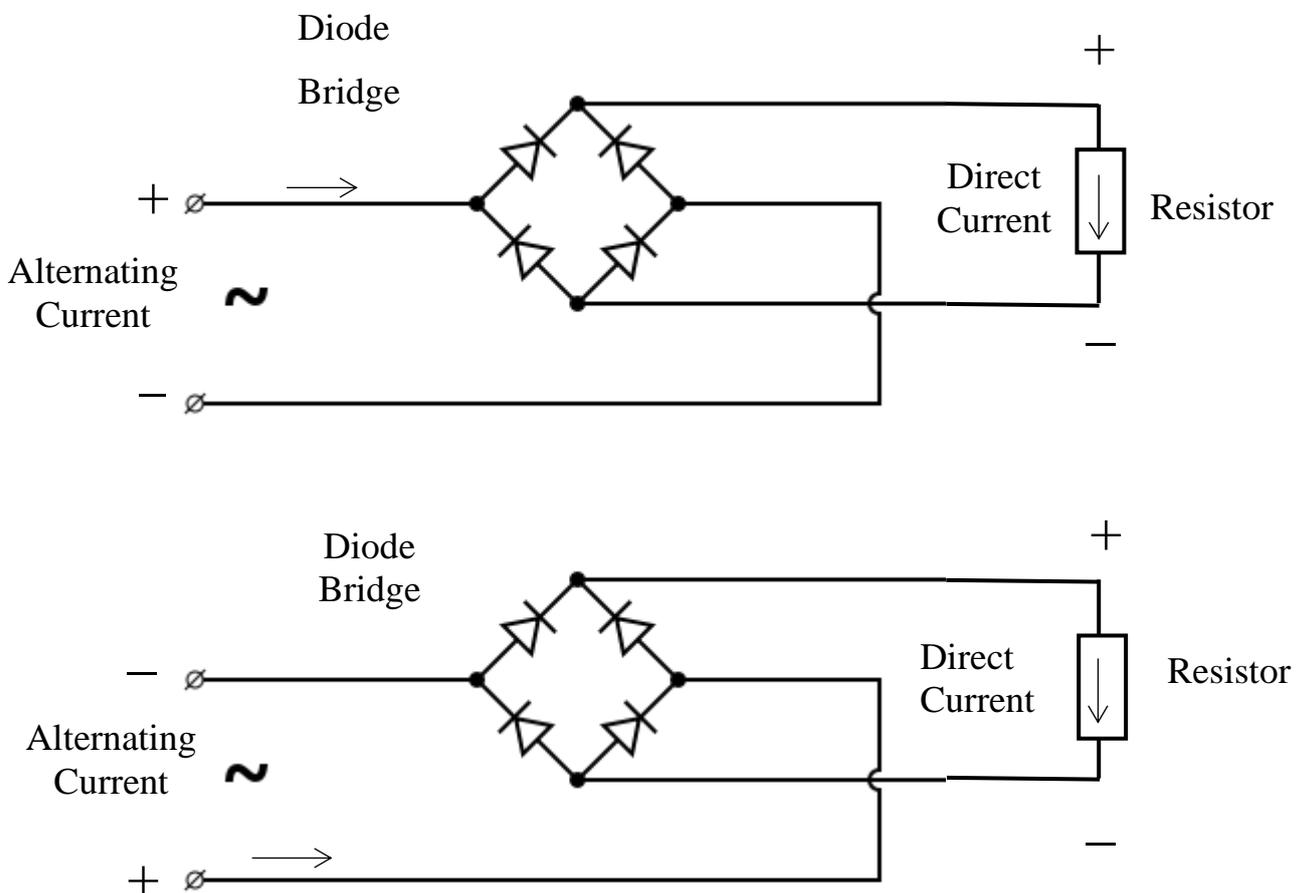
Diff = difference between Pre and Post concept scores.

Appendix K Diode exercise for Lesson 6

CONCEPT APPLICATION

A common use for power diodes is to convert alternating current into direct current. Such a device is called a bridge rectifier. Below is the circuit for a bridge rectifier. (The diode symbol, as in the diagrams below, sometimes does not have a circle).

Note: Alternating current (AC) keeps changing direction, usually 50⁺ times a second. Direct current (DC) always flows in the same direction.



On each diagram trace the pathway of the current from the alternating current positive terminal, through the resistor and back to the alternating current negative terminal. Two arrows have been put in for you as a clue.