Student co-generated analogies and their influence on the development of science understanding

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Certificate of authorship/originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signed: ____________________________ Date: ________________

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Publications and papers produced from this research

Publication

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Conference Papers

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Dedication

This thesis is dedicated to:

The students in my classes who engaged in the teaching experiment, and to those who went beyond, volunteering to participate more fully in the study. Without their support this research would not have been possible.

My three children; Catherine, David and Christopher, and to my wife Lynley, who have all provided much love, support and encouragement.

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Abstract

Science educators often use analogies to help students develop understanding, but successful learning where students develop their own analogies has rarely been reported (Harrison, 2006). This research sought to investigate how the co-generation of analogies influenced students' learning of science. It stemmed from the author's scholarly interest in helping students understand the more difficult science concepts through analogical activities. The use of analogies as tools for learning encourages students to build on what they already know and understand. This research was underpinned by a constructivist epistemology.

A pilot study was conducted and this led to the development of four research questions:

a. How do students develop analogies?
b. How does the co-generation of analogies influence student engagement with science?
c. Do students develop deep understanding through the co-generation of analogies?
b. How does a teacher support students in the co-generation of analogies?

The literature that underpins the theoretical framework for this study is drawn from two main areas. The first relates to learning science through the construction of meaning (Freyberg & Osborne, 1985) and the second relates to the nature of analogy (Gentner, 1983) and its use in learning science (Harrison & Treagust, 2006).

A teaching experiment methodology (Brown, 1992; Confrey & Lachance, 2000) suited this study of learning through analogy in school science because it provides a sound framework for a teacher exploring and scrutinising a teaching approach with his own students during the course of regular timetabled lessons. A large amount and variety of data were collected during 24 episodes of the teaching experiment. The teaching experiment involved the application of a teaching intervention with senior high school, chemistry and/or physics students (16–18 years of age). The intervention required students to develop analogies with the purpose of showing and enhancing their understanding of science concepts. Throughout each application of intervention students were supported by each other and by the teacher.

The analogy based activities included role play, model building and writing. The discussions that occurred throughout these activities were integral to the analogy refining process. Hence, the resulting analogies were co-generated.

The following conjecture was qualitatively investigated using participatory enquiry.

When students develop their own analogies (supported by their teacher) in the process of learning science, they will be able to demonstrate deep understanding about the concepts being studied.

This conjecture was founded in the literature; supported by personal experience and a pilot study; and tested through several teaching episodes.

A large amount and variety of data were collected during the teaching experiment. These data have been used in providing "rich" (detailed) (Denzin & Lincoln, 2008, p. 16) and "thick" (based on multiple perspectives) (Lincoln & Guba, 1985, p. 316) descriptions of 13 episodes in which students developed their own analogies while learning science. Similar episodes have been grouped together and presented in five vignettes.

Findings from the vignettes have been used to formulate conclusions. Data from the episodes reveal that in general, students who participated in the intervention enjoyed becoming actively engaged in analogical learning.

In all applications of the intervention the majority of students were able, with support, to develop and use their own analogies to foster and display appropriate deep understandings about complex science concepts. By developing, using and sharing analogies, students made their conceptions and misconceptions 'visible'. In the supportive classroom environment, the identification of and discussion about students' alternative conceptions and misconceptions assisted students to develop appropriate scientific understandings. In general the understandings developed were persistent over long periods of time.

The data suggests that co-generating analogies enhances student engagement and leads to deep understanding of challenging science concepts. It is thus concluded that the co-generation of analogies for science phenomena contributes positively to students' learning in science.

Key Words

Alternative conception, analogy, base, co-construction, engagement, episode, FAR guide, intervention, mapping, metaphor, misconception, model, relation, representation, role play, scholarly teacher, target, teacher/researcher, teaching experiment, understanding, vignette.

Chapter 1

1.1 Introduction

Science educators often use models/analogies to help students develop understanding, but successful learning where students construct/generate their own analogies has rarely been reported (Harrison, 2006). As a scholarly teacher (see Boyer, 1990; Trigwell, Martin, Benjamin & Prosser, 2000) and researcher, I have been actively seeking ways to enhance the learning of my students for over 20 years. This thesis is a report on a teaching experiment, conducted over a period of four years. It involved 24 applications of a learning intervention. Each episode required students to co-generate analogies relating to science concepts they were studying at the time. The students (aged 16–18 years of age) were in their final two years of schooling, in a comprehensive, coeducational, public, senior secondary college in Sydney, Australia. With only minimal guidance from their teacher (me), the students built models, wrote scenarios or developed role-plays, as analogies. Through the analogical process, the students were encouraged to develop and show their understanding about the science they were learning.

This study addresses a gap in the research (see Section 2.7) about students using their own analogies to foster understanding in science. It focuses on the areas of physics and chemistry, at the senior high school level, for two reasons. Firstly, these were the courses that I was teaching and secondly, these courses contain many concepts that are difficult for students to learn.

The analysis of 13 of the 24 episodes in which students co-generated analogies (see Chapter 4), provides data which adds practical and theoretical perspectives to the current body of information about students learning science through analogy.

This chapter provides an introduction to the research. It has seven sections. Section 1.2 provides background to the research identifying personal, local, global and historical perspectives. The nature and scope of the research (Section 1.3), briefly describes the qualitative nature of the teaching experiment methodology used. This is supported by a short vignette which exemplifies the nature of analogy in the context of the study and begins the discussion about analogical terminology. Issues related to developing understanding are linked with the research questions in Section 1.4 and this leads to the purpose (Section 1.5) and significance (Section 1.6) of the study. An overview of the thesis is provided as a conclusion to the chapter in Section 1.7.

1.2 Background

Teaching for deep understanding is hopefully what teachers at all levels aim towards. In the context of this research, deep understanding is characterised as being evident "when students [can] demonstrate their grasp of central ideas and concepts" (DET, 2003, p. 14). Ritchie (1998) provides arguments that suggests the demonstration of understanding should go beyond the recall of "the structure of ideas in texts or lectures" (p. 172); indicating that students who really understand concepts should be able to create their own relational structures to reflect that understanding. Arguably, however, deep understanding is inextricably linked to transferring the canonical learning into, and retrieving from, long term memory. Hence, if students have deep understanding about science concepts, it should demonstrably, not be short lived. In this regard, identifying evidence of students' relational structures concerning learned science concepts, in the short term and after the lapse of time, should be an indication that deep understanding had resulted from a teaching episode.

Analogical thinking is considered critical to the generation of ideas and the growth of human knowledge (Duit, 1991). Several authors have written about the use of analogies in developing understanding of science (e.g. Gilbert & Boutler, 1998; Heywood, 2002). Much of the work done however, has focused on models and analogies, developed by teachers or researchers and tested for their effectiveness as learning aids in science classes (Harrison & Treagust, 2000; Treagust, Harrison, Venville & Dagher, 1996; McSharry & Jones, 2000). While students successfully generating and using their own analogies has rarely been reported, some researchers (Aubusson, Fogwill, Barr & Percovic, 1997; Cosgrove, 1995; Pittman, 1999; Sandifer, 2003) have experienced some success in having students construct and develop their own analogies in ways that appear to engender understanding of often difficult and/or abstract science concepts.

As a precursor to this research, I reported the use of students' analogies as a means of identifying preconceptions in chemistry (see Aubusson & Fogwill, 2006). In posing appropriate questions during role play activities (see van Ments, 1989), I was able to encourage students to modify their own views and ideas to improve their analogies and their understandings about the chemistry they were learning. Aspects of the analogical pedagogy applied during that experience, match well with those suggested in the FAR guide (Focus, Action & Reflection) proposed by Harrison and Treagust (1994) and have informed aspects of the methodology for the present study.

Being mindful that the double edged nature of analogies (Glynn, 1991; Harrison & Treagust, 1994, 2006) can lead to inappropriate alternative conceptions, there are indications that in developing science analogies, students may not only learn science concepts well (Aubusson & Fogwill, 2006), they may develop an appreciation of the scientific process by engaging (defined in Section 1.6) in science (Coll, France & Taylor, 2005; Tytler & Prain, 2009). This link between analogy and scientific enquiry has been shown by Driestadt (1968) who indicated that "reasoning through analogy" (cited in Heyward, 2002, p. 233) is part of the process that many notable scientists have used in explaining abstract ideas. Supporting this notion, Gentner (1983) described Rutherford's analogy, "the atom is like a solar system" (p. 159) and Holyoak and Thagard (1995) recounted many examples including: the comparison of the sound of voices in a Roman amphitheatre to water waves, by the architect Vitruvius in the first century AD; how Huygens, in 1678, used an analogy between water waves and light to develop a wave theory for light; and developments in computers stemming from comparisons between computing and the mind, by Turing and others, post 1950 (pp. 186-188).

Appropriate interpretation of an analogy is dependent on appropriate mappings between the base domain and the target (see Section 1.4 below). Hence, the usefulness of any particular analogy, in helping individual students learn/recall information is dependent on individual students' experiences (Summers et al. 1998; cited in Heyward 2002, p. 243). This flags inherent issues in using teacher generated analogies, especially when teaching students from wide ranging cultural backgrounds. The notion that "useful analogies are often imperfect" (Holyoak & Thagard 1995, p. 202) suggests, that even trying to find "a holy grail [analogy] to explain phenomena" (Heyward, 2002, p. 239) is flawed.

Nevertheless, there are reports of the successful use of analogy, used in a variety of ways, when teaching abstract science concepts in schools. Buttler (1989), McSharry and Jones (2000), and Hiotis (1993) report the use of role-play to gain alternative perspectives on controversial issues in science. Aubusson and Fogwill (2006) identified that students “clarify their views and bring to the fore their own explanation of phenomena”, leading to “deeper understanding” (p. 94) when constructing role-plays. In 1996, I highlighted the positive role of discourse between students using appropriate science language while developing three-dimensional models (Fogwill, 1996). In addition, the positive impacts on learning, of discourse in which students articulate, consider and reflect on their own and others’ science conceptions is supported by several researchers (Coll, France & Taylor, 2005; Kearney, 2004; Lorsbach & Tobin, 1992; Ritchie & Tobin, 2001).

This research is about students generating their own analogies within the framework of a supervised science classroom. Analogies can take many forms (stories, role-plays, models etc), however to a large extent, those used in class rooms tend to be teacher generated (Treagust, Harrison, Venville & Dagher, 1993; McSharry & Jones, 2000). Previous studies in which students developed their own analogies (Cosgrove, 1995; Nunez-Oviedo & Clement, 2003; Pittman, 1999; and others see Chapter 2) have indicated that “the teacher needs to play an active role in analogy evolution” (Pittman, 1999, p. 2). This active role involves the teacher taking what Nunez-Oviedo and Clements (2003) called a “co-construction” (p. 30) role, helping to direct the thinking of students by, providing constraints, diagnosing their ideas (preconceptions) and making timely comments that encourage students to evaluate, modify/improve or reject their analogies.

The evaluation of an analogy/model is consistent with Step Five in Glynn’s (1991) Teaching With Analogies (TWA) model and with the Reflection Phase of the FAR guide proposed by Harrison and Treagust (1994) (see Table 2.3). It is in this part of the pedagogical process, that the teacher and the students’ peers, as co-generators, assist students in avoiding the perpetration of unacceptable alternative conceptions.

1.3 Nature and scope of the study

13 of the episodes have been selected for reporting and are presented in five vignettes (see Table 3.1). The vignettes provide “rich” (detailed) (Denzin & Lincoln, 2008, p. 16) and “thick” (based on multiple perspectives) (Lincoln and Guba, 1985, p. 316) descriptions about the co-generation of analogies. Findings from the analysis of the data collected during the episodes are used to consider and make generalizations about the learning that took place.

The qualitative research methodology employed in this research is supported by a number of authors (Burns, 1994; Denzin & Lincoln 2003, 2005, 2008; Eisner & Flinders, 1994) and is fully described and justified in Chapter 3.

The teaching experiment as a methodology typically involves the collection of a large amount of qualitative data (see Brown, 1992) during the application of an ‘action strategy’ (after Altricher, Posh & Somekh, 1993). In this thesis, the action strategy, which involved encouraging my own students to develop their own analogies, has been called the “intervention” (Confrey & Lachance, 2000). This approach was taken because I wanted to find out how students’, using their own analogies, could best influence their learning in science. As recommended by Harrison and De Jong (2005), this is likely to result from researching the practice with students in authentic classes. As a teacher/researcher, I used myself and my own classes.

A wide range of data was collected during the teaching experiment. During the intervention activities, students were observed and sometimes audio taped, photographed or videotaped. Informal and formal discussions in focus group feedback sessions, and interviews, were audio taped. Students completed questionnaires and provided artifacts of their work. Answers to examination questions were copied and sometimes compared to those in a parallel class who had not participated in the intervention. Data were scrutinised and findings tabulated. Analysis of a variety of data types provided triangulation that helped to offset any researcher bias.

In addition, other teachers acting as a critical friends, observed lessons in which the intervention took place and provided observational feedback. On one occasion the observing teacher used coding sheets to support her observational feedback. Then after trying the intervention with her own class, she provided feedback on her experience in an audio taped interview.

1.4 An analogy for the photoelectric effect

In this section, a short vignette is provided. This is done for several reasons. It describes a situation in which the difficult nature of a science concept was exposed, resulting in the application of the intervention for this concept. The vignette thus serves as a prelude to Section 4.8, which analyses four episodes in which student co-generated analogies about the photoelectric effect. In each of those episodes, prior to students developing their own analogies, as story was recounted to the students. This served to explain what an analogy was and exposed them to the idea of analogical mapping (see Table 1.1 below). The dialog (see below) is presented in this section: to assist in contextualising the research; to provide insights into how analogical processes can be used to link science concepts to a student's personal knowledge; and to facilitate the introduction of various terms used throughout this thesis (a more thorough analysis of terms with examples from the literature, is presented in Chapter 2).

The vignette

My Year 12 Physics students were working in the library, looking for information about the history of transistors. One student came up to me and said; "You know Sir, I am having real trouble understanding the whole photoelectric thing – especially all that frequency stuff. Can you help me out? I really need you to start from the beginning".

This student occasionally missed lessons and was the sort of student who might be late to class because he had been having a cigarette at the back of the school.

After thinking for a few minutes, I used an analogy in an attempt to help John (a pseudonym) to understand the 'photoelectric thing'. The conversation went as follows (T: Teacher, J: John):

T: John, you're a smoker right? A packet of smokes costs about $10?

J: Yes?

T: Well imagine that even though you have heard and read all the warnings and you know how unhealthy it is, you still wanted to buy a packet of smokes. There was a shortage of packets and a rule was brought in that there was a limit of one packet per person.

There was a supermarket with one person at the counter and a line of people.

Imagine the packets cost $9.50 and you were only allowed to use one note, a $5, $10, $20, $50 or $100.

If you went to the counter with $5 would you be able to get any packets?

J: No.

T: What if 20 people in a row all asked for a packet and only had $5? Would the sales person sell any?

J: No.

T: Why not?

J: none of them have enough money.

T: What if the people that lined up all had $10?

J: They would get a packet and some change.

T: How much change?

J: 50 cents.

T: What if the people that lined up all had $20?

J: They would get a packet and some change.

T: How much change?

J: $9.50.

T: What if the people that lined up all had $50?

J: They would get a packet and some change.

T: How much change?

J: $40.50.

T: Now let's relate that to the photoelectric effect experiment. What represents the photoelectrons?

J: [After a little thinking] The packets of smokes.

T: What part represents the frequency of light?

J: The money notes the customers have.

T: In what ways are they (the frequency and the money) similar?

J: Some are bigger than others.

T: What does the change represent?

J: The energy of the photoelectrons.

T: What does the cost of the packet represent?

J: The work function of the metal.

At this point, John seemed to understand the ideas, thanked me and went away very happy.

This experience with John provided the impetus to use analogy to test the understanding of others in the class. Thus began a continuous series of episodes over the next four years with successive physics classes in which the students were exposed to the idea of an analogy and supported in developing their own (see Section 4.8).

Analogical Terms

The above analogy, which relates features of the photoelectric effect with the purchase of an item, is used below to exemplify definitions for a number of terms relating to analogies.

In the analogy the target is a package of ideas (domain) about an abstract concept called the photoelectric effect. The base, for John was something very familiar to him. A package of concepts located around the purchasing of cigarettes. This is "the [base] domain that serves as a source of knowledge" (Gentner, 1983, p. 157). Here it seemed very easy for John to visualise features/minute details (attributes) of the base and processes (relations): paying money, receiving the goods (or not) and being given change. As a result it was then possible for him to match (map) the attributes and relations of the base concepts to attributes and relations of the target concepts. This appeared to lead John to increased understandings about cause and effect (relational) aspects of the photoelectric model.

In Table 1.1 below, features from the base are mapped to features of the target.

I prefer to use the metaphors of base and target because these terms engender understanding. The base is something that is already known, a foundation upon which other ideas can be built. The target is something (understanding, knowledge, skills etc), it is hoped, the learners will achieve. Attributes are specific details about the base and target and relations are cause and effect interactions between attributes. When the base or target has a number of attributes/relations it is more appropriate to collectively call them a base domain or target domain.

This short vignette reinforces that:

> By tailoring analogies to the particular backgrounds of students, a teacher can maximize the explanatory power of analogies and build upon the students' previous learning in science. (Glynn, 1996, p. 491)

Table 1.1 Mapping attributes and relations in an analogy for the photoelectric experiment

Base attributes	Target Attributes
Money	Photon frequency / energy E = hf
Shop	The metal
Sales person	Atoms
Packets of cigarettes	Electrons
Cost	Threshold frequency / energy of incident photons-also called the work function of the metal
Change	The kinetic energy of electrons that are released

Base relations	Target relations
Paying money causes the sales person to give cigarettes and change.	Light incident onto the metal surface, causes photoelectrons that have kinetic energy to be released from the metal.
No matter how often too little money is presented to the sales person they will not give any packets of cigarettes.	No matter how much light, with too low a frequency (energy), is incident upon the metal, the atoms will not be able to release electrons.

However, for the teacher, finding personally appropriate bases for every student would be a major challenge. In the above case, John was the only student in the group who was a smoker and hence while the analogy suited his learning, it was less likely to suit the rest of the students, who would have had little if any experience purchasing cigarettes. For this reason, when discussing (with the class) the concept of using an analogy to enhance understanding and recall of the photoelectric effect, the analogy used with John was described, but the students were asked to make up their own. To start them thinking, two other possibilities were provided; movie tickets and chocolates (see Section 4.8). In this way, students could use any one of three possible base domains to stimulate their own individual, possibly similar memories, to apply to the target domain.

The idea of students selecting their own base domain is supported in the literature. Clement (1993) identified that analogies can form conceptual bridges for learning; and Lakoff and Johnson (1980) identified that "conceptual metaphors [inherent in analogies] are grounded in correlations within our experiences" (p. 154). Hence, it is likely that the "source knowledge" (Gentner, 1983) for "reasoning by similarity" (Rumelhart, 1989, p. 301) is best chosen by each individual from their own prior experiences.

1.5 Purpose

The purpose of this research was to investigate, in authentic practice, the use of student generated analogies in learning science. In particular it aimed to provide evidence about how senior students, in their final two years of schooling, learn, when they use these strategies to learn physics or chemistry concepts. In addition this research may lead to improved models of teaching that have learning implications for and beyond the science curriculum in NSW, Australia.

In addressing, how students' co-generating analogies influences their learning of science, four questions were addressed.

a. How do students develop analogies?
b. How does the co-generation of analogies influence student engagement with science?
c. Do students develop deep understanding through the co-generation of analogies?
d. How does a teacher support students in the co-generation of analogies?

The emphasis in this research was on students generating analogies in a classroom environment, supported by their peers and the teacher. In this sense, the students did not individually own the final analogies that were generated. This is why the terms co-generated and co-constructed are used throughout the thesis.

1.6 Significance

This research is significant in several ways. Most importantly, the research contributes to knowledge about teaching using analogy, a practice which is common place, but as yet, not well understood. This study elevates the knowledge about students generating analogies to a more informed position, based on rich and thick descriptions from several episodes of students learning in authentic science classrooms over a period of four years. In a broader pedagogical sense it investigates a teaching strategy that may help to address issues associated with lack of student engagement in and with science. It does this by reporting on interesting and rewarding, arguably better ways for students to learn difficult science concepts. Ways, that involve scientific discourse and analogical reasoning, which might rekindle students' enthusiasm for the physical sciences; thereby, helping stem the movement of students away from such studies.

A major area of significance relates to quality of the analogies used in the process of learning science. Much of the research on analogies has focussed on analogies provided by teachers or those presented in text books. This has resulted in considerable discussion about the negative effect of analogies creating misconceptions (see Glynn, 1991; Harrison & Treagust, 2006). There is hence, an identified need for analogies used by teachers, to be thoroughly tried and tested (see for example, Harrison, 2006). While this research does not dispute that analogies should be tried and tested, it focuses on the trying and testing during their development by and with students in the processes of learning and assessing learning in science.

This view is consistent with the heuristic (as a learning tool) and *post festum* (Latin: after learning) uses of analogy discussed by Wilburs and Duit (2006). Additional support for the idea that at least initially, analogies that students use, may not, and probably cannot be, accurate, because they are developing them, is found in the research. For example, when Hogan (1999a) used an intervention that encouraged students to collaboratively co-construct knowledge, she identified that:

> Sometimes it is necessary to ease up on expecting students to construct understandings that not only are personal, but also are scientifically accurate, in order to allow them to experience what it is like to build original models, theories, and explanations in the way that scientists do. (p. 472).

This teaching experiment provides evidence that unguided, student use and development of their own analogies is fraught with concerns about students developing unscientific alternative conceptions. Nevertheless, it strongly supports the proposition that when carefully guided, using a process of co-construction, in which students consider, share, discuss and modify their own, expectedly imperfect analogies, the processes involved lead students towards developing deep scientific understandings. Thus identifying a pedagogical strategy, that engages students in the processes of science, to learn science. There are multiple perspectives to engagement. In a recent Canadian study (Willms, Friesen & Milton, 2009) three perspectives were defined as follows:

Social Engagement	A sense of belonging and participation in school life.
Academic Engagement	Participation in the formal requirements of schooling.
Intellectual Engagement	A serious emotional and cognitive investment in learning, using higher order thinking skills (such as analysis and evaluation) to increase understanding, solve complex problems, or construct new knowledge. (p. 7)

While all three permutations are significant in the context of this research, intellectual engagement is by this definition, specific to learning and therefore most relevant to the conduct of the teaching experiment. Hence, within this thesis the term engagement will hereafter refer to intellectual engagement.

The lack of student engagement in science has been identified by Goodrum, Hackling and Rennie (2001) as an international problem. Locally however, (for Australian students) they elucidate "a growing concern about the disparity between the science education provided in our schools and the needs and interests of our young people" (p. 1). They also suggest that many students in high schools "experience disappointment because the science they are taught is neither relevant nor engaging"; and suggest that "traditional chalk-and-talk teaching, copying notes, and 'cookbook' practical lessons offer little challenge or excitement to students" (p. viii). While the current research does not attempt in any way to alter the curriculum, it does test a pedagogy that is far from 'chalk-and-talk'. It employs teaching through analogy which Harrison (2006) claims, if used in "contextually, intellectually and socially familiar" (p. 62) ways, has the affective potential to encourage and engage students in the learning of science.

Students working with their analogies, as presented in this thesis, are consistent with the social constructivist perspectives about how students learn science, elucidated by Goodrum, Hackling and Rennie (2001). Links between the nature of this teaching experiment and several of their ideas, indicate that this research is significant in the Australian context. The ideas reported include:

> Learners develop knowledge and ideas in science which make sense to them by linking new information to their existing conceptual frameworks. (p. 17)

The development of analogies in this teaching experiment encouraged students to at least begin constructing their own meaning based on what they already knew.

> Opportunities for learning are enhanced when learners interact and collaborate with other people who can challenge and test their thinking. Working with peers in their classroom allows learners to test their scientific ideas against those of others and to consider new and different ideas, thus building their understandings about science. (p. 18)

The co-generation aspect of analogy development inherent in each episode of this teaching experiment typifies this sentiment.

> Effective learning in science requires a variety of approaches designed to make a particular aspect of science accessible to each particular group of students. (p. 19)

This experiment provides detailed descriptions of a variety of approaches in analogy development. When working in groups, students took an active role in deciding the nature of the base domain they used in order to develop an analogy.

> Many science concepts are abstract and can be described only by language and metaphor. Students need to communicate their understanding of science concepts in a range of forms. (p. 20)

Through the sharing of analogies about abstract and complex science concepts, students actively engaged in discourse about their own and others' analogies and the target science. Many of the concepts were also transferred into diagrammatic representations.

> Interaction between, students, their teacher and their peers is an important part of developing reflective learners. (p. 20)

The iterative and interactive nature of co-generating analogies in each episode encouraged students to reflect on their understandings. This reflection is a key aspect of the teaching intervention.

> Teachers need to identify students' current understandings so that they can implement activities that build upon these understandings through the provision of challenging but achievable tasks. (p. 20).

Especially during the initial stages of each intervention, in which students began the process of analogy development, students' preconceptions became 'visible'. This visibility provided the key to supporting students' development of canonical understandings about the target science concepts.

Beyond the development of personal understandings about the particular science concepts however, is the notion that using and developing analogies allows students to develop and test their own ideas; openly present their ideas for the scrutiny of others; and refine or discard their ideas based on feedback. In other words, they engage in the practice of science, becoming more scientifically literate in the process. The importance of this is aptly described by the words of Coll, France and Taylor (2005):

> The development of pedagogical practice that provides an opportunity for learners to identify with and emulate the type of discussion that occurs within the community of practice of scientists is of increasing importance in international science education research, and can provide significant links between the community of practice of scientists and the classroom. (p. 189)

This research is thus significant in a number of ways. It adds to the body of knowledge about teaching with analogies; provides an in-depth analysis of practical ways in which science teachers may engage their students in developing deep understanding about the science they are learning; and identifies a pedagogical strategy that may help to improve students' scientific literacy and interest in studying science.

1.7 Overview of the thesis

This thesis has five chapters. This section provides a very brief overview of the four remaining chapters.

Chapter 2 locates this research in the context of previous research and relevant theory. It thus helps to identify a gap which the present research may help to narrow. An analysis of the nature of analogy including relevant definitions within the literature, leads to a justification for the constructivist epistemology that underpins the teaching experiment. Previous research about students using analogies while learning science is identified and discussed. Following the identification of the type of research needed, an analysis of the various frameworks for teaching with analogies, leads to the justification for the framework considered in the design of the teaching experiment.

Chapter 3 describes and justifies the methodology used in this research. It provides full details of the background to and the context of the research. Features of teaching experiments from the literature and coupled with acknowledged methods for teaching with analogies, leading to a justification for the research design. Methods of establishing trustworthiness within a qualitative framework are presented and used in the justification for the methods of data collection and data analysis. Reporting in terms of the research questions is briefly discussed. Limitations, based around difficulties in collecting and analysing data and with researcher bias, are identified. Following a consideration of the research ethics, the chapter concludes by highlighting the appropriateness of the teaching experiment methodology.

Chapter 4 presents the data from 13 episodes of the teaching experiment in five vignettes. Episodes that are similar in nature have been presented in the same vignette and so the findings, presented within the vignettes are typically based on data from multiple episodes. The vignettes provide descriptions, analysis and interpretive comments about what happened when the students engaged in the analogical activities to learn specific aspects of their science courses. The first vignette describes the Pilot

Study and how it helped to shape the remainder of the research. Findings specific to the episodes are presented in the vignettes and it is these findings that form the basis of the discussion in Chapter 5

In Chapter 5 the research findings are discussed in reference to the research questions. Implications from the research about the co-generation of analogies are discussed. The ways in which this research assists in refining the knowledge in the field of using analogies in science teaching and learning, are presented and elaborated; and lead to suggestions for further research. The chapter ends with conclusions about how co-generating analogies influences students' development of science understanding.

Chapter 2

Literature Review

2.1 Chapter Overview

This chapter locates this research in the context of previous research and relevant theory. It analyses the nature of analogy and the research about students using analogies while learning science. It provides justification for the constructivist epistemology that underpins the teaching experiment. The chapter locates relevant definitions and frameworks within the literature and provides discussions to clarify key aspects relevant to the research.

The chapter is divided into eight sections. Section two discusses the nature of analogy and defines analogical terminology, providing examples from the literature. Section three outlines contributions to the current study from previous research about students using analogies in school science. Section four identifies links between constructivism and the use of analogies for learning and hence provides the justification for the constructivist epistemology that underpins the research. Section five is a discussion that links the use of analogies to learning difficult concepts in science. Section six provides evidence from the literature that identifies a need for research such as the present study. The penultimate section to the conclusion provides an analysis of pedagogical and theoretical frameworks that have been developed for using analogies, providing a justification for the framework adapted for use in this research.

2.2 The nature of analogy

This research focuses on the use of extended analogies developed by students, with the support of their teacher, to foster students' scientific understandings of abstract concepts. Hence, a detailed scrutiny of what is meant by *analogy* is appropriate. This scrutiny will lead to a working definition for, and an understanding of, analogy as it is used in this teaching experiment.

Terminology

To embark on an in depth discussion of almost anything, a special set of terms needs to be employed. The language of analogy has been developed over time and there is a range of synonyms for the relatively few major concepts involved. In this section, the various terms relevant to a discussion about analogy are identified and defined with examples from the literature.

The main terms are analogy, base, target, attribute, relations, domain and mapping (see also Section 1.4). The following discussion of these terms and related phrases is largely based on the work of Gentner (1983) and Vosniadou and Ortony (1989) and is summarised in Table 2.1.

When Gentner (1983) says that "an analogy is an assertion that a relational structure that normally applies in one domain can be applied in another domain" (p.156), what does she mean? Considering the Solar System as an analogy for the planetary model of atomic structure, students learn about the structure of atoms by considering their already known personal understandings about the structure of the Solar System. For example, if students already know that the planets are relatively small masses (in comparison to the Sun) and that they move in almost circular orbits of various radii around the Sun, they can relate this to tiny electrons orbiting in various shells around a central, relatively massive nucleus in the middle of an atom. So the two *domains* are the Solar System and the atom. The *target* concept is the one to be learned about – in this case the structure of the atom; and the *base* is the already known information – the structure of the Solar System. Each has certain *attributes* or features which can be compared or *mapped* as being similar. When the features have functional similarities they become *relational* similarities (planets and electrons orbiting a central mass). The two domains also have attributes which are not similar which are not expected to be mapped. For example, the Sun is hot; nuclei are not. Some planets have moons; there is no expectation that electrons have tinier orbiting bodies.

In Table 2.1 below, key words and synonyms taken from Gentner (1983) and Vosniadou and Ortony (1989) are listed, and descriptions and examples are provided. In addition to clarifying meanings, this table is also provided to facilitate understanding of the vignettes presented in Chapter 4.

The literature about analogies and related areas, including models, reveals a range of complexities about the term analogy. A consideration of these complexities is needed to develop an expanded understanding about the use of analogy in teaching science (see Fig 2.1).

Gentner (1983), for example, argued that while there are distinctions between literal similarities and analogies, they are "not a dichotomy" (p. 161). In considering the extremes of the continuum between the two, literal similarities share many object attributes and relational similarities. In such situations comparisons can be made without one being considered a metaphor for the other. Literal similarities can be exemplified by considering exact replicas such as a model car. These are often very carefully constructed to have most of the object attributes and most of the relational similarities to the real thing, which itself is an object that can easily be studied, measured and scrutinised. Apt examples from science teaching include; carefully constructed plastic models such as skeletons; torsos showing the internal organs; and up-scaled models of insects. It is unlikely that such things would be considered analogies for the real thing.

A little further along the continuum, however, the distinction becomes less certain. Consider the ball-and-stick models often used in chemistry to represent molecules of substances such as water. Both the model and the real water molecules have three atoms and bonds between them. The relative positions of the atoms to each other are typically mirrored in the model by ensuring that the bond angles between the two hydrogen atoms and the oxygen atom match scientific measurements. Considering that a model can be an analogy, and given the current technology by which measurements of molecular properties *are* possible, van Driel and Verloop (1999) would probably classify both a model car and model water molecule as *unscientific* analogies because in their view, a scientific "model is a research tool which is used to obtain information about a target which cannot be observed or measured directly" (p. 1142).

Table 2.1 – Analogy Terms

Descriptor	Description	Example(s)
Attribute *Object-Attribute* *Surface similarity*	A physical feature of the object	A model of an atom and a model of a Solar System will both have a central mass.
Relations *Relations predicate* *Relational similarities* *Explanatory structure*	A feature that shows similar relationships	A model of an atom and a model of a Solar System will show spherical bodies located in orbit around a central mass.
Domain	The object of comparison or model	The Solar System or the atom
Target	That which is to be explained	The structure of an atom
Base *Analog* *Source*	That which is used to facilitate the explanation	Known understandings about the Solar System perhaps facilitated by a model Solar System or diagrams/photos that show or remind about the structure of the Solar System.
Mapping	Identifying links between base and target domains	Electrons orbiting the nucleus of the atom are like planets orbiting the sun.
Structure	Features of similarity	Physical or relational (see above)
Within-domain analogies	Comparisons between entities that have strong surface similarities.	The Earth is like the moon Vosniadou and Ortony (1989, p. 415). Both are large rocky spheres that orbit the sun together.
Between-domain analogies	Comparisons between entities that “share similar explanatory structure” Vosniadou and Ortony (1989, p. 414)	Atoms and the Solar System. In essence they are very different. However an understanding of the Solar System helps to picture the planetary model for atomic structure (and vice versa).

For students however, the molecular models are scientific because the students have no way of observing or measuring real water molecules. The models provide a way of visualising, measuring and manipulating the un-seeable. Zeitoun (1984) though, would not class the model water molecules as analogues because they "belong to the same schema" (p. 110) and while this is reasonable for a person with canonical knowledge, it would only be true for students after the scientific attributes for model water molecules had been internalised through the analogical process. Hence, during lessons, the molecular models are representations, used as analogical tools to facilitate learning about molecules and reactions. This is not new to science. Several pioneering scientists have used molecular models, in analogical ways, to foster their understanding; for example, the famous Watson and Crick (1954) double helix model for DNA. Wilbers and Duit (2006) provide several other examples including models used by Dalton, Kekule, Van't Hoff and Pauling; and purport that "molecular models [have become] obligatory tools" in the study of chemistry (Wilbers & Duit, 2006, p. 120).

For analogies, Gentner (1983) argued there are "few or no object attributes" and a greater proportion of "relational predicates" (p. 159) (see Table 2.1). The atom and Solar System analogy provides a good example. Atoms and the Solar System are not at all physically alike. In making comparisons, planets are not supposed to be electrons and a Sun is not meant to be at the centre of the atom. Yet there are similarities which are useful in making comparisons (Table 2.1). This view is consistent with Zeitoun's (1984) schemata considerations, in which he identified that in analogical relationships, two domains each have their own schema. He provided the camera analogy for the eye as an example in which "the two schemas are not identical or literally similar; they are analogically related" (p. 110). To exemplify; one of the main functional components of both a camera and the eye is the lens. While the purpose of the two lenses is identical, the nature and functioning of the lenses are quite different. The eye lens is a colourless jellylike material, positioned a fixed distance from the retina. To create a clearly focused image the shape of the lens is manipulated by cilliary muscles. The camera lens is a hard piece of glass with a fixed shape. To obtain a clearly focused image, the distance from the lens to the film must be changed. Yet one lens is like the other – they are "analogically related" (Zeitoun, 1984, p. 110).

For the purposes of clarification, literal similarities and unscientific models can be considered at one end of a continuum with complex analogies and complex scientific models at the other end (see Fig. 2.1). On this level of classification, working scale models and models, such as ball-and-stick models of molecules, which have as close as is knowable, the same structural and functional relationships as their targets, would be located towards the left. “Long-distance” analogies, such as ‘the mind is like a computer’, which have comparisons that “leap across domains” (Dunbar, cited by Holyoak & Thagard, 1995, p. 197) would be at the extreme right of the continuum.

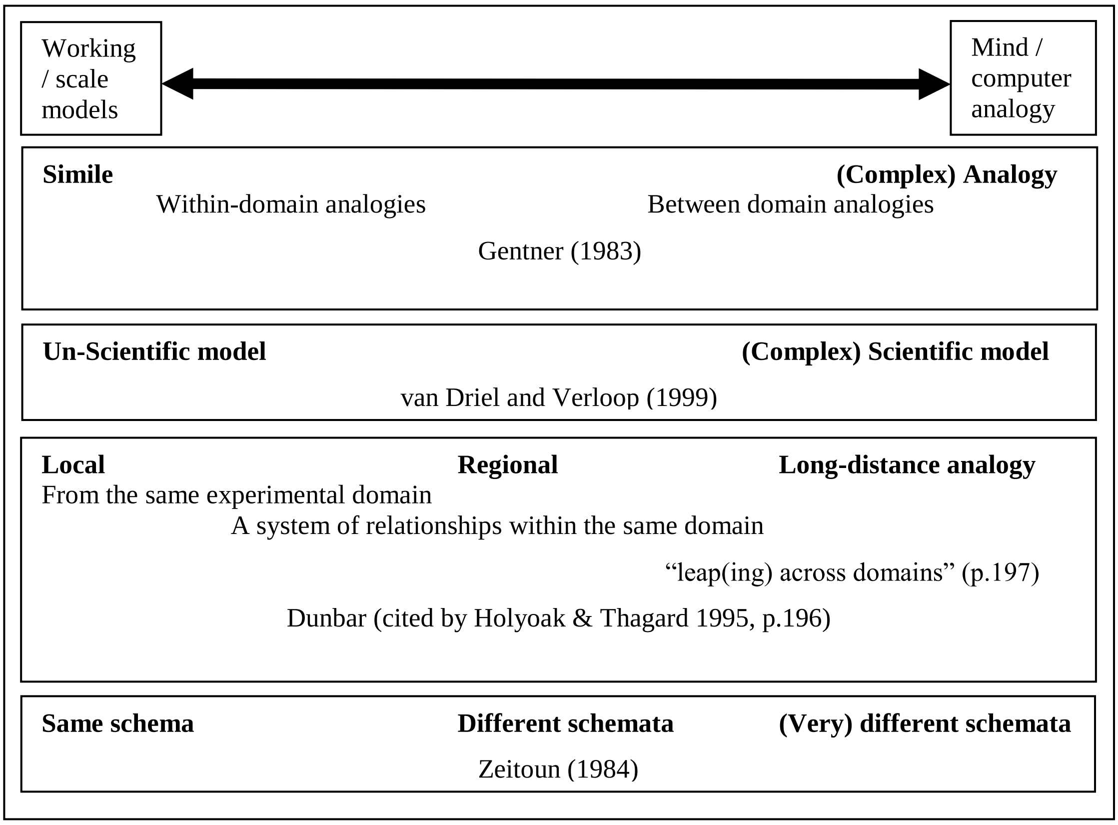


Fig. 2.1 *Analogy - a continuum of classification*

Cosgrove (1995), recognised that “both structural and functional analogies are used in science” (p. 298). He emphasised, through the metaphor of opening *black boxes,* that analogies may help students develop understanding about difficult concepts (such as conservation of electric charge). So whether something is a literal similarity or an analogy, by classification, may be less relevant than the analogical processes that are employed when developing scientific understandings. Vosniadou and Ortony (1989, p. 416) for example, believe that “analogical reasoning can be employed between any two systems” even if they “belong to the same fundamental category (those at the left hand end of the continuum in Fig. 2.1, above), if it involves transferring an explanatory structure from one item to another” (p. 416). This is consistent with the view taken in designing the teaching experiment for the current thesis.

The relevance of analogy to science teaching

The usage of analogy ranges from simple statements, to complex representations. In simple statements, the original metaphorical meaning is almost "dormant" (Williamson & Taylor, 2006, p. 28). This is exemplified; in everyday language; *'do you **see** what I mean';* in classrooms; '*That was a **brilliant** result';* and in the jargon of science; *'the Solar **burning** of hydrogen'*. The usage in this research however, lies at the complex representational end of the usage spectrum. Here, the active and deliberate modelling processes, involve discussions and comparisons in order to facilitate specific learning about key scientific concepts. Examples from the literature can be found for all levels of schooling. For example, the metaphor of *electron clouds* has been used with children as young as four years of age to introduce concepts about atoms that are consistent with quantum physics (Hancock & Onsman, 2005); and the analogy that atoms are like a mini Solar System (Gentner, 1983), is typically used in teaching atomic structure to teenagers.

Analogy is typically used in every day ways and in teaching science. Yet a search of the literature confirms that there has been continued discussion about the nature of analogy and its close relative, metaphor, for some decades. Black (1962) compared Whately's (1846) definition for metaphor "a word substituted for another on account of the resemblance or analogy between their significations" (p. 68) with more modern definitions, and puts forward one view of metaphor as being a "species of catachresis", "the use of a word in some new sense in order to remedy a gap in the vocabulary". He provides examples such as "cherry lips", indicating that the metaphor *cherry* is for want of a better word to describe the nature of the lips. Black (1962) also indicates that "recognition and interpretation of a metaphor may require attention to the particular circumstances of its utterance" and that there are "no standard rules for the degree of weight or emphasis to be attached to a particular use of an expression" (p. 67). This concept of *weight* has now been seized upon by Ritchie, Aubusson and Harrison (2006) who identify, that making the weight of a metaphor or analogy explicit, may be a key for their successful use in teaching science. Thus, the nature and use of metaphors and analogies are still evolving and educators are continuing to learn about their uses in the classroom.

In considering the use of metaphor and analogy in science teaching then, it is worth clarifying the links between the two. Metaphors and analogies can be viewed as being quite different, even “polarities”; metaphors being “plainly false” and analogies providing explicit (truthful) comparisons; yet at times they can be interchangeable (Duit, 1991a, p. 651). Nevertheless, within the written and spoken word, both analogy and metaphor are communicative devices that help people integrate new information with prior knowledge (Black, 1962; Lakoff & Johnson, 1980; Wolfe, 2001). Learning science through metaphor and analogy involves developing scientific understandings through the comprehension of familiar experiences and making appropriate inferences (Wolfe, 2001). The comparative nature of analogy and metaphor provides insight into their importance in the learning of science. If the use of a metaphor can evoke in the learner, a useful analogical comparison, then the metaphor will also have played an important part in their learning. This can be clarified using an example. Consider the Solar System analogy, as discussed in detail by Gentner (1983) and as used by the authors of countless science text books, to help students understand the structure of atoms. When used as *an atom is a mini-Solar System,* it is a metaphor and while in this form it is a false statement, to students who know the structure of the Solar System, immediate comparisons can be made. Identifying features of the Solar System and applying them to an atom is a mental process of the student. Making the comparisons, turns the metaphor into the analogy – an *atom is* ***like*** *a mini-Solar System*. Of course this does not mean that an atom contains millions of orbiting asteroids, comets and a number of planets of various sizes some of which have several of their own orbiting bodies (moons and icy rings); or that the centre of an atom is an extreme source of heat. So the statement is false and is therefore consistent with Duit’s (1991a) definition of metaphor. This said however, to teachers and authors of text books, there are other points of interest in the comparison, referred to by Vosniadou and Ortony (1989) as “similar explanatory structures” (p. 414) and by Gentner (1983) as “relational predicates” (p. 159) (see Table 2.1). These have made the Solar System analogy for the atom worthy of use by science teachers everywhere, probably since Rutherford described his model of the atom. To list a few of the useful comparisons; both the Solar System and the atom are considered to be mostly empty and the model of the atom portrayed has tiny masses (electrons) orbiting the nucleus (a central body containing most of the mass) of the atom in a similar way that the relatively small planets orbit the much more massive sun. These explicit comparisons are consistent with what Glynn

(1991), who scrutinised the use of analogy in 43 science text books, identified as the "process" of analogy (p. 223), which can make science targets "more understandable and therefore memorable" (Glynn & Takahashi, 1998, p. 1144).

During this process of analogy, when students consider the structure of an atom to be like that of the Solar System, they will also be considering that the structure of the Solar System is like that of a Rutherford atom. This "symmetrical nature of analogical relations" (Duit 1991a, p. 653), is an oscillating analogical process in which the base becomes the target and the target becomes the base. This facilitates back and forth comparisons and helps develop understanding of both the *target* and the *base* (see Table 2.1). This heuristic analogy process is the basis of Wilbers' and Duit's (2006) model of analogical reasoning which depicts an iterative process of developing scientifically appropriate mental models from initial mental images and intuitive schemata. These intuitive schemata are what Zeitoun (1984) refers to as "general knowledge" (p. 109).

This oscillating nature of analogical processing has been useful beyond learning, per se. Being akin to invention, it can lead to the development of new concepts. For example back and forth comparisons between the mind and computer by Turing in the 1950s, helped to develop understandings about the mind (Holyoak & Thagard, 1995, p. 188), and led to the development of new types of computers.

Analogies can enhance the descriptive nature of conversations; they can act as what Ausubel, Novac and Hanesian (1968) call, "organizers" which function "to bridge the gap between what the learner already knows and what he needs to know before he can meaningfully learn the task at hand" (p.171-172); and they can be useful in stimulating thoughts leading to the development of new concepts including inventions.

There are, however, limiting factors and inherent problems in the analogical process. For example, being able to use and understand the Solar System analogy to learn some of the features of atoms, presupposes that the students know the structure of the Solar System – they may not; and, if not, the analogy would be of limited use (Heywood, 2002). Limited understanding is also a problem. In learning about electricity using a water analogy, Haeberlen and Schwedes (1999) found that students, who had alternative (unscientific) conceptions about the base concept of pressure in water circuits, transferred their alternative conceptions to target concepts in electricity. Thus providing clear evidence, that misunderstandings about a base, can lead to misunderstandings about a target. There is hence, a danger that when students have limited understanding of the base concepts, perhaps resulting from oversimplification by the teacher/text book, it can "conflict with scientific validity" to the point of facilitating the teaching/learning of wrong science (Sefton, 2002, p. 11).

Concern about the nature of the comparisons made by students during the analogical process goes beyond misunderstandings of the base concepts used. Science teachers use metaphors and analogies (and issue text books full of them) to make comparisons and endeavour to have students make *similar* comparisons to develop understanding about the science being learned. However, this does not always happen; students will often also make unexpected comparisons. In this way, analogies are "like double edged swords, with one edge creating acceptable student understanding and the other generating misconceptions" (Harrison & Treagust, 1994, p. 41). In addition, as powerful learning tools (Wilbers & Duit, 1999, p. 45), their use/misuse can lead to "robust" alternative conceptions/misconceptions that defy great efforts to correct them (Coll & Treagust, 2001, p. 25).

Nevertheless, students at all levels, even very young children can develop understandings consistent with highly complex scientific ideas, such as electron clouds within atoms (Hancock & Onsman, 2005). This powerful yet dual ability of analogies to facilitate the development of understandings that are consistent with current scientific models and others that are not, has sparked a great deal of ongoing research by science educators, (e.g., Aubusson & Fogwill, 2006; Coll, France & Taylor, 2005; Cosgrove, 1995; Glynn, 1991; Harrison, 2006; Sandifer, 2003; Treagust, 1995; Wilbers & Duit, 2006; Venville, 2008a&b) to identify the most effective ways of using analogies in fostering the learning of science.

Major problems such as those mentioned above, must however be addressed, if analogy use is to be effective in teaching science. If analogical processes are transparent enough to allow the identification and correction of base *and* target misconceptions, then perhaps the analogical process will be optimized. This is a key feature of the current teaching experiment and will be discussed in detail in Chapter 3.

Conceptions and constructivism

As the deliberate use of analogy purposefully calls on students to relate their knowledge with new, to-be-learned, often abstract ideas, it is relevant here to discuss the differences associated with the terms *appropriate conceptions*, *misconceptions* and *alternative conceptions*, in terms of what is learnt. In the context of this thesis, appropriate conceptions are the expected 'correct' scientific understandings that are consistent with current scientific ideas (e.g. dogs and cats are mammals). An alternative conception is a conception about a phenomenon that a student has, that is not typical of what might be acceptable in science; or more specifically in school science contexts, in text books or in a teacher's repertoire. This is not to say, however, that, alternative conceptions are not appropriate or correct from the students' everyday perspective (e.g., humans are not animals). A misconception, however, is clearly wrong (e.g., humans are not mammals).

In a constructivist sense, student conceptions are derived from their existing knowledge (Treagust, 1995) and through their senses (Lorsbach & Tobin, 1992) and, "their personal theories and models often conflict sharply" (Glynn, Yeany & Britton, 1991, p. 13) with the scientific ones to be learned. This means that students use their pre-existing schema when attempting to interpret new information, and since a scientific interpretation is often quite different from an everyday interpretation, students may have difficulty resolving the two. While the constructivist nature of learning will be dealt with in more detail later, the following quotation is pertinent here.

> A constructivistic science instruction must accentuate a relational view of science conceptions. Science instruction must accordingly convince students that both their everyday conceptions and the science ones are conceptions in their own right that are valid in specific contexts only. (Duit, 1991b, p. 80)

It seems though that science teachers, at least sometimes, are unable to provide such instruction. Evidence from research based on Australian science students, identified limited levels of science understanding (see Goodrum, Hackling & Rennie, 2001). Harrison's (2006) study, in which he indicated, that "despite the best intentions of the teacher and the provision of excellent resources, many students who should learn, do not" (p. 61), also supports this notion. In purporting the use of interesting analogies in teaching science, Harrison (2006) suggested that that students' failure to learn may be a "failure of the teaching and the testing regime to encourage [them] to show what [they] know and can do" (p. 60), rather than being due to a lack of ability.

From a constructivist perspective, however, is not surprising that some time after what seems to have been successful science instruction; students revert to their prior understandings, or adopt a confused conflation of ideas which do not allow them to perform well on tests of their knowledge and understanding of science. Duit (1991b) explains that this is a likely consequence of the science concepts being "more abstract and more sophisticated than [the] students' conceptions" and therefore likely only to be accepted by students who are "already familiar with the science point of view" (p. 82). The "deep-seated" (Clement, 1993, p. 1242) persistence of alternative conceptions and their negative impact on learning science also results because they are often embedded in usual day to day conversations (Leach & Scott, 2000). Hence, the non-scientific viewpoints are continually reinforced. This identifies that for science ideas that clash with every day views, "it is necessary to take students' conceptions seriously" (Hewson & Hewson, 1998, p. 604); and that deliberate pedagogical strategies need to be employed to allow the science concepts/views to become as strongly embedded in the minds of the learners as the non-scientific ones.

Care however, must be taken not to dismiss students' alternative conceptions as being incorrect – they may not be. Working scientifically, a fundamental objective in the teaching and learning of science (see Harrison, 2008), necessarily means being open to new information. Historically, there are many accounts in which strongly held preconceptions have denied learning progress. Galileo's alternative conceptions that have proven to be correct science were rejected because of well established preconceptions held by authorities. Galileo's account including translation of his words (Harvard Project Physics, 1973), illuminate the classic example. Galileo's discovery on 7 January 1610 "that beside the planet [Jupiter] there were three starlets [moons], small indeed, but very bright" (p. 72), among subsequent observations of the motion of four moons of Jupiter, the rough surface of the moon, the phases of Venus and sunspots, led him to openly espouse the very unacceptable (yet correct) heliocentric (Sun centred) model for the Solar System. Despite Galileo's own realisation that "the same phenomena would result from either [geocentric or heliocentric] hypothesis" (p. 73), he favoured the Copernican view. For this inappropriate alternative, and at the time pantheistic, conception, Galileo was forced to renounce the Copernican heliocentric model for the Solar System and incarcerated in his own home. Galileo of course, did not believe the geocentric model and did not reject the conceptions that he had developed from his own experience. This dilemma is likely to also be the case for students who have their own theories, based on their own experiences and what they perceive to be common sense, that vary, from those taught in the classroom and which educators expect as answers in tests (Biggs & Moore, 1993).

In a Galilean sense, an alternative conception could well be more correct science, yet still be an inappropriate alternative/misconception; one that would be considered incorrect in terms of the current science being studied (Hewson & Hewson, 1998). Therefore, if students were to use their alternative/mis-conceptions in providing answers in an examination, they would not be rewarded with marks. Unlike Galileo however, the students' misconceptions are often just wrong. A typical area in which students display misconceptions is in electrochemistry (see Aubusson & Fogwill, 2006; Ogude & Bradley, 1994). One such misconception is that *in electrochemical cells, electrons flow through the solutions*. The flow of ions as charge carriers in solutions is, however, unfamiliar and new to students. "Pupils are introduced to current electricity before doing electrochemistry and by the time they study electrochemistry, they are familiar with conduction in metals as being due to the movement of electrons" (Ogude & Bradley, 1994, p. 33). Hence, electron flow is likely to be well embedded in pre-existing schema for students in their senior years (16–18 years of age) of schooling. Therefore, misconceptions in electrochemistry and in other areas of science which include difficult-to-learn concepts, are not only understandable but ought to be expected. Experimentation with teaching methods that will assist students to develop appropriate understandings of difficult-to-learn science concepts, allowing them to reject their preconceived ideas as inappropriate, in favour of the new, is likely to help reduce the number of students who underachieve in tests of their knowledge and understanding. Harrison and Treagust (2002) suggested that role play analogies are likely to be "helpful in encouraging . . . conceptual change" (p. 203) about the sub-microscopic particle world.

In a pilot study to this research (see Chapter 4), Aubusson and Fogwill (2006) were able to show that when Year 11 chemistry students used analogical thinking while developing a role play to show the path of ions and electrons in an electrochemical situation, the students developed persistent appropriate conceptions. Student use and development of analogies therefore may be a useful pedagogical weapon for combating alternative conceptions that students either bring with them to the classroom or develop as a result of the teaching they encounter.

This view is fundamental to the current teaching experiment and is supported in the words of Harrison (2008): "Analogy and analogical thinking is central to science and to thinking and working scientifically" (p. 21). Nevertheless, it is recognised that great care must be taken to avoid the development of misconceptions. Strategies for successfully using analogies, which aim to reduce this negative impact, have evolved in recent years. The Focus, Action, Reflection (FAR) guide developed by Harrison and Treagust (1994) from Glynn's (1991) Teaching with Analogies (TWA) model has been adapted in this teaching experiment for use with and by students. The FAR guide and related strategies are discussed in section 2.7.

2.3 Student's developing analogies while learning science

This section analyses the contribution of previous research that has investigated students developing their own analogies. It situates the current research within the evolution of understanding about the use of analogy in science teaching and learning.

As has been discussed above, the contribution of analogy to the development of scientific understanding dates back many centuries and is ongoing. Yet the development of understandings about the use of analogy in teaching science is relatively new. The usefulness of analogies as aids in scientific development, and early thoughts about the use of analogy in teaching science, can be found in a paper by Weller (1970); below are some pertinent excerpts.

> Most scientists will admit that analogies have been instrumental in extending the frontiers of science. (p. 114)

> Analogies may be able to play a very practical role in science education. (p.118)
>
> Analogies have a legitimate function as a pedagogical tool. (p. 119)
>
> Used with proper precautions, an analogy may be an excellent time-saving device, but improperly used it may serve equally well as an obstruction to the learning process. (p. 119)

While Weller (1970) recognised the learning potential of analogies, he also recognised and issued a warning about potential pitfalls in their use, thus flagging the need for research (see also Section 2.6) into the nature of pedagogical analogies and how best to use them.

Only a few decades ago researchers (Gentner, 1983; Vosniadou & Ortony, 1989) analysed and discussed the nature of analogy (see Section 2.2). Recognising that analogies were often used in teaching science and that there were some inherent pitfalls associated with how they were used, ways were sought to better develop and use analogies with science students (Glynn, 1991; Harrison & Treagust, 1994; Salih, 2007; Wilbers & Duit, 2006; Zeitoun, 1984). Research that identified that students could develop and use analogies themselves (Cosgrove, 1995; Pittman, 1999; Sandifer, 2003; Wong, 1993a, 1993b) was followed by more specific research about the benefits of students developing their own analogies; for example, towards developing an interest in learning science (Harrison, 2006); and towards gaining enhanced understanding of difficult-to-learn science concepts (Aubusson & Fogwill, 2006; Bennett-Clarke, 2005; Crowley, 2002; Fels & Meyer 1997; Spicer-Dance, Mayer-Smith, Dance & Khan, 2005) (see Table 2.2 below).

It has been recognised for a long time that there are benefits to using analogies in teaching science (e.g. Weller, 1970; Holyoak & Thagard, 1995; Treagust, 1993), however, by the early 1990s little had "been determined from empirical studies about the actual learning process associated with analogy assisted instruction" (Treagust, 1993, p. 295). Since then, interest about teaching with analogies has inspired a number of researchers to work with students using analogies to learn science. Treagust (1999) reported, however, that only Cosgrove (1995) had had success with students generating their own analogies. By 2003, still little research about analogy had been about students developing their own analogies to learn science (Sandifer, 2003). The relatively few studies done (an overview of 12 studies is presented in Table 2.2) in this specific area, however, provide significant findings that are of interest and have informed and helped to justify, the research design for the current study.

Collectively, these studies, which mostly involve high school students, have identified several positive outcomes that can occur when students are involved in the process of generating analogies. For the students, these include: identification and use of prior learning; enhanced motivation, engagement and interest in learning; greater understanding of the target concepts; and an increase in the length of time over which they can remember what they have learned. For the teacher, the process provides opportunities for discussion and observations that help to show students' understandings and misunderstandings about the science being studied. The research (especially the Pilot Study to this teaching experiment (Aubusson & Fogwill, 2006)) also highlights the importance of the teacher's role in guiding students' learning in directions that facilitate the development of more scientifically accepted understandings. These previous findings have informed the current research as will become apparent in the methodology for the teaching experiment (see Chapter 3).

Table 2.2 Studies about students generating analogies

Author(s)	Participants	Concept(s)	Contribution
Wong (1993a&b)	Pre-service teachers from a range of faculty areas	Air Pressure	Learners can use self generated analogies to develop their own understanding of scientific phenomena by drawing together fragments of their own poorly connected understandings.
Cosgrove (1995)	Physics students	Electric circuits	The creation and development of analogies can enhance student understandings. Students can have an active role in developing analogies.
Fogwill (1996)	Year 7-9 students	Reproduction Eyes Seismometers Weather instruments	Students enjoy building models and their understanding can be enhanced when they do so. The teacher plays an active and important role in guiding students towards producing scientifically accurate representations.
Aubusson, Fogwill, Barr, Perkovic (1997)	Year 8 Science students	Electric circuits Gas exchange in the lungs	Students can construct understanding through role play. Role play can show prior knowledge about Science concepts. Concepts learned through role play can provide solid building blocks for later learning.
Fels and Meyer (1997)	Pre-service teachers	Forces	Development of interest in and understanding of Science concepts can occur through dramatization.
Pittman (1999)	Year 7 and Year 8 students	Protein synthesis	Students who develop their own analogies show "deeper understanding" (p.16) about the Science being studied.
Crowley (2002)	High ability male Year 7-9 students	Erosion Volcanoes Electricity	Students can identify analogies in texts and develop their own. While concept mapping is often poor, the process can assist retention of concepts over time. Students who learn through analogy may move beyond (forget) the analogy yet remember the science.
Clement and Nunez-Oviedo (2003)	Year 8 students	Human respiration	Co-construction (the teacher providing support) enhances the evolution of students' mental models.
Sandifer (2003)	College Physics students	Forces and energy	When students generate spontaneous analogies it "can improve [their] understanding of physics concepts and problems" (p. 96).
Spicer-Dance, et al. (2005)	Undergraduate Chemistry students	Oxidising power of halogens.	Students who develop their own analogies, can achieved better results and have higher levels of understanding than other students who are given analogies by their teacher.
Bennett-Clarke (2005)	12 at risk students	Meiosis	Self-generated analogies stimulate interest in, and motivation for, learning.
Aubusson and Fogwill (2006)	Year 11 Chemistry students	Movement of ions in solutions	Generating role play analogies promotes active discussion and analogical reasoning among students. By watching and listening to students generating role plays, the teacher can identify students' understandings and misunderstandings. The teacher can play a significant role in guiding students in refining their analogies to more accurately align with accepted scientific understandings.

2.4 Analogies and constructivist learning theory

In this section the constructivistic (Duit, 1991a) nature of learning with analogies is demonstrated to be consistent with many of the ideas of Piagetian schema development, social constructivism, cognitive load theory and recent neuroscientific explanations about learning.

Early constructivist learning theorists theorised that learning was a purely personal endeavour which occurs in three ways. When children (students) use an existing schema to encode new information thereby building on the existing schema; when an existing schema is modified in a process that sees the schema evolve; and through a process of restructuring in which new schemata are created (Duit, 1991a). Students' views, however, are often "simple and naïvely positivistic" (Duit, 1991b, p.81), "focus[ing] on aspects of a phenomenon that are close to their own experience" (Biggs & Moore, 1993, p. 16) and their interpretations (alternative conceptions) are typically unscientific. Learning science, therefore almost "always means learning a totally new point of view" (Duit 1991b, p. 83). In this sense, students cannot adequately build on or modify their existing schemas and in terms of schema theory, to learn science, students will typically need to restructure existing schemata or create new ones. This happens through analogical processes, which according to Glynn (1991) are processes that are "hard wired in human beings" (p. 239). The process of analogical reasoning by which learners may move towards alternative (scientific) schema development is activated when existing schemata are inadequate. This is highlighted in the following quote by Zook (1991).

> When presented with novel information, learners attempt to instantiate an existing schema. If such an instantiation is possible, new information is readily assimilated into the preexisting structure provided by the subsuming schema. Thus structure is imposed on the new information by mapping previously acquired concepts and relationships onto incoming data. If an existing schema cannot be mapped onto new information, however, an available schema possessing more abstract relational similarity may be activated and modified to permit assimilation. Learners, therefore, automatically engage in analogical reasoning

> whenever they must understand new information that cannot be readily assimilated into an existing schematic structure. (p. 48)

The use of analogy as a teaching tool, sits comfortably within the paradigm of this early constructivist learning theory, because it is a “process of actively employing the already familiar to understand the unfamiliar” (Duit 1991a, p. 652). Hence, in teaching science, “if the analogies [used] are appropriate, they promote concept learning because they encourage the students to build links between past and familiar knowledge and experiences and new contexts and problems” (Harrison & Treagust, 2006, p. 12).

Vygotsky’s (1978) definition of learners’ *zones of proximal development* provides an additional perspective that is particularly relevant in considering the use of analogies as presented in this thesis.

> The zone of proximal development 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 learners. (Vygotsky & Cole, 1978, p. 131)

The significance here is that while individuals construct personal meaning of new information based on their prior understandings, and on what is presented to them in science lessons and in text books, this meaning may not be optimal. Ogude and Bradley (1994) showed that, even “students who pass exams sometimes show gross misunderstandings when required to give a qualitative interpretation of scientific processes” (p. 29). In a ‘cross age’ study of chemical bonding, Coll and Treagust (2001, p. 30) found that while students of various ages spontaneously develop analogies, alternative conceptions were particularly prevalent among high school science students and existed even in understandings shown by high achieving postgraduate science students.

Vygotsky and Cole’s (1978) ‘guidance’ and ‘collaboration’ were integral components in a study by Nunez-Oviedo and Clement (2003) who referred to teacher supported development of student analogies (models), as co-construction. The Nunez-Oviedo and Clement (2003) study identified the importance of others, in enhancing the development of understanding during personal construction. From a constructivist perspective, during the process of co-constructing new, scientifically more accurate schema, students may also reorganise preexisting concepts, perhaps facilitating the correction of previously held, “robust” alternative conceptions (Coll & Treagust, 2001), and “scarring misconceptions” that are “extraordinarily resistant to change” and which may otherwise “inhibit further conceptual growth” (Tasker & Dalton, 2006, p. 156). If this is true, the co-development of analogies may also help to provide platforms (schema) from which students can springboard, more successfully towards scientifically acceptable learning of yet-to-be-learnt science concepts.

Learning through analogy development with the support of the teacher and peers is social construction consistent with Vygotsky’s socio-cultural theory. Vygotsky, however, suggested that the others who might extend the learner into their *zone of proximal development* should be “more capable” (Vygotsky & Cole, 1978, p. 131). While the teacher as expert, has an obvious part to play in this regard, others that help may not be, or need to be, more capable. This social nature of knowledge construction by students has been reported several times. According to Bakhtin (1986, cited in O’Laughlin, 1992), “dialogicality” and “sociocultural situatedness of speech types” (p. 812); that is, engaging in appropriate conversations using terms that are mutually understandable; are key elements in the construction of understanding. Hogan (1999a) reported students being involved in “sense-making discussions” in which they “were asked to construct, apply and refine conceptual models and use them to explain laboratory observations” (p. 460). Onsman (2005) purported that while students will generally accept the first meaning that makes sense to them, they will explore other possibilities when contextual cues are provided for them. In addition to emanating from dialogue with peers and the teacher, these contextual cues may emanate from other “vehicles of thought” within the socio-cultural setting, including, the types of activities and the surrounding in which the activities take place (Bell, 2005, p. 47).

The timing of discourse may also be a critical factor in the development of understanding. Coll, France and Taylor (2005) insist that “to successfully develop conceptual understandings in science, learners need to be able to reflect on and discuss their understandings of scientific concepts as they are developing them” (p. 194). This highlights that when students co-construct/develop their own analogies, active discourse with their peers and their teacher during the process, is likely to be of significant importance (Aubusson & Fogwill, 2006; Bell, 2005; Coll, France & Taylor 2005; Mortimer & Scott, 2000) in developing personal, scientifically acceptable, understanding.

Recent neuroscientific evidence supports construction of understanding

While there is not scope within this thesis to fully explore how recent neuroscientific techniques have been applied to discovering the biology of learning, it is relevant to note that what is being discovered supports a constructivist learning theory.

Recent imaging techniques, including positron emission tomography (PET) and magnetic resonance imagery (MRI), have been used to provide detailed structural information about the brain and how it functions. These studies provide additional support to the conceptual ideas about learning. While these techniques are still being developed, data about encoding and retrieval processes in the fontal regions of the brain have identified areas for rehearsal/working memory processes and semantic links, while they are in action (Nyberg, Cabeza & Tulving, 1998). Processes of innervation (growth of nerve cells) in the brains of monkeys, measured before and after learning to use tools, has supported the complexities of neural networking and the development of new synaptic linkages between nerve cells, through the growth of new dendritic structures at the ends of axons (Johansen-Berg, 2007, p. R142).

These types of studies are suggesting that the brain is not “hard-wired and static”, rather, “as we learn new skills or acquire novel experiences, our brain cells alter the way in which they respond to the outside world” through localised structural changes (Johansen-Berg, 2007, p. R141). These biological studies about the nature of learning and possible mechanisms of learning through the growth of additional synaptic cross linkages and other changes between neurons in the brain, coupled with information about encoding and retrieval, are not inconsistent with the development of schemata as presented in this paper and supports a general model of learning through constructive mental processes.

The constructivistic epistemological stance taken in this research can be aptly summarised using a few words from Lorsbach and Tobin (1992). They described constructivism as “an epistemology, a theory of knowledge used to explain how we know what we know”(p. 5); suggesting it is “useful to teachers if used as a referent; that is, as a way to make sense of what they see, think, and do” (p. 5). Most relevant to this research, they also suggested that “just as teachers have to learn how to teach from a constructivist point of view, so too must students learn how to learn” (p. 5). Teachers ought therefore, to provide students with the “opportunity to use their prior knowledge and senses in making connections to the new concepts” (p. 5) they encounter in science.

2.5 The learning of difficult concepts in science

Apart from students personal backgrounds that result in their preexisting schema, students’ capabilities in using and developing analogies in learning science may be determined by several limiting factors such as age, reasoning ability, cognitive load and working memory capacity.

It is likely that as children become older their abilities to use analogical processes improve. Piaget for example, considered that logical reasoning ability develop as children reach a stage of formal operations, around 11 years of age (Piaget, cited in Wadsworth, 1984). This does not, however, seem to preclude young children from effectively using analogies. In a recent study, Hancock and Onsman (2005) showed that very young children can use analogies to develop understandings consistent with highly complex scientific ideas. For example, they found that through an analogy based story, *Ellie the Electron*, pre-operational children as young as four years old were able to learn features of electrons that are consistent with quantum physics. One eight year old student for example, could draw diagrams that showed an electron as a cloud with spin. While these are abstract ideas embedded in quantum mechanical models for electrons, it is unlikely that these young students had a deep understanding of quantum ideas. However, the foundations were laid for future learning of quantum ideas because the concepts embedded had “essential integrity” with that future learning (Hancock & Onsman, 2005, p. 2). Similar to Bruner’s (1960) pre-curriculum ideas, if students develop non-contradictory ideas through analogy, foundations for current and future learning may be enhanced. This has implications for the role of the teacher when allowing / encouraging students to develop their own analogies for science concepts. That is, there is an obligation that teachers endeavour to ensure that what the students come up with, will as far as is possible, relate positively with more elaborate learning that may follow in the future.

Cognitive load theorists take a view that the ability to make sense of tasks is linked to working memory capacity. Richland, Morrison and Holyoak (2006) investigated the development of analogical reasoning in children from 3-14 years of age. They found that “analogical reasoning provides a basic cognitive tool that children may use to approach novel phenomena and transfer across contexts” (p. 271), however, their “ability to reason analogically at higher levels of relational complexity develops with age and related increases in working memory capacity” (p. 270). This concept of working memory is also supported by Heron (1990) and Johnstone (2006) who, citing the neo-Piagetian work of Pascual-Leone (1970) discussed links between schema development and working memory capacity. In this theory, as children develop, the number of things they can hold in working memory increases to a maximum of about six by the time they reach 16 years of age (Johnstone, 2006, p. 53). So, as they get older, they can handle more complex tasks. Working memory is short term memory that lasts for approximately 17 seconds. It receives information that has been processed from the very short term, sensory storage. This sensory storage receives information from the sensory nervous system (visual, auditory, etc), that lasts for about 200 milliseconds. In general, while working memory can handle between 5 and 9 units of information at one time it forgets the information in a matter of seconds unless it is coded or organized in a way that allows it to be stored in long term memory (Rosenthal & Zimmerman, 1978, p. 25). While the students in the current research are old enough to be at the upper end of the working memory continuum, many of the concepts they are expected to learn are both unfamiliar and complex.

In teaching science therefore, science teachers are regularly challenged with taking students beyond what they know and must often present students with information to which they have difficulty relating. Many researchers (Biggs & Moore 1993; Clement & Nunez-Oviedo, 2003; Cosgrove 1995; Hancock & Onsman, 2005; Harrison & Treagust 2006; Harrison & De Jong, 2005; Justi & Gilbert, 2002a&b; Pittman, 1999; Treagust, 1995) have identified this difficulty of learning science concepts, often attributing it to the complex, abstract and unfamiliar nature of the concepts being studied. This is particularly evident in physics (Cosgrove, 1995; Mulhall & Gunstone, 2008; Sandifer, 2003; Sefton, 2002) and chemistry (Coll, 2006; Coll & Treagust 2001; Johnstone, 2006; Justi, 2002; Ogude & Bradley, 1994; Tasker & Dalton, 2006) courses undertaken by students in the final years of schooling. According to Goodrum, Hackling and Rennie (2001), "The problem is that upper level science courses were designed to select and prepare students for further science study and have a heavy, discipline-based focus on science content." (p. 8). Many of the science concepts, such as ion-electron equations, mole calculations and projectile motion, encountered by students in these courses (such as the NSW Higher School Certificate) are the same as those identified by Johnstone (2006) as requiring the highest level of working memory capacity (p. 53).

Using analogies involves linking new ideas to existing knowledge in long term memory. It is therefore likely to increase the amount of processing; coding and organizing; in the working memory time available (perhaps only 17 seconds-see above). While speculative, and perhaps an area for further research, it seems that analogical processes may allow the material to be learned, to be more quickly transferred into long term memory via links to existing schema. Hence, by definition, the student who successfully use analogies should retain the information longer and need less reinforcement of the concept; thus enhancing the learning of the new material.

The use of analogies in physics and chemistry courses may therefore be a way of reducing the load on working memory by helping to create or develop schema (in long term memory). Enabling deeper understanding of at least some aspects of the most demanding concepts may well enable students to solve the more complex problems by breaking them down into less demanding chunks (Johnstone, 2006).

2.6 The call for research

There have been ongoing suggestions from researchers (Aubusson & Harrison, 2006; Harrison & Treagust, 2006; Justi & Gilbert, 2006; Ritchie, 1998; van Driel & Graber, 2002) for more extensive research into analogical strategies that seek to enhance students' understanding of hard to learn science, especially those associated with chemistry and physics.

The view that the students would benefit from learning science through analogies has considerable support in the science education literature. For example, Justi and Gilbert

(2002b) indicated that “a comprehensive understanding of models and modeling is essential for students’ learning of chemistry” (p. 49); Lakoff and Johnson (1980), in relating the use of metaphor (considered here to be synonymous with analogy) in teaching, suggest that “its primary function is understanding” (p. 36); Coll (2006) concluded that models (including analogies) make it easier to “understand complexity” (p.75); and Tytler and Prain (2009) suggest that science teachers should “provide a representation-rich environment, with opportunities for students to negotiate, integrate, refine and translate ideas across representations” (p. 20); and that in doing so, they foster the development of a “more engaging sense of science ideas, that could better capture scientific ways of thinking” (p. 21).

Over the past 20 years there has been an ongoing call for research about students constructing meaning in science; and about the use of analogies in doing so. The following points in support of this argument, which inform the nature of the current research, are presented in chronological order.

- Lorsbach and Tobin (1992) challenged teachers to “provide students with opportunities to use their prior knowledge and senses in making connections to new concepts” (p. 21).
- Holyoak and Thagard (1995) suggested that having students generate their own analogies might be a way of “finding out what students know before being shocked by their exam” results (p. 207).
- In the same year, Cosgrove (1995) concluded that “an extended exploration of analogies preferably starting with those, that students generate themselves” (p. 308), would be useful in teaching science.
- Harrison and Treagust (1998) reported that the ability to model in ways that are multiple, flexible, purposeful and relational is rarely found in school students (p. 424). They recommended that teachers should “encourage their students to use and explore multiple models in science lessons at all levels” (p. 420). In 2000, they proposed several questions for further research, including:
    - Which learning conditions encourage students to modify supplied models or build their own models?
    - Does the FAR guide enhance the way teachers teach and students learn in science?

- Why are students reluctant multiple modelers and what motivates multiple model use? (p. 1023).

- Ritchie (1998) argued from a social constructivist perspective, that teachers should "engage students in activities that are likely to help students develop a deeper understanding of canonical science" (p. 183).
- After working with students in a junior high school Pittman (1999) suggested that "student generated analogies could be a tool to assist the science educator in identifying or addressing existing students' conceptions that are not compatible with scientific conceptions"; and "student generated analogies may also reveal misconceptions in students' selected topics used for the analogy" (p. 19).
- Hogan (1999b) suggested a need "to refine instructional methods to help students reason with others to generate and make sense of observations and data as they tackle scientific questions and applied problems" (p. 1085).
- Heywood (2002), called for the "recognition of the role of analogy in generating engagement in the learning process" (p. 233).
- Justi and Gilbert (2002) indicated that "a comprehensive understanding of models and modeling is essential for students' learning of chemistry" (p. 49) and indicated, in 2006, that "how to go about the introduction and sustained use of modeling activities at the classroom and laboratory level will present considerable challenges for teachers" (p. 128).
- Sandifer (2003) suggested "it may be that group interactions play a crucial role in helping students generate SAs [spontaneous analogies] of their own" (p. 95).
- Coll, France and Taylor (2005) concluded that "further research may provide the evidence that the explicit metacognitive use of models and analogies may be an appropriate choice of pedagogy to integrate the development of science concepts while developing students' understanding of the 'Nature of Science'" (p. 195).
- After reviewing "the small group of studies that comment on the motivating potential of teaching with analogies", Harrison (2006) concluded that "the affective dimension of science analogies should be a research priority" (p.51).
- Tytler, Haslam, Prain and Hubber (2009) have espoused a focus on multi-representational learning in which student-generated representations, being "subject to challenge and negotiation" are "active components of thinking and learning" (p. 9). They claim that "learners need to coordinate appropriate representations to show

understanding of concepts in use" (p. 8) and suggest that students "benefit from multiple opportunities to explore, engage, elaborate and re-represent ongoing understandings" (p. 2).

- After reviewing Australasian research about learning and teaching with analogies, Aubusson, Treagust and Harrison, (2009) concluded that: "Little is known about the relationship between the use of analogy in science teaching and the positive, affective outcomes some researchers have noted"; and "the long term influences on science learning and memory of using analogies in teaching science concepts is almost unexamined" (p. 213).
- In considering students' development of understanding in science, Waldrip, Prain and Carolan (2010) argue that "unless learners can represent their understandings in diverse modes, then their knowledge is unlikely to be sufficiently robust or durable" (p. 69). Significantly, they also stress that "at all stages in the learning process, the teacher must rely on interpreting students' representations as evidence of their understanding" (p. 78).

There have been very few studies concerning students generating their own analogies (see Table 2.2) and as indicated above, there is a resounding call for more.

The nature of the research needed has been described by Harrison and De Jong (2005).

> The needed research of students generating analogies in an analogy-conducive context will likely be longitudinal, participant interpretive phenomenology. The preferred context will be a class wherein ideas are openly and socially constructed and critiqued. Adequate time will be available for inquiry, thinking and discussion, and the teacher will have strong PCK (pedagogical content knowledge). (p. 1156)

This teaching experiment is a response to the need for such research. It is underpinned primarily by socio-cultural theory and social constructivist learning within a general constructivist epistemology. It recognises that learning through analogy may be powerful and may play a critical role in the development of lasting understanding.

2.7 Frameworks for using analogies in teaching science

In this section, various frameworks developed for using analogies are scrutinised and their collective impact for the current research is identified.

Analogies are commonly used in teaching science concepts to students (Glynn, 1996). Several researchers, including Zeitoun (1984) and Holyoak and Thagard (1995), suggest this is because in science, the content is often unfamiliar and may even contradict beliefs students have acquired in everyday life. Despite the recognition that "useful analogies are often imperfect, . . . good teachers frequently use analogies to render unfamiliar matters comprehensible to their students" (Holyoak & Thagard, 1995, p. 199, p. 202). Enhanced comprehension occurs because appropriate "analogies provide a comparison which can explain something difficult to understand by pointing out its similarities to something easy to understand or [which] is already understood" (Zeitoun, 1984, p. 123).

There has been considerable comment in the literature, about how analogies have been successfully or otherwise used in text books (Glynn, 1991; Sefton, 2002) and how teachers have used analogy in the delivery of science in schools (Cosgrove, 1995; Freyberg & Osborne, 1985; Pittman, 1999). Much of this research highlights the inherent issues, such as transferring irrelevant attributes between base and target (Zeitoun, 1984) and developing misconceptions (Zook, 1991), that can arise when analogies are used. The well used statement that analogies are a "double edged swords" (Duit, 1991; Glynn, 1991; Harrison & Treagust, 2006) typifies current thinking about the use of analogies in science teaching. In a constructivist view of learning, even if there is a majority of students in a class who develop consistent understandings, "there will always be a number of different constructions present" (Gunstone, 1995, p. 4). To exemplify; teachers of chemistry regularly ask students to use molecular ball-and-stick model kits to build molecules of compounds based on formulae and two dimensional diagrams in text books, when investigating shapes of molecules and developing understandings about naming them. During the process however, it seems that students develop a range of misconceptions about the nature of atoms and molecules (Tasker & Dalton, 2006) such as, that "particles in solids are static and 'stuff' exists between molecules in a molecular compound" (Tasker, Dalton, Sleet, Bucat, Chia & Corrigan, 2002, VisChem Reflections, p. 2).

Several theoretical and pedagogical frameworks for the use of analogies have been developed. These include Gentner's (1983) theoretical framework called S*tructure-Mapping*; Zeitoun's (1984) nine stage *General Model of Analogy Teaching* (GMAT); Glynn's (1991) six step *Teaching With Analogies* (TWA) model; Harrison's and Treagust's (1994, 1999) 3 step *Focus Action Reflection* (FAR) guide; and Salih's (2007) three phase *Self-Generated Analogical Reasoning* (SGAR) model of translation.

Gentner's (1983) theoretical framework which includes terminology such as *attributes* and *relations* has been discussed in considerable detail in Section 2.2, however it is relevant here to reinforce that it provides a vocabulary for discussing the use of analogy.

The FAR (Focus Action Reflection) guide was developed by Harrison and Treagust (1994) from Glynn's (1991) six steps to Teaching With Analogies (TWA) model as a way for teachers to more successfully use teacher and text book analogies with their students. As this guide has several parallels to processes used in this research it is worthy of further explanation.

> Focus involves pre-lesson planning, in which the teacher focuses on the concept's difficulty, the students' prior knowledge and ability, and the analog model's familiarity. Action deals with the in-lesson presentation of the familiar analog or model and stresses the need to cooperatively map the shared and unshared attributes. Reflection is the post-lesson evaluation of the analogy's or model's effectiveness and identifies modifications necessary for subsequent lessons or next time the analogy or model is used. (Harrison & Treagust, 1998, p. 423)

Note here; the strong reliance on the teacher being able to choose familiar bases; the emphasis on cooperative mapping of base and target attributes; and the importance of discussing where the analogy breaks down. These emphases are important when a teacher provides analogies as examples for students and when students develop their own analogies, to avoid the danger of the students developing misconceptions. Since no single analogy can be perfect, the teacher should encourage the use of "multiple explanatory models" (Harrison & Treagust 1999, p. 428) and have students consider how each of the analogies are unlike the target concepts as well as identifying the important similarities.

This multiple analogy idea is a feature of Salih's (2007) self-generated analogical reasoning (SGAR) model, which is an attempt to consolidate many of the ideas in previous models including: Zeiton's (1984) General Model of Analogy Teaching (GMAT); Glyn's (1991) Teaching with Analogies (TWA) and hence the FAR guide (Harrison & Treagust, 1998); as well as Clement's (1993) bridging analogies and the structure mapping of Gentner (1983). The SGAR model focuses on the learner as much as on the teacher. It has three phases; the Reception phase, in which the learner is exposed to the target concept or the abstract science concept to be learnt; the Interaction phase-or process phase during which student emotions, visual representation and social interaction are important features of how the analogy will be received; and the Emergent phase in which matches and mismatches, and responses to the mismatches, aid the transfer of information to long term memory (Salih, 2007). This model like all of the others is predominantly a one way model in which students develop understanding about a target based on prior understandings about a base concept that is already known. During the analogical processes however, students switch between seeing the target from the perspective of the base and the base from the perspective of the target. In this sense, understanding of the base and the target are developed at the same time. This additional perspective of learning through analogy is only represented in the heuristic model proposed by Wilbers and Duit (1999, 2006). While this notion of reciprocity between base and target adds an additional layer of complexity to any investigation of learning through analogy, it also adds the exciting possibility of developing (therefore enhancing) the already known while fostering scientific understanding of the to-be-learned concepts.

Table 2.3 matches the key components of the various models proposed above. It shows that there are clear similarities in the various approaches and provides reasonable guidance for developing a process suitable to use when helping students develop their own analogies in learning science.

In the compilation (Table 2.3), it can be seen that each of the models for using analogies are either specifically three phases or can be divided into three main, broad phases. An introduction phase in which an analogy is chosen, a mapping of attributes and relations phase, and a phase in which understanding is consolidated. In this final phase, decisions about the appropriateness of the analogy are pertinent to considering the level of understanding developed from the analogy. Some of the elements, as shown within the phase divisions, can be considered as micro-structural, depending on the usage situation (e.g., personal; in a text; given by a teacher in the process of learning; after the event, as consolidation; or students developing their own analogies) and their positioning therefore in one phase or an adjacent phase are somewhat arbitrary. In general however, there is a consensus of ideas across all models that allow each to be divided into three phases as shown. Harrison and Treagust's (1994, 1998) three phase FAR guide is a close approximation for this three phase consensus and as such serves as a suitable starting point in designing how analogy will be used in this teaching experiment.

In this research, however, a key element in the design is that the phases of the FAR guide are applied with and by the students, during the process of using and developing their own analogies. Hence, student/teacher and student/student co-construction is a micro-structural element in each of the phases. The suitability of teacher participation during analogy development by students is supported by the words of Zook (1991):

> Because cognition within unfamiliar target domains is influenced by the analogical models spontaneously selected by learners, learner generated analogies should be monitored carefully by educators. Educators who encourage learners to generate personal elaborative analogies should be prepared to guide the selection process, diagnose inferential errors, and provide remediation. (p. 55)

Table 2.3 Comparison of models of teaching with analogies

Phase	Structure Mapping	Bridging	General Model of Analogy Teaching GMAT	Teaching With Analogies TWA	Focus, Action, Reflection FAR Guide	Self-Generated Analogical Reasoning SGAR	Heuristic Analogies
1	Base knowledge	Anchor A well known concept	1.Measure students characteristics 2. Assess prior knowledge about the topic 3. Analysis of the learning material of the topic 4. Judge the appropriateness of the analogy 5. Determine the characteristics of the analogy 6 Select the strategy of teaching and medium of presentation.	1. Introduce the target concept 2. Cue retrieval of analogue / base	1. Focus – pre-lesson planning Including consideration of the difficulty of the concept, and suitability of the analogy for the students	1. Reception phase – exposure to the target (and teaching about analogy generation if needed)	1 Base / analogue provides a proto-theory for the target concept.
2	Mapping of structures and relations between a target and a base	Bridging Comparing an inter-mediate analogy to both the base and a more obscure target	7 Present the analogy	3. Identify relevant features of the target and base / analogue 4. Map similarities 6 Indicate where the analogy breaks down	2. Action – using the analogy in class and mapping shared and unshared attributes	2. Interaction phase – the long term memory retrieval, social and emotional processes leading to accession/ generation of the analogy - matching and mismatching	2 Hypothesis about the target triggers mental images that provide associations with the base.
3	Target under-standing	Target under-standing	8. Evaluate the outcomes 9 Revise the stages	5. Draw conclusions	3. Reflection Post-lesson evaluation of the analogy's effectiveness	3. Emergent phase – Possible modification of source content. Target under-standing	Iterative cycle. Associations with the base allow a refined theory about the target, revised hypotheses and associations
Ref.	Gentner, 1983, p. 155	Clement, 1993, p.1244	Zeitoun, 1994, Fig 3, p. 119	Glynn, 1991 p.230	Harrison & Treagust, 1998, p. 423	Salih, 2007, pp. 4-7	Wilbers and Duit, 2006, p. 43

2.8 Conclusion

The literature review draws together ideas from constructivist learning theory and ideas about the nature and use of analogy. It has revealed five main themes with implications that guide the teaching experiment.

1. If students are to employ analogy as a tool in science learning, there is a need for them to clearly identify relevant and irrelevant aspects of the base and target. Therefore, for effective use of analogy with students, the teacher needs to facilitate discussions about the nature of analogy and the process of mapping attributes and relations.
2. To be meaningful an analogy must make sense to the person using it. Taking a constructivist view suggests that students ought to learn best when they can link their own prior knowledge to the target science concepts. However, because the concepts are often new to the students, finding those links may be difficult. The teacher may therefore need to take a guiding role in assisting student to make appropriate links.
3. Care must be taken to avoid the development of misconceptions. The socio-cultural nature of learning necessarily means that the students will share their ideas and listen to each other and the teacher. Apart from sharing and developing accurate scientific ideas, students will share and develop misconceptions. This identifies a need for the teacher to take a pro-active co-constructive role: watching what students do, listening to their conversations and taking part in the analogical process; thus helping students to develop scientific understandings.
4. The speculation that using analogies may be useful in learning concepts that have a high cognitive load suggests that it would be appropriate to select the more difficult concepts for analogical intervention during the teaching experiment.
5. An analysis of the various approaches to using analogies in teaching, strongly suggests a three phase approach: Focus, Action and Reflection. Each of the phases, however, may include a number of micro-cycles leading to an iterative development of the students' analogies and the subsequent understanding of concepts.

The key elements that underpin this research are therefore:

(i) The use of analogy;

(ii) A constructivistic epistemology (constructivism as a referent, Lorsbach & Tobin, 1992)

(iii) Socio-cultural learning theory;

(iv) The difficult nature of some science concepts; and

(v) Using a structured approach while reasoning through analogy.

How these factors are designed into the use of analogy in this teaching experiment will be presented in Chapter 3 and exemplified in the vignettes presented in Chapter 4.

Chapter 3

Methodology

3.1 Chapter overview

This research employed a teaching experiment methodology. The teaching experiment investigated the conjecture that: When students develop their own analogies (supported by their teacher) in the process of learning science, they will be able to demonstrate high levels of understanding about the concepts being studied. The experiment involved multiple applications of an intervention in which students were supported and encouraged in developing their own analogies for science concepts.

This chapter describes and justifies the methodology used in this research. The background (Section 3.2) identifies previous work that led to the current research and establishes it's scholarly nature. Section 3.3 identifies the pertinent features of teaching experiments, supported by examples from the literature. The following section elaborates on how the research design calls upon; constructivism; theories about and models for, using analogies; and a range of practical considerations. Section 3.5 describes the participants, the site and context of the research. The next three sections are devoted to discussing the data collection methods, the trustworthiness of the data and how the data were analysed. Section 3.9 explains the method of reporting and this is followed by a discussion of the limitations of the research. Ethical considerations are outlined in Section 3.11. The conclusion supports the appropriateness of the methodology and the research design from theoretical and practical perspectives. The final section provides a summary in which key points are reiterated.

3.2 Background

This research has grown from a personal interest in enhancing the learning of science by students in my own classroom. Through several extended professional development projects over two decades, while Head of Science in a number of schools, I became engaged in "the scholarship of teaching" (see, Boyer, 1990; McKinney, 2003; Trigwell, Martin, Benjamin & Prosser, 2000). Trigwell, Martin, Benjamin and Prosser (2000) identify five categories associated with the scholarship of teaching. These are:

> A. Knowing the literature on teaching by collecting and reading that literature.
> B. Improving teaching by collecting and reading the literature on teaching.
> C. Improving student learning by investigating the learning of one's own students and one's own teaching.
> D. Improving one's own students' learning by knowing and relating the literature on teaching and learning to discipline-specific literature and knowledge.
> E. Improving student learning within the discipline generally, by collecting and communicating results of one's own work on teaching and learning within the discipline. (p. 159)

In general terms McKinney (2003) describes scholarly teaching as:

> The systematic study of teaching and/or learning and the public sharing and review of such work through presentations or publications; (p. 2);

and identifies several characteristics about scholarly teachers which aptly describe my continued involvement.

Scholarly teachers:

- View teaching as a profession and the knowledge base on teaching and learning as a second discipline in which to develop expertise.
- Reflect on their teaching.
- Use classroom assessment techniques.
- Discuss teaching issues with colleagues.
- Try new things.
- Read and apply the literature on teaching and learning in their discipline.
- Publicly share and review ideas through presentations or publications. (McKinney, pp. 1-2)

During almost all of my (35) years of science teaching, mostly in comprehensive secondary schools in working class areas of Western Sydney, with students aged 12–18 years, I have found that didactic methods of teaching often do not allow students to develop a lasting understanding of many science concepts. Given that the "fostering of understanding of science is a difficult task at all levels" (Gunstone, 1995, p.3), the development of effective teaching strategies should be a priority for all science teachers. This scholarly philosophy led me to pursue opportunities to learn how to enhance learning. In 1989 I became involved in the Learning in Science Project (LISP), (based on findings from the Learning in Science Project conducted through the University of Waikato New Zealand (1979–1982 & 1983–1985) by Freyberg and Osborne (1985)) led me to begin experimenting. Reading about the Project for Enhancing Effective Learning (PEEL) of Science (Baird & Mitchell, 1986; Mitchell, 2006) provided further incentive to explore and to share with others, a variety of teaching ideas.

Subsequently, my interests developed around activities in which students used analogical processes in learning science and led to a number of publications. These articles reported classroom based research about; constructing models of reproductive organs with 14-15 year old students (Fogwill, 1996); developing role-plays to help 13–14 year old students understand electricity (Aubusson, Fogwill, Barr & Perkovic, 1997) and; senior chemistry students (16–17 year old) developing their own role-plays to demonstrate their understanding of chemical reactions (Aubusson & Fogwill, 2006). While these research activities and several years of teaching science, provided the foundation for conducting this teaching experiment, the work leading to the 2006 publication was highly significant, as it began the Pilot Study which is presented as the first of five vignettes in Chapter 4.

Each vignette provides detailed, thick descriptions of lessons in which students were engaged in analogical activities. Presentation of classroom based data as vignettes is not unique to this research. Davis (1995) described vignettes as narrative presentations used to "vividly portray the conduct of events" (p. 447) using data such as field notes, audio and video recordings and artefacts. She indicated that in vignettes:

> Quotations from field notes and interviews as well as extended discourse from interviews and video- and audio-tapes of events are often used as representative examples of general assertions. (Davis, 1995, p. 447)

Researchers such as Freyberg and Osborne (1985), Tobin (1990), Cosgrove (1995) and Harrison (2006), have presented data relating to learning in science, in similar ways.

3.3 Teaching experiments

A teaching experiment (Brown, 1992) refers to a research method through which a teacher carries out, scrutinises and evaluates a teaching strategy (intervention) used with his/her own students. By designing the elements of the experiment and "anticipating how these elements function together to support learning" the experimenter gains understandings about what happens in the classroom (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003, p. 9).

The central idea behind a teaching experiment can be, "engineer[ing] innovative educational environments" (Brown, 1992, p. 141); a conjecture about a teaching innovation (Confrey & Lachance, 2000); a hypothesis to be tested (Steffe & Thompson, 2000) or a theory to be supported (Barab & Squire, 2004). During the experiment, the classroom organization, the selection of tasks, activities, and resources are driven by the central idea (Confrey & Lachance, 2000) and hence the teacher unavoidably has a major influence on what happens.

Confrey and Lachance (2000) describe teaching experiments as "conjecture-driven" (p. 232), "planned intervention(s) that take place over a significant period of time in a classroom where a continuing course of instruction is taught" (p. 239). In this research there is a central idea/hypothesis/conjecture, that:

When students develop their own analogies (supported by their teacher) in the process of learning science, they will be able to demonstrate high levels of understanding about the concepts being studied.

In this research, there are central tasks; (the analogical activities) designed so that learning, relevant to the various sections of the syllabi takes place; and the intervention was used many times with students in different classes over a number of years. As such, the methodology used is consistent with the teaching experiment methodology. The nature of this classroom based research can aptly be described in the words of Confrey and Lachance (2000), as a research model that "utilizes both theory and common core classroom conditions in order to create and investigate new instructional strategies" (p. 231).

In this research the term hypothesis; a supposition formed as the basis for an investigation (Moore, 1996, p. 537) is used synonymously with conjecture; an opinion based on incomplete information (Moore, 1996, p. 217). This is because both are used in the literature and as defined above are relevant in the context of the classroom research. I have chosen, however, to use the term conjecture to describe my supposition rather than hypothesis, because investigations in classrooms are confounded (see Brown, 1992) and so the information can never be complete. However, the supposition is the basis for the investigation and so is like an hypothesis.

The design of a learning intervention to investigate a conjecture, cannot take into consideration all aspects of a complex classroom. It can, however, aim to seek "credible evidence" (Barab & Squire, 2004, p. 7). To achieve this, large amounts of data are required (Brown, 1992) and "triangulat[ing] multiple sources and kinds of data" about specific "processes of enactment" typically allows generalisations about the nature of learning to be made (Design-Base Research Collective, 2003, p. 7).

Collecting large amount of data from within the classroom however, almost ensures that the researcher becomes a participant in the learning process. Geelan (2003) has suggested that such participatory research (Kemmis & McTaggart, 2000) which could perhaps be better described as participatory inquiry (Lincoln & Guba, 1985), would be best conducted by the class teacher.

Teacher/Researcher as Participant

Brown (1992, p.167), in describing design (teaching) experiments, labels them as "messy" research, partly because the researcher must "intervene in all aspects of the [classroom] environment". Nunez-Oviedo and Clement (2003) who worked on model evolution with school aged students, indicated that "the teacher played a key role during the teacher/student co-construction" (p. 2) phases of model development. Thus, while the teacher, actively participating and interacting with students during the learning process adds confounding aspects to the data interpretation, the co-constructive role was a deliberate inclusion in the design of their teaching experiment.

In this research carried out by me (as the teacher/researcher) in my class room with my students, I was not a mere observer of students using a particular strategy. I was actively and purposefully participating in the activities; supporting the students' learning by providing resources, answering questions, and asking the students questions about their work; guiding their discussions and supporting the feedback they gave to each other. At the same time, identifying key aspects about the intervention and making observations and judgments about its worth. Lincoln and Guba (1985) identify that when research is done in a "natural setting" where "context is heavily implicated in meaning", the "inquiry demands a human instrument" (p. 187) "with extensive background and training" (p. 195). In this research, I was that human instrument. The co-constructive nature of my participation was designed, at least at times, to impact directly on what occurred.

The research therefore closely resembles what Kemmis and McTaggart (2000) call participatory enquiry. Since I was a teacher conducting a teaching experiment (Brown, 1992) with my own students, the research is also teacher research (Johnson, 1981) about the experimental use of a learning intervention (Confrey & Lachance, 2000) as the core focus. Importantly, during each use of the intervention, observations, leading to an interpretation of what happened, were a key aspect. Perhaps the most suitable general description of what was happening at the core of this research (within the smallest circles on Fig. 3.1) is Erickson's (1986) idea of hermeneutic or interpretive, participant observational fieldwork. He describes this as being more inclusive than ethnography or case study; essentially qualitative in nature, perhaps with some quantifications, and which seeks to elucidate meaning from how humans interact in social settings (p. 119).

Considering all aspects from above, there are multiple descriptions each of which adequately describes this research at one methodological level or another. The diagram below is an attempt to show how all of these descriptions are relevant in methodologically situating this teaching experiment.

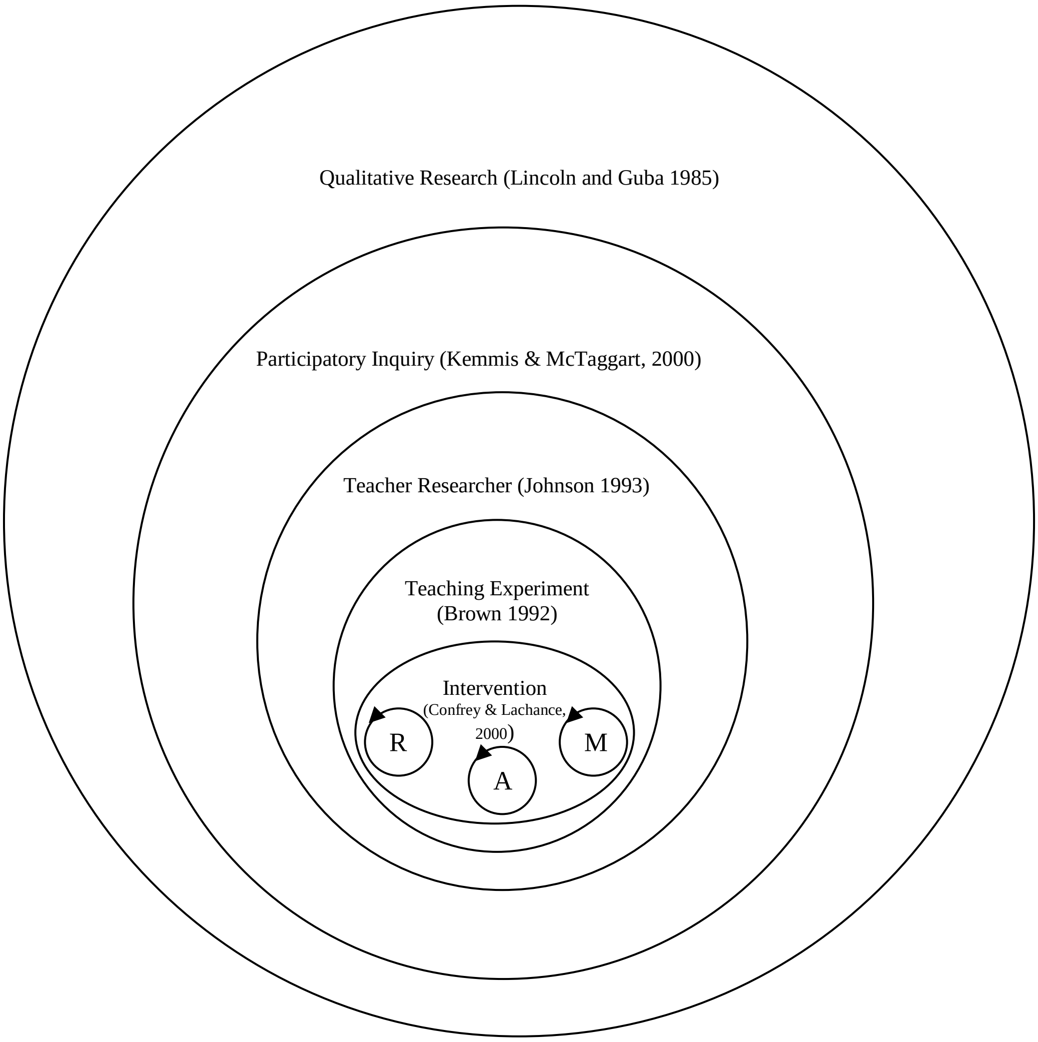


Fig. 3.1 Schematic showing the methodological position of this research (R = Role play, A = written Analogies and M = Models. The arrows on the smallest of the circles, identifies iterative processes (Cobb, et al., 2003) inherent in each of the analogical activities. Within the circles is where Erickson's (1986) "interpretive, participant observational fieldwork" (p. 120) takes place.

3.4 Designing the activities

Constructivism, theories and models for teaching/learning through the use of analogies and a range of practical considerations have been considered in the design of this teaching experiment. This section draws together ideas from these areas.

3.4.1 A constructivist perspective

For decades researchers have espoused constructivist approaches to improving learning in science and have made pedagogical suggestions for science teachers to use in the process. For example, Freyberg and Osborne (1985), after finding poor levels of students understanding for many science concepts, espoused that a generative (constructivist) approach to teaching would help to improve student learning. Recognising the heavy content base of science curricula, a problem that is still an issue in today's science curriculums (see Goodrum, Hackling & Rennie, 2001), Freyberg and Osborne (1985) were critical of teachers who "are in a hurry to get across the facts, rather than taking time to develop sound thinking procedures which will help pupils make better sense of the world about them" (p. 94). They urged teachers to take a serious experimental approach to teaching, in which teachers assess their students' views, as to whether they have developed understanding from a scientific perspective and how they relate differences in their personal and scientific viewpoints. Consistent with earlier discussions about long term memory (see Section 2.7), Freyberg and Osborne (1985) recommended that understanding be assessed, not only at the time of the lessons, but also "some months after the teaching" (p. 94); and suggested that teachers "must provide plenty of opportunities for pupils to express their ideas" (p. 93) and give them "opportunity to act upon the information they encounter, not just passively receive it" (p. 94). Two decades later, Coll, France and Taylor (2005) further supported the active participation of students in developing understandings in science, identifying that:

> In order to successfully develop conceptual understandings in science, learners need to be able to reflect on and discuss their understandings of science concepts as they are developing them. (p. 194)

Some broad suggestions of opportunities that teachers could provide for students to facilitate deep understanding have been recently purported by the local (NSW) education department. These are;

- Exploring relationships,
- Solving problems,
- Constructing explanations, and
- Drawing conclusions in relatively systematic, integrated or complex ways.
  (DET NSW, 2003, p. 14)

When activities including aspects such as these occur in the socio-cultural settings of classrooms, such as science classrooms in which students often work in groups, there is a very real possibility of what Hodson (1998) refers to as "massive social pressure [of students] to conform" to the views of others, who are perhaps more important, within their group (p. 53). This flags an important role to be played by the teacher. If all students in a group are to develop a common/acceptable understanding of the canonical science, the teacher may need to take an active role in guiding how students process information. Towards this role, Osborn and Freyberg (1985), provide the following tips for the teacher;

1. Gently point out logical errors such as inconsistencies and unjustifiable inferences;
2. Challenge students to consider all possibilities or suspend judgment;
3. Point out over or under-generalisations and where arguments are based on false assumptions (p. 93):

and suggest that teachers "should present materials in several different ways and formats" (p. 94).

From a constructivist perspective, the teacher, working with individuals and groups in these ways, is taking a co-constructive role.

3.4.2 Considering prior research

Considering prior research is a key aspect of designing a teaching experiment. This is because it guides the development of the conjecture that is to be scrutinised and helps to provide justification for “differentiation” from central ideas (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003, p. 10). Teaching experiments also test developing theories and while building on prior research, they also “foster the emergence of other potential pathways for learning and development by capitalising on contingencies as the design unfolds” (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003, p. 10).

In designing this teaching experiment there were several factors, informed by both research and classroom teaching experience, taken into account. These include theoretical consideration such as: using analogies and metacognition; and practical considerations such as: student generation/co-construction; time and planning; recognising and assessing understanding; and collecting data. Each of these is briefly addressed below.

3.4.2.1 Theoretical considerations

Using analogies

The intervention in this teaching experiment required students to develop and use their own analogies about particular science concepts. The concepts chosen were ones that past students had typically found difficult to grasp. Thus the pedagogical purpose of the intervention was to provide experiences in which students could develop and show their understanding of these concepts. While the theoretical understandings, advantages and pitfalls in using analogies with students rests here on the work of several researchers, including: Coll, France and Taylor (2005); Cosgrove (1995); De Jong (1989); Hancock and Onsman (2005); Harrison (2006); Heywood (2002); Holyoak and Thagard (1995); Justi and Gilbert (2006); Gentner (1983); Glynn (1996); Nunez-Oviedo and Clements (2003); Pittman (1999); Wilbers and Duit (2006); and Zook (1991) (see Chapter 2); the lessons in general, followed processes developed during earlier personal research (Aubusson & Fogwill, 2006; Fogwill, 1996) that are consistent with Treagust’s (1995) three stage FAR (Focus–Action–Reflection) guide developed from Glynn’s (1991) six step, TWA (Teaching With Analogies) model.

It is relevant here to highlight that while there have been several models developed for using analogies in teaching; and these have varied considerably in the number of steps recommended (see Table 2.3), each can be shown to fall into the three main stages as suggested by Treagust (1995).

The following identifies, the general process, in stages, used with students during the teaching experiment. Specific details about individual teaching episodes are provided in the vignettes (see Chapter 4).

Focus

Concepts that I considered would be difficult for my students to learn, were considered for inclusion in the teaching experiment. The decisions were based on previous experiences teaching particular units of work and knowledge of my students' levels of ability. At the beginning of a teaching episode, I discussed with the students, the science concept(s) that I had considered. During these discussions, students were asked to answer questions to establish evidence of any prior knowledge of the concept(s). This helped in identifying; the difficult nature of the concept(s); issues the students had with what they thought they already knew well (misconceptions); or that the concepts were new and unknown to the students. It also provided reasons for adopting 'special processes' to ensure the concepts were learned well and why they were suitable for inclusion in the research.

It was during this focus period that the nature of the task was explained. Prior to students developing an analogy of their own it was first necessary to teach/remind them about analogy and discuss the purpose of their analogy. When necessary, examples were provided to assist students in beginning the task.

Action

The students produced a role play, built a model or developed a written analogy to demonstrate their personal or group understandings about a particular scientific concept. During this phase, constructive support was provided by asking and answering questions. This helped to ensure that the students focused on the key concepts to be learned and that the development of misconceptions was kept to a minimum.

Reflection

Students knew from the initial discussions that; they were expected to share the final product of their work with others; discuss how it related to the science concept(s); and identify what aspects it could not help explain. In some cases, especially the role play activities, this was an iterative process in which students made modifications based on the feedback they received and then re-presented their ideas. Students shared and discussed their analogies with others in the class. On occasion prior to this sharing, they were asked to formally map (record in a table), attributes and relations between their base domain and the target science domain being studied.

Metacognition

It is pertinent to identify that there is a plethora of factors that impact on learning and which ensure classrooms are “rich, complex and constantly changing environments” (Brown, 1992, p. 144). As a consequence, developing understanding about specific learning processes is difficult, however, helping students understand how they, as individuals learn, may be a key factor in helping them to develop deep understandings.

Several researchers (Brown, 1992; Gollub, 2002a&b; Mitchell, 2006; Wittrock, 1994) have identified advantages of students becoming metacognitive about their learning and emphasise the teacher’s role. Teachers leading students, through co-constructive processes, to generate more scientific and more useful models about phenomena, than they previously held (Wittrock, 1994), fits well with the idea of metacognition. Metacognition about the intervention, therefore became an important part of the research design. Students were encouraged to become aware of the learning processes involved and to be mindful of how they were learning through analogy. This thinking-about-learning was especially important for the students who took a more active part in the research by participating in interviews about the intervention.

The concept of metacognition however, is very broad and extends to areas such as Gardiner’s multiple intelligences (Gardner, 2006); learning issues that stem from students socio-economic background (Spicer-Dance, Mayer-Smith, Dance & Khan, 2005); personal values; and even genetic heritage (Cosgrove & Schaverien, 1999, 2000). Hence in a broad sense, students levels of metacognition adds to the complexities of an authentic classroom, but a comprehensive discussion here is beyond the scope of this thesis.

3.4.2.2 Practical consideration

Student generation – co-construction

The student generated aspect of analogy development was a key aspect of the design, and while kept to a minimum, so was the teacher input. In this regard the final product of the intervention was co-generated. Here the challenge was (as the teacher) to encourage the students to be actively engaged in developing their own ideas, while at the same time providing support which guided them towards scientifically acceptable outcomes, in a way that ensured the students still owned the result. The level of teacher participation in helping students, described as co-construction (see Nunez-Oviedo & Clement, 2003), necessarily varied depending on what the students developed.

Time/planning

As Confrey and Lachance (2000) suggest, the investigation must be conducted over a significant amount of time and since the intervention was to be implemented with students completing a science course as part of their normal studies, time was an important factor. With this in mind, it was important that the intervention was the teaching method for the concepts involved. There would not be enough time to do the intervention and then teach the concepts some other way. In this regard the teaching experiment was a planned series of teaching activities – which in this thesis have been labelled episodes of the intervention.

In general, the intervention required students to develop their own analogies about difficult-to-learn concepts that were part of their HSC Science courses. This was done in three ways: producing role plays (R); constructing models (M); and developing written analogies (A) (See Fig. 3.1). As the research was intimately embedded in a real classroom (see Aubusson & Fogwill, 2006), where learning must take place among the constraints of the syllabus, assessments, and examinations, there were all the normal pressures on the students to develop appropriate knowledge and skills and for the teacher to complete the course and meet deadlines; such as marking examinations and reporting. Hence, this teaching experiment needed to be designed so that the intervention could be nested among a range of teaching strategies employed during the usual teaching time for the courses.

Detailed descriptions of the structure for particular teaching episodes within the teaching experiment are presented within the vignettes (see Chapter 4).

Understanding

Developing understanding of difficult science concepts is a challenge taken on as part of this teaching experiment. It was therefore necessary that students were aware that a level of understanding is what they were trying to achieve. Hence, as part of their metacognitive process, they needed a reasonable knowledge of what that meant. While in general terms, understanding was related to the students as being able to explain concepts, the SOLO taxonomy (Biggs & Moore, 1993), which delineates levels of understanding, was considered, when assessing the explanations/understandings displayed (see Section 3.8.2 for a full discussion).

The nature of the data

In designing the experiment, decisions needed to be made about the nature of the data to be collected. While during the Pilot Study, it was identified that capturing student discourse may prove very useful, and so several ways of doing so were sought; the types of data possible were related to the nature of each episode and so varied throughout the teaching experiment. Consistent with Brown's (1992) suggestion, a wide variety and large amount of data were sort (see Section 3.6).

3.5 Site and context of the research

The NSW HSC Science Syllabi (2002) and the related examinations, require students to demonstrate their understanding of many concepts by being able to answer questions that begin with verbs such as discuss, explain, and assess. It has been evident through the lack of detail and incorrect responses to examination questions, that while many students can learn to regurgitate information, they often show limited understanding of many of the concepts they have studied in science courses (personal experience, see also Goodrum, Hackling & Rennie, 2001). This research has been driven by a personal desire to seek ways to assist my own students in developing their understanding of difficult-to-learn science concepts. The development of deeper understanding is consistent with the NSW Department of Education and Training's (DET) focus on Quality Teaching and Learning (DET, 2003). This was a significant factor that led to the very favourable support within my school throughout the research and from those at higher levels within the DET, to allow the research to progress.

The students involved in this research were 16–18 years of age and completing Higher School Certificate Science courses in Chemistry, Physics and Senior Science in a co-educational, comprehensive, senior, Secondary College in the Western Sydney region of NSW, Australia. While the students in the classes were mixed in their abilities, there were few students who were academically in the top 10% of their age cohort. This was largely due to the presence of five selective high schools within reasonable proximity of the College drawing area. The more academically able Primary school students from the surrounding area typically sit for entrance examinations to these selective high schools when they are in Year 5 (11 years of age) and those who are successful attend one of the selective schools from Year 7-12. Other students who attend the non-selective high schools and who perform well in the Year 10 School Certificate examinations, can gain entry to these selective schools for their senior (Years 11 & 12) studies. Consequently, even the top senior students in the school where the research was conducted, often struggled with the more difficult science concepts. In this regard, carrying out a teaching experiment that had a potential outcome of improved understanding of the more difficult concepts, also had the potential to assist all students in the classes involved, to achieve better results. This may also link to the favourable support from the students, who were actively involved in the research and their parents who gave permission.

3.6 Data

3.6.1 Trials of data capture methods

Each of the earlier projects referred to in Section 3.2 involved using and scrutinising specific teaching strategies with my own students. Analysis of students' learning in the normal context of their Science classrooms/laboratories was based largely on qualitative data, including field notes; student artefacts; student surveys; transcripts of audio-taped interviews; and observations from video tapes of the lessons. While all of these investigations were similar to what Brown (1992) has called teaching experiments, the 2006 investigation (Aubusson & Fogwill, 2006) in which Year 11 students developed a role play showing the movement of ions in a chemical reaction, served as a pilot study for the current research.

While field notes and photos were used to provide data in the Pilot Study, it became apparent that the data would be richer if student conversations, while they were generating their analogies, could also be captured. Capturing the conversations of students while they worked in a small group at a cluster of three desks in the classroom was achieved using a small battery operated portable tape recorder with microphone attached; and later with a small digital video recorder mounted on a tripod. Capturing the conversations while groups of students were moving around in the process of creating role plays and building models was problematic and led a number of options being tried during the course of the research. Several methods (digital voice recorder; remote FM radio microphones wirelessly linked to MP3 player/recorders and small portable tape recorders; a video camera; and a mobile phone camera) of recording conversations were investigated. Digital voice recorders were eliminated due to cost while the others were trialled in a variety of situations.

One method trialled with students involved the use of remote FM microphones with a small portable tape recorder/radio receiver. The tape recorder was also an FM receiver and it was possible to record the radio on the players own tape. Tuning the radio receiver to a frequency unused by any local radio station and then adjusting the frequency of transmission by the microphone to match the unused frequency, it was possible to record the voice of a student while they were walking around up to 10 metres from the recorder. After trialling this successfully using one microphone, it was hoped that using multiple microphones, all adjusted to transmit on the same frequency, would make it possible to gather the conversations of all students in each group on a single recorder; even if the members were spread out over several metres. If this was successful, each group could have their microphones tuned to a different frequency and all of the groups' conversations could be captured at the same time. Unfortunately when this method was tried with just two microphones, the signals interfered with each other. It seemed that the radio receiver would selectively choose the signal that was strongest.

Subsequently, the tape recording produced was extremely difficult to interpret, making transcription or use in any other way, of little value.

The most successful method of collecting at least some audio data, during activities in which students were moving around, was to have more than one member of a group carry a tape recorder with microphone attached and so, two additional portable cassette tape recorders were purchased. In practice however, while this more successfully captured more voices than having a single recorder, matching conversation segments when transcribing the tapes, was so difficult that the method was impractical for other than short, individual voice audio data.

A decision was made that capturing all student conversations during role play activities was beyond reasonable possibilities within the resources available and so while conversational data were collected for these activities, the data are incomplete. Nevertheless, these recordings were useful to some extent, especially in checking and enhancing field notes.

Other attempts to capture how students were interacting during the development of role plays and model construction, included using a video camera, a mobile phone camera to take still photos and short video clips, and field notes. Field notes were written after the activities. This was necessary because managing the activities, moving from group to group and engaging in discussion with students about what they were doing, did not lend itself to taking notes during the lessons.

Additional information was sought through student surveys and interviews. Reviewing the student survey and focus group questions used in the Pilot Study, led to the development of those used in the current research (see Appendices 2b & 3). Procedures for conducting semi-structured focus group interviews (Vaughn, Schumm & Sinagub, 1996) and individual student interviews were developed during the Pilot Study. Students were asked to participate on a voluntary basis after participating in the various activities. Times for the interviews were negotiated with those willing and the location for the interviews was consistent with the implications of the DET Code of Conduct (2004). In this regard, the classroom in which the interviews were conducted was well situated on the ground floor with large windows on both sides allowing open visibility. The interviews were recorded using a Sony Walkman cassette recorder and due to the ease of portability and the reasonable quality of the recording, this became the preferred method for recording focus group discussions and interviews with individuals throughout the research.

3.6.2 Data Collection

This section describes the nature of the data collected during the teaching experiment and provides a rationale for the volume of data collected.

The teaching experiment is a methodology in which a particular teaching idea is used and scrutinised. This had significant appeal for the current thesis because it allowed me to examine what was happening as students learned science in my lessons. The teaching experiment methodology was used specifically to investigate what happens when students (16–18 years of age) develop their own analogies for difficult-to-learn concepts.

The experiment was conducted over a four year period and involved using the intervention more than 20 times with a variety of science classes; Years 11 and 12 Physics, Year 11 and 12 Chemistry and Year 11 Senior Science (see Tables 3.1 & 3.2). Repetition of the intervention with the same content and successive groups of students in the same course, provided opportunities for refinement of processes and comparison of data (see the solenoid, reflection of light and MRI vignettes, Ch. 4).

Each time the intervention was used, a range of qualitative data was collected, as is indicated below and shown in Tables 3.1 and 3.2.

Collecting meaningful data during classroom research is difficult. Given the "socially constructed nature of reality"; the "intimate relationship between the researcher and what is studied"; the "situational constraints" that shape qualitative inquiry (Denzin & Lincoln & 2000, p. 8); and the complex, "multiply confounded" nature of the classroom (Brown, 2002, p. 167); this type of research is complex. To overcome some of these inherent complexities and to maximise the trustworthiness of the research findings, Brown (2002) stresses the need for the teacher to collect a large volume of data.

Hence, a wide range of data has been collected to enhance the richness of evidence. These have included field notes, video and audio recordings during lessons, students' surveys, recorded interviews with individual students, teachers and groups of students, samples of students work (artefacts) and peer observations. In the context of this study, each of these has been described below.

Field notes.

Field notes typically allow the researcher to record observations as they are made (Flick, 2002, p. 168) and "should be written as soon as possible" (Burns, 1994, p. 285). Each time field notes were made during this teaching experiment, they were coded to identify the type of activity, the class and the date (see Appendix 4). The field notes typically described the class, the location and nature of the activity; and included the observations made during the episode being reported.

Due to the dynamic nature of the classroom including my active participation as the teacher/researcher, it was generally impractical to write notes while teaching. As a result the notes were written after the event. In some cases, it was possible to enter details into a notebook directly after the lesson. However, I almost always had limited time before the next class and the notes were typed as a word processor document in the evening after the activity. While at times even this was not possible, all field notes were produced within a couple of days of the events.

Video recordings

Using a standard videotape recorder, some video records were taken by the students and some were taken by me during class activities. During the group activities, small groups of students (usually 5 per group) were spread out. The interactions of the groups were captured by a wandering camera operator and hence there are not complete records of conversations or movements for any specific group for the whole of the activities. In an attempt to overcome this aspect, some activities were simultaneously recorded on audiotape using small portable tape recorders. On several occasions I used a mobile phone with a built in video camera to capture one minute long snippets of groups of students as they worked. Even though the quality of the mobile phone video snippets is quite poor, they form a valuable addition to the data set.

Table 3.1 Record of episodes presented in Chapter 4

Count	Date	Episode Code	Vignette	Description	Class	No. of students in activity	No. of Student surveys	Field Notes	Audio Tape Lesson / Interview	Photos &/or Videos	Work samples / artefacts	Test Results	Comment
1	14/03/2003 20/09/2004	Pilot 11Ch140303RP	1	Copper ions role play	11Ch	15	5 on 20/09/04	Y	Y	Photo	Y		Led to published book chapter
2	10/03/2005	11Ph100305RP	2	Reflection role play	11Ph	20	4 on 17/06/05	Y	Y		Y 10/08/05		After TGA for refraction
3	12/04/2006	11Ph120406RP	2	Reflection role play	11Ph	18		Y		Video	Y 18/05/06	Sep-06	Used phone to capture video clips
4	6/03/2007 27/04/2007	11Ph060307RP 11Ph(B)A270407(A)	2	Reflection Role Play	11Ph(A) 11Ph(B)	12	5 on 17/06/07	Y	Teacher interview 04/05/07	Video	24 from 27.04.07	Sep-07	Coding sheet completed by teacher observer. ASERA 2007
5	20/09/2005	12Ph200905RP	3	Medical Physics role plays	12 Ph	11	3 on 4/11/05	Y	Y on 4/11/05	Video			Audio tapes made during lesson
6	17/6/2004	11Ph170604M	4	Solenoid valve model	11Ph	16		Y				16	Topic test answers collected
7	17/06/2005	11Ph170605M	4	Solenoid valve model	11Ph	17	3 on 17/06/05	Y	Y	Photos			Provided a trolley of bits and pieces
8	29/06/2006	11Ph290606M	4	Solenoid valve model	11Ph	15		Y			11		Provided a trolley of bits and pieces. ASERA 2006
9	17/06/2007	11Ph170607M	4	Solenoid valve model	11Ph	15	13 on 20/06/07	Y		Video			Suggested they added water pipes
10	20/09/2004	12Ph200904SGA	5	Photoelectric effect analogies	12Ph	15		Y					Began with 'smokes' analogy for John
11	12/09/2005	12Ph120905SGA	5	Photoelectric effect analogies	12Ph	11		Y	Y				Class transcripts 12/09/2005
12	8/06/2006	12Ph080606SGA	5	Photoelectric effect analogies	12 Ph	10	10	Y			CF grid 13/08/06	21 students Sep-2006	Question 30(c) in Trial HSC paper Classes A&B
13	1/06/2007	12Ph010607SGA	5	Photoelectric effect analogies	12 Ph	17		Y			AM grid 01/06/07		Dr. Peter Aubusson Observation notes

Table 3.2 Episodes conducted but not formally reported on in Chapter 4 of the Thesis

Count	Date	Episode Code	Vignette	Description	Class	No. of students in activity	No. of Student surveys	Field Notes	Audio Tape Lesson / Interview	Photos &/or Videos	Work samples / artefacts	Test Results	Comment
14	18/11/2004	11SSc181104RP		Detergent role play	11SSc	15	11 on 18/11/04	Y					Several ESL students
15	1/03/2004	11Ph010304RP		Light refraction at a boundary	11Ph	20		Y					Teacher generated-sample task
16	4/11/2004	12S041104RP/M		Model-attraction of water to charged rod	12SSc	12		Y					Working with a Student teacher
17	27/04/2005	11Ph270405RP		Model-attraction of water to charged rod	11Ph	15		Y			Y 4 on 28/04/05	Y 14 from June.05	ANOVA against Class B
18	31/10/2005	11Ch111005RP		Production of polyethylene	11Ch	9		Y		Y	Answers to 2 questions		Working with a Student teacher
19	1/05/2005	11Ph0505SGA		SGA after analysis of text analogies for electricity	11Phy	12		Y			10 SGA Maps		A mapping task followed by SGA
20	19/12/2005	11Ch191205RP		Galvanic Cells	11Ch	7	7	Y			2 SGA Maps and answers		Working with a Student teacher
21	17/03/2006	12Ch170306SGA		Equilibrium written analogy	12Ch	13		Y			6		Student mapping grids for their SGAs
22	1/11/2006	11Ch011106RP		Catalysts			13	Y		Y			Working with a student teacher
23	21/03/2007	11Ch210307RP		Copper carbonate decomposition role play	11Ch	16		Y		Y			35 minutes of video
24	12/05/2007	12Ph120507		Force between wires carrying currents	12Ph	13		Y					Very brief revision activity

Audio recordings

Several attempts to capture the discourse among students during activities were undertaken using small portable tape recorders. This worked quite well during classroom discussion when students were seated facing each other at a small cluster of tables and during group activities where there was one group of students in a closed space, such as a classroom. However, despite considerable effort, it was a major challenge to record student discourse during outdoor role-play activities and at other times when there were multiple groups in an area such as a classroom (see Section 3.6.1).

Questionnaire

An activity questionnaire (see Appendix 2b) was developed that requested students to answer 10 questions. The completion of these questionnaires was voluntary. Students were asked to write a response for the first and last question and for Questions 2 – 9 they needed only tick one of five boxes on a Likert type scale. Space was provided for an optional comment for each of these questions. The answers to these questions provided information about; the students' perceptions about the purpose and usefulness of the activity; their personal level of engagement and enjoyment; and the nature of their discourse during the activity. While at times it was possible for students to complete the questionnaire immediately after an activity, in general they were completed up to a week after the event.

Interviews

Individual students were interviewed and overall, there were three focus group interviews. While questions similar to those on the questionnaire were used to stimulate discussion, a semi-structured interview format was adopted allowing for more open discussion and probing. All students who participated in the activities were invited to participate in the interviews. However, because these interviews were conducted during lunch times and other free lessons, only some students opted to be involved. Interviews were recorded using a small portable tape recorder and transcribed. Field notes were made if an impromptu interview/discussion occurred (see for example, Vignette 3).

Artefacts

Artefacts are samples of students' work. In this teaching experiment, it was possible to collect samples of students' written work such as written analogies, diagrams and answers to test questions. However, during activities in which students built working models using school laboratory equipment and miscellaneous items such as rubber bands, cardboard and sticky tape or constructed and performed role-plays, photographs and short video clips provide records of the work completed.

Taking the advice of Burns (1994), all artefacts that could be archived, were coded for easy reference (see Appendix 4). The first two letters of the code were SA – representing student artefact. A code representing the class; for example, 11Ch for Year 11 Chemistry; the date, (e.g., 2004 or 150604), and the nature of the activity (e.g. RP for role play), were also added. In cased where it was important to recall which student produced the artefact, the code included the student's initials. In reporting, however, these initials have been modified or replaced by numbers to ensure the anonymity of the students involved.

Peer observation

In the final stages of the research, I asked another teacher to watch while I conducted role play activities with my students. While watching, her role was to observe the students and complete a Quality Teaching lesson coding sheet (DET, 2004). The coding sheet contains descriptions of several features of lessons and requires the coder to make judgments on a 1-5 rating scale about the features as they appear in the lesson (See Appendix 5). These readily available sheets were used because the teacher and I were familiar and comfortable with the metalanguage they contained and had previously used similarly completed sheets as stimulus for professional discussions about other lessons. During the research, two student teachers used the intervention with my students and two science teachers used the strategies with their own students. Interviews with these teachers, about their experiences provided additional data that enhances the trustworthiness of findings (see Chapter 4).

3.7 Trustworthiness

In qualitative research, traditional ideas such as reliability (internal and external), validity (internal and external) and objectivity, have been judged inappropriate (Burns, 1994; Lincoln & Denzin, 1994; Flick, 2009; Lincoln & Guba, 1985; Trochim, 2006).

This is because qualitative research is often confounded from many perspectives (see Brown, 1992). To exemplify; my research occurred in a regular classroom setting and involved a large number of episodes in which an intervention was applied in a variety of learning situations. Each episode was therefore unique, due to factors such as; the particular group of students; the nature of the intervention (role play, modelling or developing written analogies); the varying nature of the content being studied; students being at different stages of development in learning about concepts; and the experiences of the teacher-researcher and students developing with each application of the intervention.

While idiosyncratic factors such as these, "can lead to the claim that no ethnographic study can be assessed for reliability" (Burns, 1994, p. 270); qualitative research can have features that suggest something similar. Reliability, suggests that an independent researcher who applies a similar methodology in a different setting, should reach similar conclusions ("external reliability"); and an independent researcher, analysing another person's data, would come to similar conclusions as that person ("internal reliability") (Wilson, 2006, p. 124). In this research there are factors (see below), which are at least suggestive of what Wilson (2006) describes as measures of reliability; however, the unique nature of the data demands that a different view be taken.

In naturalistic research, Lincoln and Guba (1985) argue that the researcher "seeks means for taking into account *both* factors of instability and factors of phenomenological or design induced change" (p. 299 – emphasis added). Naturalistic research of the nature thus identified by Lincoln and Guba (1985) is consistent with this teaching experiment, which necessitates an, albeit small, "measure of control when compared with purely naturalistic investigation" (Cobb, Confrey, DiSessa, Lehrer & Schauble, 2003, p. 10). "Dependability is therefore a broader [and more appropriate] view than the conventional concept of reliability" (Lincoln & Guba 1985, p. 299).

Adopting this view, which stems from a constructivist paradigm (see Lincoln & Denzin, 1994, Table 1.2, p. 13) the trustworthiness of this qualitative research, is more likely to be established by considering its dependability, credibility, transferability and confirmability (Lincoln & Guba, 1985, p. 219) rather than from the positivistic views of reliability and validity (Guba & Lincoln, 1994). In this respect, and under separate headings, each of the more appropriate terms is defined below and features of this research which attest to its trustworthiness are identified.

3.7.1 Dependability

According to Lincoln and Guba (1985) dependability is linked to both credibility and confirmability (see below). They suggest in establishing these, the dependability of the research may also be established. However, they favour establishing dependability as a stand-alone quality, suggesting that this can be done by an independent auditor who would critically examine both the process of the inquiry and "the product – the data, findings, interpretations and recommendations - and attest that it [the product] is supported by data and is internally coherent" (p. 318). In this research, the vignettes include "rich" (detailed) (Denzin & Lincoln, 2008, p. 16) and "thick" (based on multiple perspectives) descriptions (Lincoln & Guba, 1985, p. 316) to allow the reader to act as this auditor.

Linked with dependability is the concept of consistency (Lincoln & Guba, 1985, p. 298). Like repeatability, consistency is impossible to achieve in qualitative research (see above), however, the following descriptions about aspects of this research show that there were some consistencies which support its dependability as a stand-alone quality.

- Each application of the intervention was implemented in stages, informed by research (see Chapter 2), similar to Treagust's (1993) FAR guide, leading to a general consistency in application. This has been clearly stated in general in Section 3.4 above, and specific details for each application of the intervention are shown in each of the vignettes. The coded data reported in the vignettes allows the reader to "examine the process of the inquiry" and view parts of the "audit trail" (Lincoln & Guba, 1985, pp. 318-319), showing that conclusions are drawn from multiple perspectives.

- Several episodes were repeated with similar classes, doing the same course, studying the same material at the same stage in their course, using the same staged (FAR guide) approach. In addition to the consistency of approach, this repetition encouraged the exploration of "all reasonable areas" and helped to ensure that early closure did not occur, thus reducing the impact of researcher bias (Lincoln & Guba, 1985, p. 324).

3.7.2 Confirmability

Establishing confirmability is linked to what Lincoln and Guba (1985) call the "audit trail" (p. 319). After Halpern (1983) they suggest a "residue of records stemming from the inquiry" (p. 319) that fall into the following six categories, are relevant to an audit trail. These are:

1. Raw data
2. Data reduction analysis products
3. Data reconstruction and synthesis products
4. Process notes
5. Materials relating to intentions and dispositions
6. Instrument development information. (p. 320)

Examples from this research of records that fall into these six areas are identified below.

Raw Data

In this research a large amount of raw data was gathered. This has included audio tapes, videotapes, photographs, field notes, questionnaires, observer notes and a range of physical artefacts.

Data reduction and analysis products

Data reduction and analysis products have included; refined accounts from episodes, notes which have been clarified after viewing field notes and checking with participants; transcripts from interviews stored electronically as Microsoft Word™ files; Microsoft Excel™ spreadsheets, constructed from raw survey data; and qualitative and statistical analysis from artefacts.

Data reconstruction and synthesis products

Data reconstruction and synthesis occurred throughout the research time. Materials have been produced, presented and discussed at two consecutive international conferences leading especially to the refinement of two of the vignettes. This thesis document which represents "a final report, with connections to the existing literature (Chapter 2) and an integration of concepts, relationships, and interpretations" (Lincoln & Guba, 1985, p. 319) is inclusive of the vignettes (Chapter 4) which, within this document are the vehicle for reconstruction and synthesis of data from the episodes in this research; the overall findings (Chapter 5) and conclusions (Chapter 6).

Process notes

Process notes are about the methods used, the trustworthiness and evidence pertaining to an audit trail. These are discussed separately in this chapter (see Trustworthiness above).

Materials relating to intentions and dispositions

Materials relating to intentions and dispositions include the doctoral report and ethics applications, which are documents that have been formally assessed and judged prior to the completion of this thesis. Personal notes made throughout the research years exist in written and/or electronic form and have been archived

Instrument development information

Examples of instruments developed/used during this research including a student questionnaire and a lesson coding sheet are provided in the appendices (see Appendices 2 & 5). The initial survey and list of questions for use during the semi-structured interviews with students were developed during a pilot application of the intervention and revised. Revision of the survey facilitated clarity for the respondents and provided greater certainty about the responses when processing the data.

In a qualitative inquiry, the nature of the data will vary depending on the data collection methods used. Being able to identify, use and produce that data however, is what provides confirmability. Tables 3.1 and 3.2 identify the nature of the data collected for each episode within this research. The episodes listed in Table 3.1 are those which have been presented in the vignettes (Chapter 4). Data for all episodes have been coded and archived (also see the section below on referential adequacy). Coding the data allowed the identification and use of multiple perspectives when justifying findings through triangulation. This triangulation (see Fig. 3.2 below) “which dovetails with the audit process”, assists confirmability (Lincoln & Guba, 1985, p. 319).

3.7.3 Credibility

As mentioned above, the trustworthiness of qualitative research is intrinsically linked to credibility. Lincoln and Guba (1985) use the term credibility in place of internal validity and identify five ways towards ensuring credibility is likely to ensue. These are:

1. Prolonged engagement
2. Persistent observation
3. Triangulation
4. Peer debriefing
5. Negative case analysis. (p. 301)

Each of these points will be addressed below.

Prolonged engagement

Prolonged engagement is considered essential in helping to support the concept of credibility in qualitative research because it assists the researcher in “learn[ing] the culture, testing for misinformation introduced by distortions either of self or of the respondents, and building trust” (Lincoln & Guba, 1985, p. 301). In this research, the data were collected over a period of four years with several groups of students. Some of these students were involved in various facets of the research for almost all of their two years as students of the school. This was advantageous because it allowed time to develop understandings about the students and their interactions. This was especially important for the Year 11 students because they were new to the senior school and had come from a range of backgrounds and schools. However, while it is acknowledged that the development of trust and rapport generally requires significant amounts of time, the time needed in this case is likely to have been reduced because I was the teacher.

Trusting the teacher (and here the researcher as well) comes with the role of being the teacher. It is also possible that my credibility as someone to be trusted may have been enhanced because I was the head of the Science Faculty in a Senior High School and I was involving the Year 11 students in doctoral research. Learning the culture of the students was ongoing and by the time the students were in Year 12, because I had taught them during the previous year, the level of trust and rapport had been enhanced through the prolonged engagement (Lincoln & Guba, 1985, p. 303).

Prolonged engagement also helps to reduce the impact of distortions in the data from the researcher and/or participants. As examples; the researcher may have prior uninformed assumptions and participants may respond in ways merely "to please the investigator" (Lincoln & Guba, 1985, p. 302). Gathering data over a long period of time provides the researcher with the wherewithal to make critical decisions relating to their own preconceptions, and possible misinformation, intended or unintended, represented in the data (Lincoln & Guba, 1985, p.303). In this research, the large volume of data gathered over four years, presented in the vignettes, provides the reader with evidence of the prolonged engagement that occurred during this research.

Persistent observation

Persistent observation is "using adequate numbers of observations, meetings, interviews, etc." to allow participants to develop confidence about and have trust in, the researcher and it allows the researcher to study the cultural context and check for misinformation (Davis, 1995, p. 445). In addition to the formal features of the research associated with particular episodes of the intervention, as a teacher/research, every lesson with the students was an opportunity for the development of confidence and trust.

Persistent observation also allows the researcher to "identify those characteristics and elements in the situation that are most relevant to the problem or issue being pursued and focusing on them in detail" (Lincoln & Guba, 1985, p. 304). In other words, it helps to identify what is and what is not important. The Pilot Study (see Vignette 1) was a valuable part of this research during which "salient factors" (Lincoln & Guba, 1985, p. 304) were identified for further investigation. These included: student engagement and enjoyment; discourse between students and between the students and the teacher; students justifying their views and actions; and time needed by students for review and improvement of their analogies. These factors became important features in the design of, and data collection during, future episodes. For example, students were more actively encouraged to share and openly discuss their ideas with each other and myself during subsequent activities. Specific questions were asked during interviews about engagement, enjoyment, the use of scientific language during conversations, and the level of support provided by the teacher. Where necessary, time was allocated to allow students to refine their analogies based on critical feedback from their peers.

Triangulation

Triangulation in qualitative research is defined as "the use of two or more methods of data collection in the study of some aspect of human behaviour" (Burns, 1994, p. 272). "Combining different sorts of data against the background of the theoretical perspectives that are applied to the data", provides more than is possible by using one approach and helps in "promoting quality in [the] research" (Flick, 2009, p. 41). Triangulation therefore, allows the researcher to view events from multiple perspectives, "reflect[ing] an attempt to secure an in-depth understanding of the phenomenon in question" (Denzin & Lincoln, 1994, p. 2). It helps the researcher avoid early acceptance of first impressions and "adds rigor, breadth, and depth" (Denzin & Lincoln, 1994, p. 2) to the investigation, leading to a higher degree of credibility. Eisner and Flinders (1994) also identify that having a range of data helps to minimise issues associated with possible researcher bias.

Lincoln and Guba (1985) describe different types of triangulation; triangulation by the use of multiple and different, sources, methods, investigators, and theories." (p. 305). Of these, multiple and different data sources is most consistent with the type of triangulation used in this research and is consistent with Vosniadou and Ortony's (1989) view that in qualitative research large amounts of data are needed. In this research, various types of analogical activities (see Table 3.1) were used and developed with students over an extended period of time and a huge amount of rich qualitative data were collected from a wide range of sources (see Fig. 3.2 below) and analysed. The data have been reported in vignettes, which themselves have been used as different perspectives for comparison purposes. Figure 3.2 shows the range of sources from which data has been gathered. These have included field notes, surveys, video and audio tapes of students working in groups, audio tapes and transcripts of interviews with students, artefacts of students work, audio tapes and transcripts of interviews with peer teachers who watched lessons and/or tried the strategies with their own classes, observer comments and examination results. These data have enabled the establishment of key features which have been viewed from multiple perspectives, through interpretive practice, to identify both the "hows and whats" (Gubrium & Holstein, 2000, p.488) of the research, to inform about the effective use of the intervention.

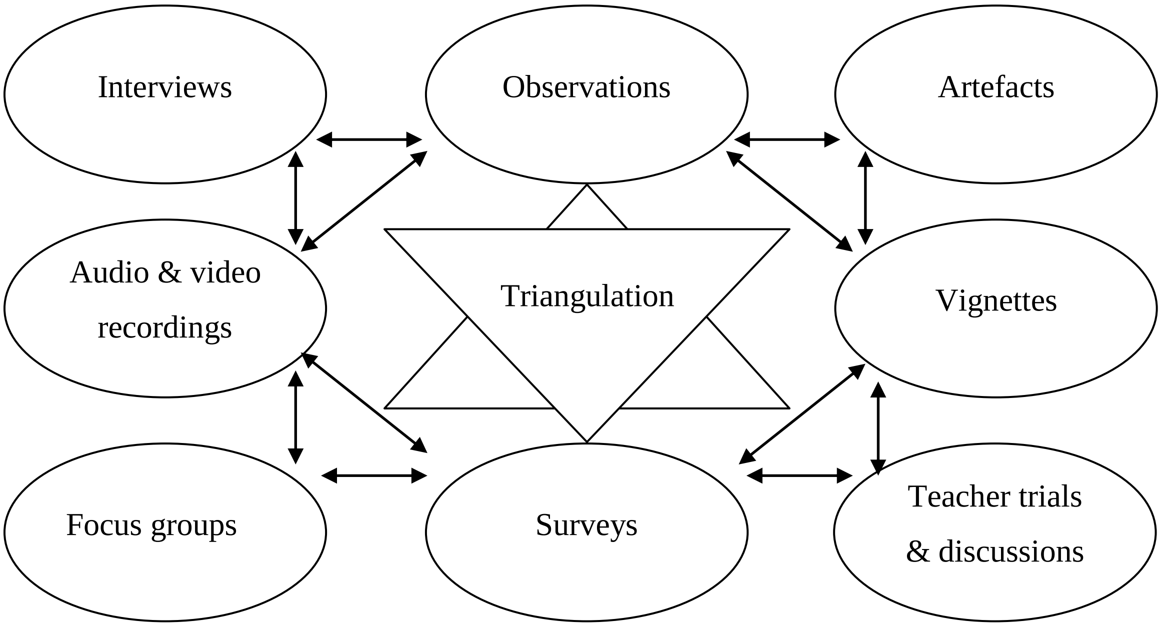


Fig. 3.2 *This research has a vast amount of data from multiple methods (collections of artefacts, student surveys, observations/field notes, audio and video recordings of students at work, interviews, focus group discussions and teacher trials) and comparisons made between vignettes which provide ample opportunity for triangulation.*

Peer Debriefing

Peer debriefing is a process in which the investigator discusses the investigation with peers "for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirers mind" (Lincoln & Guba, 1985, p. 308). Lincoln and Guba (1985) propose this does four things to help facilitate the credibility of the research.

1. Searching questions asked by the peer allows inquirer biases to be probed, meanings to be explored and the bases for interpretations clarified. This helps to keep the inquirer honest.
2. When the inquirer discusses and tries to justify their hypotheses with a peer, this puts their hypotheses to the test of scrutiny by others and themselves.
3. The debriefings provide opportunities to discuss directions to be taken, thus playing an important role in the ongoing formulation of the methodological design.
4. The peer as a listener, helps the researcher unload emotions and feelings which might otherwise effect their judgment and this may help to diffuse issues and assist the inquirer develop coping strategies. (p. 308).

Lincoln and Guba (1985) describe a suitable debriefer as a person:

> Who is in every sense the inquirers peer, someone who knows a great deal about both the substantive area of inquiry and the methodological issues. (p. 309)

During this research there was one person, who met all of these criteria and who played a most significant contribution in each of the four areas mentioned above. My doctoral supervisor is someone that I have known for a number of years and with whom I have engaged in several instances of research about teaching. Most recently, we co-authored a book chapter (see, Aubusson & Fogwill, 2006) focussing on role play as analogical modelling in the science classroom; he as the academic and myself as the classroom practitioner. The work that formed the basis of that chapter became part of the Pilot Study for this research. While Lincoln and Guba (1985) recommend that members of the research committee should not be debriefers (p. 309), as a most trusted friend and learned colleague with a particular interest in matters analogical, my supervisor provided much appreciated support.

This support was both formal and informal. Regular meetings provided opportunities to discuss all aspects relating to the progress of the research, the nature of the data gathered and preliminary findings. This included watching and discussing video footage of students engaged in intervention activities. He also visited the school to observe the intervention as it was applied (see Vignette 5). This provided an opportunity to gain written feedback and discuss methodological procedures, viewed through the eyes of a critical friend.

Two teaching colleagues who worked in my Science Faculty also played a significant role in one or more of the four aspects mentioned above. These teaching colleagues were experienced science teachers who taught similar content to similar students and so met several of Lincoln and Guba's (1985) criteria to be a debriefer. These two teachers were interested in the research to the point of supporting it in a range of ways. One watched and coded a lesson in which students were engaged in intervention activities. She then trialled the intervention with her own students and participated in an interview about the use of the intervention (see Vignette 2). The other, often chatted about the research, providing a critical ear. This teacher worked closely with me to avoid ethical issues relating to keeping the assessment of students in my class and his parallel class, fair (see Vignette 4). The informal discussions held with these two colleagues had debriefing perspectives matching one or more of the above four points and their ongoing moral support was also very much appreciated.

Beyond the debriefing possible, within the processes of collecting and discussing the data with colleagues in the local setting, aspects of the research have been presented at two international conferences; ASERA 2006 and 2007. This opened the research to the scrutiny of a wide range of educational researchers, some of whom made supportive and usefully critical comments. Sharing of ideas in this way, not only supports the trustworthiness of my own research, as a process of validation, it helps to "establish a history of trustworthiness within the field" (LaBoskey, 2004, p. 860).

The open nature of this research and the feedback gained from colleagues-as-debriefers at a number of levels adds to the depth and credibility of the data and hence, enhances the trustworthiness of the research and its findings.

Negative case analyses

Negative cases are those that do not support a hypothesis/conjecture. The lure of finding negative cases during data analysis is that it supposedly allows the researcher to "refine a hypothesis [/conjecture] until it accounts for all known cases without exception" (Lincoln & Guba, 1985, p. 309). Reaching this utopian situation is unlikely to occur in qualitative research, involving the nature of learning in which dozens of students have been involved. Nevertheless, negative cases should be sought: firstly because not looking for them, may indicate a measure of researcher bias (Huberman & Miles, 1994, p. 439); secondly, looking for and perhaps finding and analysing examples of negative cases may help in refining hypotheses/conjectures; and thirdly, the process involved improves credibility.

One might ask though, in a practical sense, how refined need the hypothesis/conjecture be? Lincoln and Guba (1985) have indicated "if a hypothesis could be formulated that fit some reasonable number of cases – even as low as say 60%-there would seem to be substantial evidence of its acceptability" (p. 312). Hence, finding additional negative cases after developing a refined hypothesis may still enhance the credibility of the research (because they were found) without substantially affecting the acceptability of the hypothesis (here conjecture).

In this research a small number of negative cases were identified and have been reported in the vignettes. For example, see Bob's account in Vignette 1 – in which he indicated that he was not very engaged in the role play activity and could not remember much about it. If the research conjecture (C) had been as stated below (C1), this negative case could be used as evidence to revise it.

Activities requiring students to generate their own analogies, actively engages them in learning to a level of deep understanding. (C1)

As Bob was, from his own admission, not very engaged in the learning, the above conjecture was not true for him. A more refined conjecture (C2) based on his negative case might state:

Actively engaging students in generating their own analogies helps them learn to a level of deep understanding, (C2)

This new conjecture (C2) excludes those who were not engaged. In this research it was evident from what would be negative cases to this second conjecture (C2), especially in subsequent episodes (see for example, Vignette 2), that the teacher needed to play a small but significant role in helping students refine their analogies to suitably map with the targeted science concepts; thus explaining the inclusion of, 'supported by their teacher', in the research conjecture (see Section 3.3.2 above).

However, even if the data largely supports a refined conjecture, it is likely that the conjecture will still not be true for some students and, perhaps for others, it will be true only sometimes. This supports the notion that "zero exceptions [to a hypothesis/conjecture] may be too rigid a criterion" because "it seems almost impossible to satisfy in actual studies" (Lincoln & Guba, 1985, p. 312). An acceptable hypothesis/conjecture is likely, however, to come from credible data in which negative cases have been considered.

3.7.4 Referential adequacy

Referential adequacy refers to archiving research data against which findings can later be checked. Video tapes and audiotapes of students working in classrooms are raw forms of research data (see Eisner & Flinders, 1994), that if stored, could readily be made available to, and used by sceptical others, "to satisfy themselves that the findings and interpretations [of the research] are meaningful" (Lincoln & Guba, 1985, p. 313).

While this research has inherently generated a huge amount of data, Brown (1992, p. 162) warns about "the Bartlett effect"; that is, unintentionally misrepresenting the data by selecting only samples that represent the desired theoretical stance being taken. Brown's suggestion to keep all data on file so that "selection bias" could be checked if necessary has been adopted as a feature of this research. To elaborate, the considerable amount of video and audio recordings, student artefacts surveys and transcripts have all been duplicated and archived. In addition, all of the duplicates have been stored in a safe, separate location to the originals and, as specified by the university ethics committee guidelines, both sets will be maintained for five years after the research has been completed.

In addition, some of the stored data have not been reported in the vignettes. While it does provide evidence, a position of "theoretical saturation" had been reached in which "the capacity of the data to generate new ideas ha(d) been exhausted" (Dey, 1999, p. 116). Lincoln and Guba (1985) have suggested that not using some of the material for the inquiry, "but reserving it exclusively" for testing adequacy, might be a drawback (p. 313). Here, however, this is not the case, because the data do not provide anything new.

3.7.5 Member checking

Member checking is "the most crucial technique for establishing credibility" (Lincoln & Guba, 1985, p. 314). They describe it as process in which the researcher provides information back to participants who were involved in some way during the data collection. This serves to ensure that any reconstructions or summaries from the researcher are "adequate representations" (Lincoln & Guba, 1985, p. 314) and provides opportunities for the members to respond and make corrections, if they are not. In addition, Lincoln and Guba (1985) suggest that member checking may lead to the participants adding relevant clarifications and further data to that collected in the first instance.

During this research several opportunities for member checking were taken.

Participants:

- Checked transcripts of their interviews and recounts of their analogies;
- Watched videotapes of group activities and provided clarifying points that allowed field notes to be improved; and
- Participated in a video stimulated interview, during which the group of students discussed what was happening, both on and off screen (see Vignette 3).

While member checks such as these are low level member checks (see Flick, 2008, p. 33) because they are not of the final document, they are nevertheless important in establishing credibility of the data.

3.7.6 Transferability

Transferability suggests that a conjecture found to be relevant in one setting, will be relevant in another very similar setting (see Lincoln & Guba, 1985). In this sense, an intervention applied in one classroom may show similar findings in another, if the classes were very similar in make-up and if enough detail to apply the intervention in a very similar way, was provided. An inquirer who provides “thick descriptions” which include “the widest possible range of information” (Lincoln & Guba, 1985, p. 316) may allow others to make judgments about transferability.

Reflecting on Brown’s (1992) description of classrooms as “messy” (p. 167) places however, it is unlikely that any two classrooms will truly be similar, and so “there is no guarantee of [the] effectiveness [of the intervention] in other settings” (Collins, Joseph & Bielaczyc, 2004, p. 18). During this research, however, data from having another teacher try similar activities with a similar class were gathered (see Vignette 2). This teacher did not have to rely on thick, written descriptions to decide how to apply the intervention, or to decide that using similar methods with students would be worthwhile. The teacher was able to gain knowledge of the application through direct observation of my lesson and through discussion with myself as the researcher and colleague. The ability of this teacher to apply the intervention with her own class, to her own satisfaction, is direct research evidence suggesting transferability is a possibility and adds to the trustworthiness of the research. This evidence also suggests that the detailed descriptions provided in the vignettes, may well have the potential to inform educational practices of other science teachers and science teacher educators.

From a different perspective, LaBoskey (2004) identifies that in self study, which to some extent this research has been; “the construction, testing, sharing and re-testing of exemplars of teaching practice” (p. 860) provides validity through validation. She also suggests that validation occurs when we incorporate into our teaching, “understandings and procedures we deem trustworthy enough to risk trying” (LaBoskey, 2004, p. 860).

This research has three levels of validation consistent with this idea. The first is the teaching experiment itself. It provides a measure of validation for the existing body of knowledge (see Chapter 2) because it extends previous ideas in using analogies in teaching. Secondly, the teacher at the research location who voluntarily tried aspects of the teaching experiment with her own class, provided validation of the local research. Thirdly, the students who were openly aware that the teaching strategies were part of a doctoral research and who willingly participated in learning through the development of their own analogies, placed trust in both, their teachers and the processes involved. In taking the process of validation to be a process of supporting transferability, this research calls upon, and enhances "the history of trustworthiness within the field" (LaBoskey, 2004, p. 860) of teaching with analogies.

3.8 Data Analysis

3.8.1 Stages in analysis

Data analysis is a process through which the data are used to reveal consistencies that can be used to "describe and explain a pattern of relationships" (Huberman & Miles, 1994, p. 430) and includes the processes of "data reduction, data display, and conclusion drawing/verification" (Huberman & Miles, 1994, p. 429). Lincoln and Guba (1985) endorse the notion that data analysis is a continuous and developing process that occurs throughout an inquiry (p. 340). While the nature of the data collected has been adequately described in the Section 3.6, the following quote from Erickson (1986) is pertinent because it helps to justify the nature of that data collected and relates in general to some of the ways in which the data in this research have been analysed towards answering some specific "what is happening" (Erickson, 1986, p. 121) questions when students generate their own analogies.

> Interpretive, participant observational fieldwork has been used in the social sciences for about seventy [now 100] years. Fieldwork research involves (a) intensive, long term participation in a field setting; (b) careful recording of what happens in the setting by writing field notes and collecting other kinds of documentary evidence (e.g., Memos, records, examples of student work, audiotapes, videotapes); and (c)

> subsequent analytic reflection on the documentary record obtained in the field, and reporting by means of detailed description, using narrative vignettes and direct quotes from interviews, as well as by more general description in the form of analytic charts, summary tables, and descriptive statistics. (Erickson, 1986, p. 120)

What follows is a brief discussion of the data processing used in this research, under headings that are consistent with the processes identified by Huberman and Miles (1994).

Data reduction

Huberman and Miles (1994) identify that data reduction is the process of selecting and condensing data. They say it involves such things as coding and working with raw data to produce summaries, finding themes, clustering data for comparison purposes, and writing stories (p. 429).

Processes in this research that are consistent with the above description include the following.

- Field notes, student artefacts and transcripts from audio taped interviews, were read and scrutinised for evidence relating to particular research questions. Several images that students had drawn were scanned and saved as image files. Items of particular interest were highlighted for easy reference and when used in producing the vignettes they were coded to show their origin.
- Field notes and video/audio tape recordings of students at work, along with summary data from artefacts were used when writing detailed accounts for several of the episodes. Video files were watched on a computer screen. Relevant dialogue was transcribed and the instances were captured using the ‘print screen’ function and saved as image files. This process also allowed images which served as artefacts of students’ models to be collected. Other images were captured to show positional, gestural and facial data. The files were saved with appropriate codes.
- Survey and test score data were summarised into Microsoft Excel™ spreadsheets and where relevant, statistical analyses were performed.

- The coded data were used to identify which episodes were most suitable to present in the thesis. The following points were considered when choosing the episodes for presentation in the thesis.

  1. Data from the episode could be used to address a number of the research questions.
  2. The episode typified one of the three types of activities (role play, model or written analogy).
  3. The episode was a repetition of a previous episode and as such could be used to compare findings and allow discussion related to transferability and trustworthiness.
  4. Episodes that were conducted at different stages (early and late) in the learning process were included.

- The detailed accounts for similar episodes were grouped and used to produce vignettes that compared these episodes, describing common themes and inconsistencies.
- Episodes that provided limited data or which did not add additional perspective to the data have not been presented. All episodes however, are shown in Tables 3.1 and 3.2.

Data display

"Defined as an organised, compressed assembly of information that permits conclusion drawing and/or action taking" (Huberman & Miles, 1994, p.429), data display is useful in constructing meaning from the data. In this research the vignettes provided this function. As previously mentioned, the initial research associated with the Pilot Study (see Vignette 1) was published (see Aubusson & Fogwill, 2006) and episodes for two of the vignettes (Vignette 2 & Vignette 4) were open to scrutiny by the education community at international conferences. Both producing and presenting these vignettes provided opportunities for discussion and reflective thinking, useful in clarifying ideas and gleaning understandings.

Conclusion drawing/verification

Conjectures are refined through “an iterative design process featuring cycles of intervention and revision” (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003, p. 10). This iterative process in which, analysis of the intervention and data lead to decisions to change the intervention while it is being investigated (Design-Based Research Collective, 2003), not only result in refinements to the intervention, it fosters the development of conclusions. Supporting this view, suggesting that conclusion drawing and verification are iterative processes that occur over time, Huberman and Miles (1994) identify important tactics (described above) such as making comparisons, identifying themes, clustering, triangulation, looking for negative cases, and member checking. (p. 429).

As an example from this research, the Reflection Vignette (see Chapter 4) shows that the intervention was implemented in essentially the same way, several times with different students over a four year period. This multiple application produced a cluster of four episodes, and data from another teacher, which, in an iterative way: allowed refinements of data collection methods; provided verifications about ways of implementing the intervention; provided direction in seeking answers to the research questions; and helped in the process of refining conclusions. Beyond this vignette, final conclusions to the teaching experiment were only made after identifying common themes in the conclusions across all of the vignettes.

3.8.2 Recognising high levels of understanding

The development of high levels of understanding of science concepts is a key feature of the intervention applied in the current teaching experiment. Recognising the evidence of the development of understanding is therefore an important part of the data analysis. In this section, the concept of understanding is discussed and a mechanism for assessing the level of student understanding is elaborated.

Understanding in science classrooms has not always been a high priority for teachers. This is very evident in the following quote from Tobin, Butler Kahle and Fraser, (1990).

> There is little evidence that the majority of science teachers are concerned with the extent to which students understand what they are to learn or with implementing the curriculum to emphasise student understanding of science. (p. 3)

The reason provided was that “most teachers feel constrained to prepare students for tests and examinations and cover the science content from text books” (Tobin, Butler Kahle & Fraser, 1990, p. 3). As Fensham (1994) identified in a study focusing on concepts in chemistry, despite the fact that substantial numbers of secondary and university students, and graduates including teachers, often held misconceptions they had prior to learning specific concepts, they could be successful in their examinations because the examinations did not challenge the conceptions (p. 18). This is consistent with what has been happening in Australian schools as reported by Goodrum, Hackling and Rennie, (2001):

> The present emphasis in secondary schools on traditional testing that focuses on the extent to which students memorise and recall science facts hinders the development of meaningful understanding. (p. 179)

While these statements have implications for the amount of content in current science curricula (a matter beyond the scope of this research), the need for an emphasis on improving levels of understanding is clear and suggests, seeking pedagogical strategies that may enhance students’ understanding should be a matter of considerable priority. Indeed the development of deep understanding has become a point of focus in current quality teaching priorities in all NSW government schools (see DET, 2003).

The teaching experiment that forms the basis of this thesis has the fundamental objective of seeking ways to enhance students’ understanding of science. What is meant by understanding however, needs clarification.

A dictionary meaning of the term *to understand* is “to perceive the significance or explanation or cause of” something (Moore, 1996, p. 1187): and here, the something is a scientific concept. There is, however, more than one level of understanding.

The type of understanding sought in this teaching experiment and which needs clarification, is a deep personal understanding of the canonical science embedded in the science curriculum. Ritchie (1998) and Ritchie and Tobin (2001), calling on the work of Bain (1994), identify this type of understanding as transformative; an understanding that students can demonstrate through their own discourse, using their own examples, as opposed to "reproductive understanding" which is more akin to regurgitation of what the students have read in texts or heard from their teachers (Ritchie 1998, p. 172). Since the development of this deeper level of understanding is unlikely to come solely from working with a text book or listening to a teacher, alternative strategies that encourage students towards "dialogic discourse" (Ritchie & Tobin, 2001), must be undertaken. Situations in which students can experience instances of conflict and co-construction through interaction with their peers, have been shown to allow students to develop and refine their ideas about scientific phenomena and be "conducive to the development of understanding" (Kearney, 2004, p. 431).

The discourse inherent in students working with their peers is consistent with the socio-cultural emphases of Vygotsky, in which "an idea's meaning is worked out in the context of its use" (Prawat 1993, p. 13). Prawat (1993) emphasised that when students conjure up mental images, maps or ideas, processes are invoked that:

> Serve to 'educate attention' enabling [them] to search out important detail as part of the perceptual process. . . Changes in thinking that result from discussing ideas in a social context [encourages transformation of ideas, because when the ideas are] used to describe and explain objects and events, [they] acquire meaning that they cannot possess when they are known only in an abstract or definitional way. (p. 12)

While these features which are the foundation of Prawat's (1993) idea-based social constructivism are consistent with the development of deep understanding as it applies in this thesis, ways to assess the level of students' understanding needed to be identified.

In assessing students' learning Biggs and Moore (1993) developed a Structure of Learning Outcomes (SOLO) taxonomy, based on the observable outcomes of students' learning. There are five levels in the taxonomy. These are:

Prestructural	preliminary preparation but the task is not appropriately attacked
Unistructural	an aspect of the task is picked up
Multistructural	a number of aspects of the task are picked up in a serial or unrelated way
Relational	Several aspects of the task are integrated into a coherent whole.
Extended abstract	generalization from the integrated whole to higher levels of abstraction. (Biggs & Moore, 1993, p. 68)

These five levels can be used to assess students' levels of understanding of science concepts. Claesgens, Scalise, Wilson and Stacy (2009), for example, used a framework based on the SOLO levels, to assessing students' levels of understanding in chemistry.

In drawing together the above ideas, students who, perhaps through social dialogical processes, interacting with their peers and the teacher, display a high degree of relational accuracy with several aspects of target science concepts, would be demonstrating a deep level of understanding. Conversely, students who show fewer relational aspects, inaccuracies and/or misconceptions, could be assessed as having lower levels of understanding. In this respect the SOLO taxonomy (Biggs & Moore, 1993) may be used to assess the levels of student understanding. These levels of understanding were used to identify and code students' levels of understanding expressed in the data (see Chapter 4).

3.9 Reporting the study

The aim of this research is to seek evidence about, how students' co-generating analogies influence their learning of science.

The research investigates the following four questions in addressing this aim.

a. How do students develop analogies?
b. How does the co-generation of analogies influence student engagement with science?
c. Do students develop deep understanding through the co-generation of analogies?
d. How does a teacher support students in the co-generation of analogies?

This research therefore investigates not only what students learn but also the processes of that learning. It attempts to find out what is happening while they learn; how the teacher can best support that learning and report on ways to help students be interested, motivated and engaged in their learning.

The data from 13 episodes of the teaching experiment are reported in five vignettes in Chapter 4. Each vignette presents a range of data (see Section 3.6) which collectively form rich descriptions about the nature of the learning that took place during several applications of the intervention.

To address the research questions, a designed teaching experiment methodology was used because it allowed the teacher to conjecture about the effect of an intervention and then through repetition, modification and refinement of processes, in an active and reflective environment, make judgments. These judgments are presented in Chapter 5.

3.10 Limitations

Significant limitations have been discussed in the Section on Trustworthiness (Section 3.7). There was, however, a number of other limitations that affected the quality of the data collected and which therefore limit the interpretations of that data. These are outlined below.

Capturing Discourse

Capturing the discourse between students was problematic and limited the quality of transcripts for a number of reasons.

1. Often relevant discourse was spontaneous and therefore easy to miss using a single audio device or video camera. This was especially true when students were spread out – for example, during role-play activities outside the classroom.
2. Conversations were sometimes limited, with discourse being replaced by considerable body language, gestures and physical manipulation.
3. When the students were actively engaged in close conversation, extracting clear conversations from tapes was difficult because students often spoke over one another and/or responded to half sentences (because they had predicted the rest of the sentence being uttered).
4. Some students stayed quiet when a camera or tape was present; some students showed off when a camera or tape was recording; and on at least one occasion, students self recorded what they thought was important in their conversations – by turning the tape on or off as they saw fit.

Questionnaires and interviews

All students were involved in the classroom activities, because the activities were the teaching strategies being used to deliver those aspects of the curriculum; and all students were invited to complete questionnaires and participate in interviews. However, only a small percentage of students volunteered to complete questionnaires and participate in interviews. Thus, findings based on the data available for any one activity, may not truly be representative of the whole group.

Iteration

The intervention was repeated with successive classes over a period of four years. Consistent with the design experiment methodology (see, Brown, 1992; Confrey & Lachance, 2000; Cobb, Confrey, diSessa, Lehrer & Schauble, 2003) this provided opportunity for reflection, refinement of the specific interventions, slight modifications in the processes of implementation and comparison of results. As a consequence however, since each intervention required students to use analogical thinking, in an iterative way, the students who were involved in more than one episode, learned from their previous experience; and so did I.

Whether with different topics with the same students; different content with different students; the same content with different students; or merely the experience of using the intervention with previous students, the experiences focused my attention to particular details in delivery and observation. For students who were involved more than once, it is likely that their metacognition of the processes involved altered their levels of engagement and output. Hence, no two episodes can be considered to have been conducted in exactly same way.

Researcher bias

As a teacher-researcher, I have conducted this research, which investigated the effectiveness of a teaching strategy I have used with my own students, in my classroom. In addition, data have been used from interviews of other teachers in my faculty, who trialled processes with their own students in their own classrooms. Hence, the possibility of researcher bias in selecting data and in reporting findings must be considered and defended.

Three levels of defence are inherent in this research and its presentation.

1. A vignette style of reporting has been adopted. The descriptions, data and interpretations, provided in the vignettes (Chapter 4), will allow the reader to "become a coanalyst of the data and interpretations presented" (Davis 1995, p. 448).
2. Data used in the vignettes has been verified at some level, by participants in the research.
3. A complete collection of all data is available for scrutiny. This also helps to provide referential adequacy (see earlier section).

It is expected that the presentation of the research data in Chapter 4, will 'speak for itself' thus, allaying fears of researcher bias and provide strong support for the trustworthiness (see also Section 3.7) of the teaching experiment.

To minimise the effect of these limiting aspects, which add to the list of complexities that typify a classroom as an interactive system or "learning ecology" (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003, p. 9), a wide range of data was collected during many activities with several groups of students over a considerable period of time.

3.11 Ethics

Formal ethics approval to conduct this research was needed (see Appendix 8). This was sought from and granted by both the state authority for schools (NSW Department of Education & Training) and the University of Technology, Sydney ethics committees.

Consent forms provided to parents via the students (Appendix 1) set out in brief what the research was about. These forms sort approval for: the students' participation in the research process (interviews etc); collection of data, including photographs and artefacts to be used for research purposes; the use of the data for conference presentations and publications such as journal articles and the thesis; and required signatures of a parent and the student. Confidentiality was built into the consent form which indicated that data gathered would not be published in a form that would identify students by name. Importantly though, because the intervention activities were the strategies used to deliver the course material, it was not necessary to seek permission for students to participate in the lessons. In addition, the school provides an opportunity for all students to request their photograph not to be taken or used for educational purposes. None of the students involved in this research had elected not to have their photograph taken.

A key factor in the research design was that the teaching intervention would as far as possible be the pedagogical method of delivery for the sections of work covered for the courses concerned. This was to avoid negative impacts on the students' learning time. Time was an important factor because the intervention was conducted in an authentic classroom situation as part of regular courses that arguably are already too packed with content to do them justice (Goodrum, Hackling & Rennie, 2001). In addition, the time allocated to the courses (120 hours, see BOS, 2002) is typically reduced to some extent by factors such as time for examinations, school assemblies, excursions for other subjects and sporting events.

Nevertheless, brief discussions, involving the nature of the intervention were held. As part of these discussions, all students were invited to participate in the research by volunteering to be interviewed, complete surveys and provide samples of their work. The emphasis, however, was on encouraging all students to actively participate in the class activities so that they could learn well, irrespective of trying to evaluate how successful the activities were in helping them learn. As such, all students were aware of the research aspect while being involved in their science lessons. All students in the classes were willingly involved to some extent and several had a more extensive role. For example, some students completed interviews and surveys outside of lesson time, while others were merely observed, audio taped or videotaped as part of the group activities and/or provided examples of their work.

Care was also taken to ensure that students involved in the research, were neither advantaged nor disadvantaged in terms of their overall assessments, over others who were in parallel classes. To exemplify, one particular instance arose where this could have been possible. A question relating to a research intervention activity was included in an examination. The purpose was to identify whether the students' level of understanding developed during the class work would be revealed when answering a question under authentic examination conditions, a considerable length of time after the intervention. In developing the marking criteria for this question, I worked closely with the teacher of the other class to ensure that the students in both classes had equal opportunity to receive marks and then, the other teacher did the marking. After marks had been awarded, an additional check was conducted to ensure that the marking scheme had been consistently applied (full details are presented in the Reflection Vignette in Chapter 4).

Very sadly during the research period, one of the student participants was killed in a motor accident. This student had taken a starring role in some of the role-play activities which had been videotaped. A collection of snippets showing him role playing, were compiled on a videotape and provided to his family. They were very appreciative. This was, however, beyond the original permission granted for using the videotaped lesson segments and it is likely that the tape will not be destroyed five years after the research, as originally indicated for similar research data in the permission note (see Appendix 1). Several steps were taken to ensure this was ethical. A consultation meeting was held with key members of the boy’s family and the school principal. Phone conversations were held with the parents of each of the other students appearing in the videotape segments. Discussions were held with the other students and with a member of the university ethics committee. All discussions met with favourable approval. No foreseeable consequences of the family retaining the tape beyond the life of the research were envisaged and there have been no known negative consequences since providing the tape. In addition, I asked the family of the deceased boy if they wanted the video footage to be excluded from the research. Their response was a sincere permission to “please use it in his memory” (personal account – research Field notes).

3.12 Conclusion

This research which fits well with the nature of the classroom based research called for by Harrison and De Jong (2005) (see Section 2.7), has the characteristics of a teaching experiment. Applications from a conjecture are considered for a particular context. The practices derived from the conjecture were trialled and modified in an authentic setting in a series of cycles. The data contribute to the development of a refined conjecture and the outcomes/findings inform practice.

The practitioner/researcher design of the research was collaborative. The co-generation aspect of the intervention, purposely involved the students in co-developing their own analogies, supported by their teacher (as expert providing stimulus and advice) to develop scientific understanding of particular concepts. In this process the teacher is therefore a necessary participant and an integral part of the enquiry.

The research design involved the collection of a wide range of qualitative data from a large number of classroom based episodes over an extended period of time. The coding and analysis of these data, allowed the research questions and the conjecture to be addressed. The nature of the research facilitated a vignette style of reporting in which thick descriptions about the applications of the intervention in an authentic setting, help to make obvious, the trustworthiness of the research.

The methodology chosen for this research has supported the bringing together of theoretical perspectives from constructivism and learning with analogies, allowing an analysis within the context of authentic practice. Therefore, from both theoretical and practical perspectives the teaching experiment methodology has been an appropriate methodology for this research.

3.13 Summary

This research has been guided by a scholarly interest in researching, investigating and implementing practices to enhance teaching and the learning of students in science classes. Within the local context, a need for learning interventions that encourage students towards improved learning outcomes, led to a teaching experiment. The teaching experiment involved the application of an intervention in which students co-generating analogies to learn science concepts. This intervention was applied many times with a number of classes over a period of four years.

The wide range of data collected and the number of the episodes conducted over a period of four years attests the extensive nature of the research. Issues of trustworthiness have been addressed by considering factors that affect the dependability and credibility of the research. Data analysis involving the making of comparisons, identifying themes, clustering similar data, triangulating aspects from a number of different data types, looking for negative cases, and checking accounts with participants has led to a narrative vignette style of reporting in which thick descriptions about the conduct of the teaching experiment are presented.

Practical limitations to the research included, difficulties capturing students discourse, small numbers of students volunteering for interviews, making comparisons between similar episodes, and attempting to reduce researcher bias. Ethical considerations inherent in the teaching experiment included; seeking permission to conduct the research; issuing and collecting permission for the participants to be included and ensuring their anonymity; ensuring the participants were neither advantaged nor disadvantaged in comparison to other students; and maintaining open communication with all relevant parties when ethical issues arose.

Finally, it can be concluded from both theoretical and practical considerations that the teaching experiment methodology is an appropriate methodology for the research.

The following chapter (Chapter 4) presents, in a series of five vignettes, data and descriptions from 13 episodes of the participatory enquiry that, over a period of four years, with many students, was the teaching experiment. Findings from Chapter 4 will be further discussed in Chapter 5.

Chapter 4

Data Analysis

4.1 Chapter Overview

This chapter presents the data from the 13 episodes of the teaching experiment in five vignettes. Episodes that are similar in nature have been presented in the same vignette and so the findings, presented within the vignettes are typically based on data from multiple episodes. The vignettes provide descriptions, analysis and interpretive comments about what happened when the students engaged in the analogical activities to learn specific aspects of their science courses. The first vignette describes the Pilot Study and how it helped to shape the remainder of the research. Findings specific to each episode are presented within each vignette. These findings form the basis of the discussion in Chapter 5.

4.2 Introduction

The teaching experiment, as discussed in Chapter 3, constituted the implementation of a teaching intervention. The intervention required students, with help from their teacher, to generate a variety of analogies. These included models, role play and text based representations. Through the analogies, students sought to develop and/or show their understanding of particular science concepts. The development and use of analogies during each episode of the intervention were observed and a wide range of data was collected. The data from each episode of the intervention are presented in this chapter in five vignettes. The vignettes contain detailed descriptions and data to indicate how the intervention influenced the students' learning.

The intervention was applied many times with several classes over a period of four years (see Tables 3.1 & 3.2). To address the broad question about how student generated analogies influence the development of science understanding, the data were analysed seeking answers to four questions.

a. How do students develop analogies?
b. How does the co-generation of analogies influence student engagement with science?
c. Do students develop deep understanding through the co-generation of analogies?
d. How does a teacher support students in the co-generation of analogies?

These questions were chosen to focus the attention of observations and data gathering on the two areas drawn together in this research; students' personal construction of knowledge and understanding and; the use of analogies in learning science. These two areas are discussed in detail in Chapter 2. The questions have also been used to focus the analysis of data from the episodes in which the intervention was applied.

Episodes varied in length depending on the nature of the content. Some constituted a single lesson and others were a series of lessons. As each episode was an application of the intervention with a particular group of students, at a particular stage in their learning of a particular concept, each one provides a unique set of data. It is for this reason that the episodes have been reported as vignettes. Despite the uniqueness of each episode, where the intervention was applied in a similar way to address the same concepts with different groups of students who were at a similar stage in their learning, the episodes have been grouped together and reported as one vignette. A vignette therefore, may present data from a single or many teaching episodes.

24 episodes were conducted during the teaching experiment (see Tables 3.1 & 3.2). Due to "theoretical saturation" (Dey, 1999, p. 116), however, the vignettes presented, only include the Pilot Study and the 12 other episodes shown in Table 3.1.

The vignettes, grouped by the type of activity, are:

Role Play analogies (Vignettes 1-3)

- The extraction of copper from copper carbonate (Pilot Study)
- Reflection of light (3 episodes)
- Medical imaging techniques (1 episode)

Models as analogies (Vignette 4)

- A model for a solenoid valve (4 episodes)

Verbal/written Analogies (Vignette 5)

- The photoelectric effect (4 episodes)

Each of these vignettes is presented in the following sections.

4.3 Pilot Study-The extraction of copper from copper carbonate

Year 11 Chemistry – Role Play

Vignette One

The application of teaching strategies that are based on learning through analogy have been part of a range of pedagogical tools that I have used for many years in my teaching of science to high school aged students (see Aubusson, Fogwill, Barr & Perkovic, 1997; Fogwill, 1996). The role play activity reported in this vignette was designed to enhance students' understanding of chemistry concepts embedded in the Preliminary Higher School Certificate course for students in Year 11. Reporting on this activity (see Aubusson & Fogwill, 2006) was the stimulus for the research that led to this thesis. Processes that were used in this activity provided a basis for planning the episodes of intervention and data collection over the following three years. Students, who were part of this initial activity in Year 11, were interviewed 18 months later at the end of their Year 12 chemistry course. The findings from their recollections formed a data set for the overall research. The role play activity reported in this vignette became a pilot investigation for the current research.

As a pilot investigation, this episode permitted an exploration of the potential and feasibility of the proposed analogical interventions with senior classes; provided initial data on the intervention to inform the larger doctoral study; and tested the efficacy of data collection based on observations, notes, surveys and student interviews.

Background

In this episode the intervention was a role play development activity with 15 Year 11 students, in a school in Western Sydney, NSW, Australia. The students were 16-17 years of age and emanated from a range of cultural backgrounds. The students had come to the Senior College from a number of other high schools and had only been together as a group for approximately six weeks.

As part of the course, the students are expected to be able to trace the path of ions through reactions such as those involved in the extraction of a metal from its ore. Students are also expected to develop understandings about the arrangement of electrons in ionic and covalent bonds. These features are confirmed in the following extracts from the NSW Chemistry Syllabus (Board of Studies, 2002):

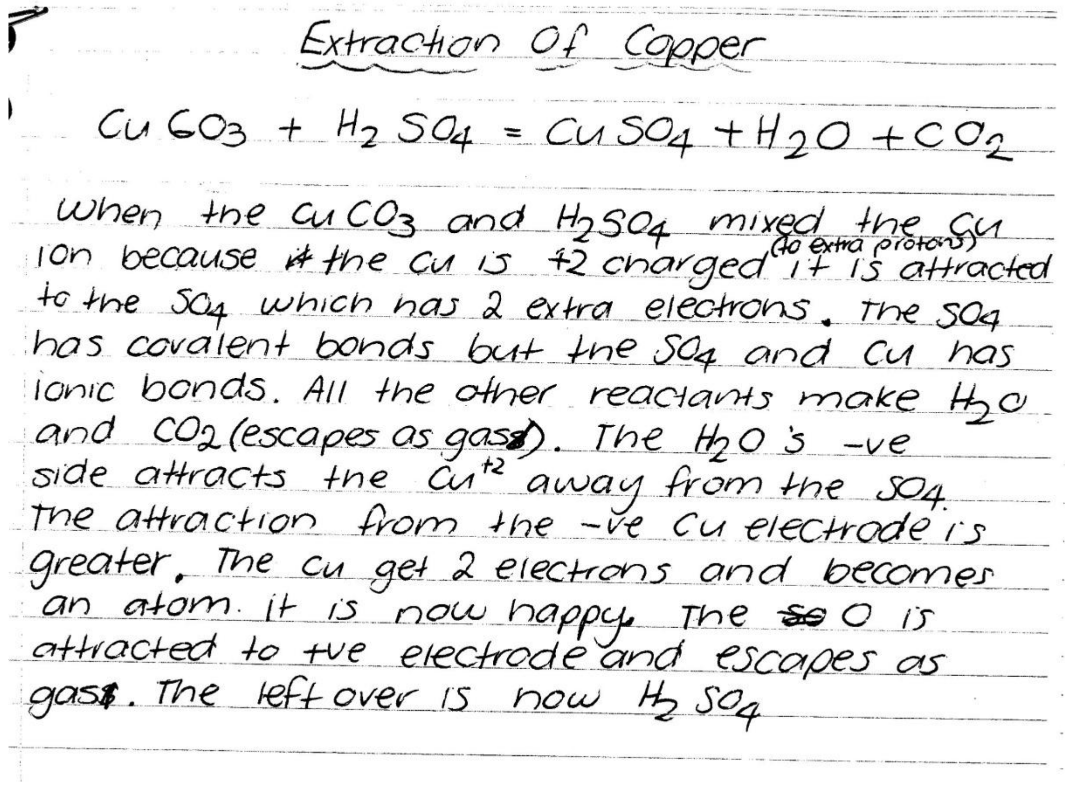
> Describe the formation of ions in terms of atoms gaining or losing electrons. (p. 25)
> Describe the formation of ionic compounds in terms of the attraction of ions of opposite charge. (p. 25)
> Analyse information by constructing or using models showing the structure of metals, ionic compounds and covalent compounds. (p. 25)
> Describe the separation processes, chemical reactions and energy considerations involved in the extraction of copper from one of its ores. (p. 32). (BoS, 2002)

A typical practice in NSW high school chemistry classes is to perform a series of experiments involving the extraction of copper from copper carbonate and discuss the path taken by the copper through the reactions that take place.

Two typical teacher directed experiments were conducted with the students. In the first one, the students reacted copper carbonate powder with dilute sulphuric acid. This formed a blue copper sulfate solution. In the second experiment, students placed two electrodes connected to a source of low voltage direct electric current, into the copper sulfate solution. In this second experiment copper from the solution was deposited onto the negative electrode and bubbles of gas could be seen coming from the positive electrode.

After completing the experiments; follow-up discussions involving verbal explanations; using molecular model kits; and making notes; the students were asked to write an answer to a question that asked them to explain the path of copper in the extraction process. The wide range of responses to the question supports research reported by Tasker and Dalton (2006, p. 141), in which they identified that visualising at the atomic level is difficult for students and hence they sometimes make mistakes.

Three of the students' responses are discussed below (see Figs. 4.3.1 - 4.3.3).



Extraction Of Copper

$CuCO_3 + H_2SO_4 = CuSO_4 + H_2O + CO_2$

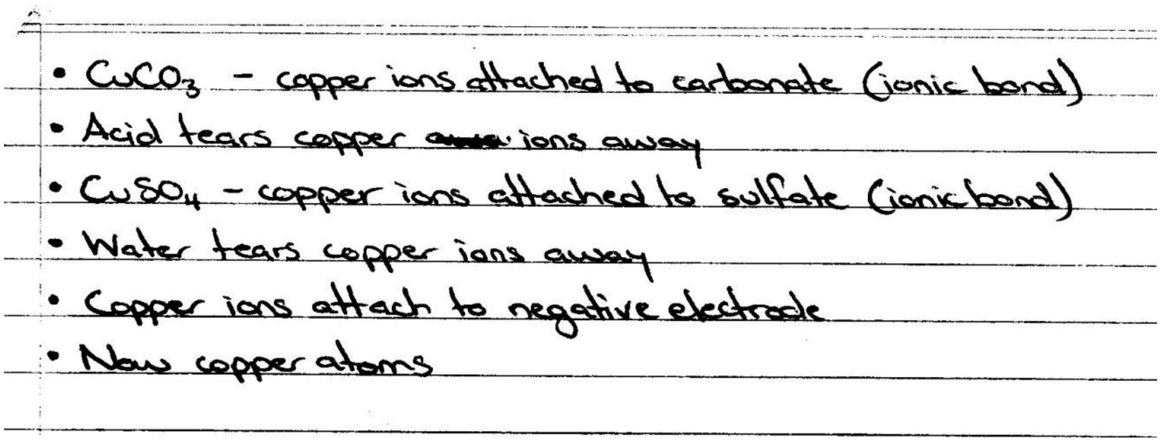
When the $CuCO_3$ and H_2SO_4 mixed the Cu ion because ~~it~~ the Cu is +2 charged (to extra protons) it is attracted to the SO_4 which has 2 extra electrons. The SO_4 has covalent bonds but the SO_4 and Cu has ionic bonds. All the other reaciants make H_2O and CO_2 (escapes as gas). The H_2O's -ve side attracts the Cu^{+2} away from the SO_4. The attraction from the -ve Cu electrode is greater. The Cu get 2 electrons and becomes an atom. it is now happy. The ~~so~~ O is attracted to +ve electrode and escapes as gas. The left over is now H_2SO_4

Fig. 4.3.1 Student 1 Response – Extraction of copper (SA11Ch2003RP-A1)

While Student 1 remembered the procedures and the reactions for the two experiments reasonably well, several minor incorrect aspects about ions and bonding and the experiments, are noteworthy. These include:

- Copper ions are inconsistently represented as Cu and Cu^{2+} and the sulfate ion is represented as SO_4 rather than SO_4^{2-}.
- The charge on the copper ion is specified as being due "extra protons". While this could correctly identify that the student is aware that the copper ion has two more protons than electrons, the charge is due to a loss of electron rather than a gain of protons, which the student's wording suggests.
- There is confusion about the nature of bonding in the statement "The SO_4 has covalent bonds but the SO_4 and the Cu has ionic bonds".
- It is not clear in the student's statement that there were two stages in the extraction process.

- While there was not an emphasis in the practical activity on what was occurring at the positive electrode and while there is some confusion about what happens there in the student's statement, the reference to it shows that the student made relevant observations that are worthy of further discussion.



- $CuCO_3$ – copper ions attached to carbonate (ionic bond)
- Acid tears copper ions away
- $CuSO_4$ – copper ions attached to sulfate (ionic bond)
- Water tears copper ions away
- Copper ions attach to negative electrode
- Now copper atoms

Fig. 4.3.2 Student 2 Response – Extraction of copper (SA11Ch2003RP-A2)

- In the first point, Student 2 has correctly concentrated on the bonding of the copper ions in the solid copper carbonate. The word 'attached' however, indicates a possible lack of understanding of the mutual attraction between the positively charged copper ions and the negatively charged carbonate ions.
- In the second point, there is a clear misunderstanding about the reaction between the acid and the carbonate. The student indicates there is a reaction between the acid and the copper rather than identifying that the hydrogen ions in the acid solution react with the carbonate ions in the copper carbonate to form the products water and carbon dioxide gas. In this process the copper and sulfate ions are termed spectator ions and remain as by-products of the reaction, forming a solution of copper ions and sulfate ions.
- The third point identifies that the student thinks that the copper ions and sulfate ions are ionically bonded together in the solution rather than separated by water molecules forming a solution of separated copper ions and sulfate ions.
- While the student's fourth and fifth points indicate awareness that the copper ions move towards the negative electrode and become copper atoms, the lack of reference to the positive nature of the copper ions, or that the ions collect the

required electrons to form atoms of elemental copper, identifies a need to discuss the inclusion of more detail when providing answers.

The copper carbonate reacts
with the acid and
the copper comes out.
~~It~~ The copper atoms go to
the electrode

Fig. 4.3.1 Student 3 Response – Extraction of copper (SA11Ch2003RP-A3)

In this very brief answer, the student shows some understanding of the process of extracting copper, however, the student makes no reference to ions at all or that there were two stages in the extraction process.

Responses such as these, which facilitated the identification of conceptual errors, provided the impetus for correctional strategies. The challenge then, was to devise a strategy that would allow most, if not all, students to refine their understandings without using a huge amount of additional teaching time. Student generated role play was the activity chosen for this purpose.

Developing the role play

The students were asked to devise a role play to show what they understood about the movement of ions; in particular, the path taken by copper ions in its extraction from copper carbonate. Despite that the students had not previously develop a role play and had little time to get to know each other well, they embraced the idea and began discussing what should be done. They decided that there would need to be two acts; one representing each experiment.

During the development of the role play students became actively engaged in discussions about how they thought the atoms, ions and electrons could be represented and how the interactions between them could be demonstrated. Different groups of students formed different substances. For example, one group of five students formed the ionic compound copper carbonate as shown below (Fig 4.3.4).

Another group of students formed sulfuric acid using similar strategies. In their role playing of molecules in solutions, the students initially did not show the presence of the water that the substances were in. The students were focusing on the structure and interaction of the reactants. This aspect was not, however, ignored and through teacher input - asking questions such as "how could the soluble ionic compounds be better represented?" and "what represents the water in your role play?" (FN11Ch2003RP), the students were able to demonstrate that they knew water was present and necessary for the reaction. They described the water as being the room and explained that they had deliberately not included it in their role play because they would have needed more people than they had.

In this pilot investigation, the students were not asked to write descriptions of their understandings about the movement of copper through the two experiments after the role play. However, observations of just some of the discourse among the students revealed that students were themselves clarifying and improving their understandings with support from each other through the process of developing their role play. One notable example was observed when the copper carbonate group of students were *reacting* with the sulfuric acid group. In the formation of carbon dioxide, (two oxygen students and one carbon student) the oxygen students were holding hands with the carbon student. Another student in the group told the two oxygen atoms (students) to hold onto the carbon atom (student) with both arms "because it's a double bond" (FN11Ch2003RP). This additional detail showed considerably more understanding than that which had been demonstrated in the written answers completed prior to developing the role play.

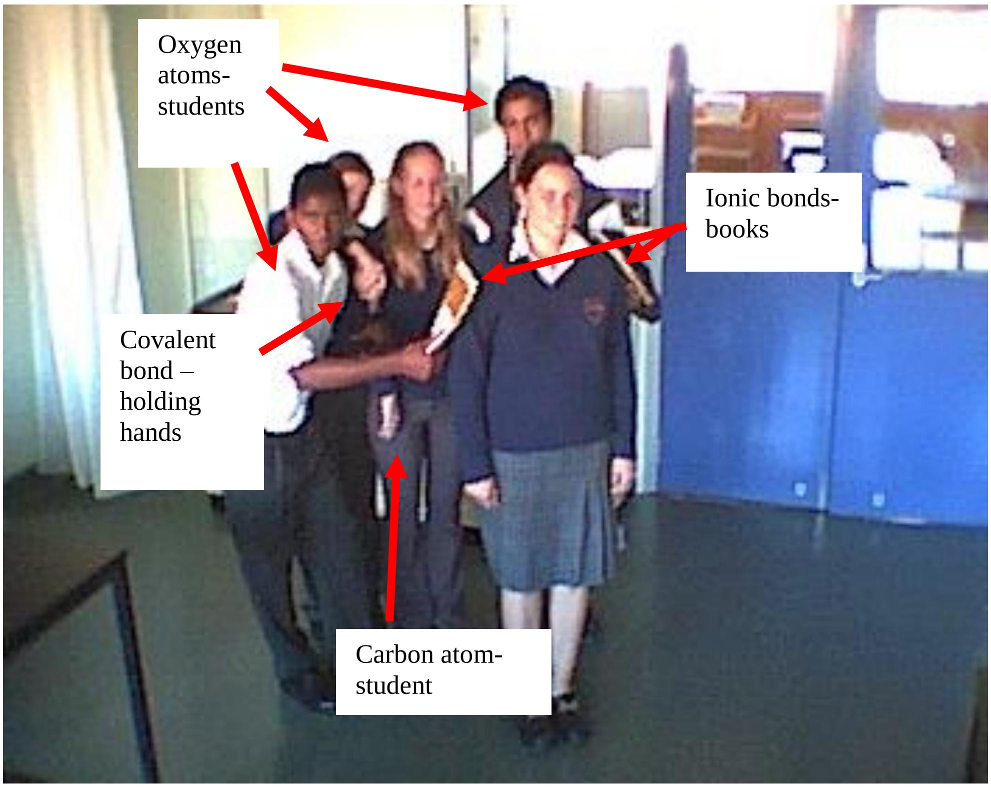


Fig. 4.3.4 Year 11 students demonstrating how they thought a carbonate ion bonds with a copper ion during a student generated role play performed after extracting copper from copper carbonate in a Chemistry lesson.

This early work suggested that through the role playing process the teacher could: gain clearer understandings about what the students understood; identify misconceptions from aspects of the students interactions and discourse and; by making comments or asking questions, steer the students' conversations and actions in more scientifically acceptable directions. It also strongly suggested that students were actively reviewing and revising their own understandings through their discourse and actions while developing their role play with each other. Observations such as these led to the following conjecture.

When students develop their own analogies (supported by their teacher) in the process of learning science, their understanding of the concepts being studied will be enhanced.

Through this pilot investigation it became evident that further research would need to provide data that would address several questions about what happens when students engage in activities that require them to generate analogies in the process of learning science. These questions became the research questions (see above).

Consideration of the research questions, guided the planning for further investigations. For example, (i) it became evident that capturing the students' conversations would provide data that would be helpful in gaining insights about the impact of the activities on the students' learning; and (ii) collecting data, several months after the activities, may provide insights about the depth of understanding; reflected by the persistence and accuracy of the learning.

Further data from the pilot investigation.

18 months after the initial activities, the students who had progressed into the Year 12 Chemistry class, were asked to volunteer as participants in interviews about role play activities in which they were involved in Year 11. Five students, volunteered and were interviewed. Due to the students' availability, these five students were interviewed during three sessions. The first of these interviews (SI21904RP) was conducted as a semi-structured small focus group interview with three students. The other two students were interviewed individually. The individual interviews, (SI22904RP & SI23904RP), were also semi-structured interviews. The semi-structured format was chosen to allow questions to be derived from student responses and so that in the group interview, students could respond to comments made by others in the group. The interviews were audio taped and transcribed verbatim.

When gathering data about each of the research questions (see above); in these interviews I was interested in:

- Ascertaining whether the students could remember doing the activity and the sort of detail they could remember.
- Identifying aspects of the role play experience that influenced any lasting memories

- Seeking the students' opinions about the effect the activity had on their learning.

A questionnaire was developed and given to students prior to their participation in the interview. The students voluntarily did these as individual tasks and were aware that their responses would be used as data in the research.

It was expected that completing the survey/questionnaire would help the students to focus their thinking on the role play tasks prior to the interview and provide data to cross check things they said during the interview. The questionnaire asked students to rank their choices from 1-5 (see Appendix 2a). The few students who completed the survey had no difficulty in doing so, and their grading provided useful feedback. The questionnaire was later modified to provide a more specific range of choices so that future survey data could be compared with greater confidence. An extra question which sought to gain data about the use of science terminology in the students' discourse, was added (Q.9) before the last question (see Appendix 2b).

The numbered/tick-a-box responses to the questionnaire were recorded in a spreadsheet SS200904R(11Ch) (shown below Fig. 4.3.5) and analysed for trends.

During the semi-structured interviews, some questions asked, were similar to those asked in the survey. This provided students with opportunities to expand on their earlier thoughts and to make generalisations. It also provided "structural corroboration" - an opportunity to identify "a confluence of evidence that breeds credibility" (Eisner, 1998, p. 110).

As a number of role play activities had occurred in both the chemistry and physics class taught by the researcher, and several of the students were in both classes, the interviews started with a general question, in which I asked if they could remember the role play activity done about 12 months ago.

Other questions explored:

- The students' level of involvement;
- The students' level of engagement in thinking about the science content;
- Whether the students thought the activity was enjoyable; and

- If the students thought the activities had helped them to learn and why.

Science Activity Questionnaire Result sheet

SS200904R(11Ch)

Activity:	Copper sulfate Role Play	No. of students	15
Conducted:	14-March-2003	No. of students surveyed	5
Class:	Yr 12 Chemistry	No. interviewed	5
Teacher:	Fogwill S.	Comment:	
School:	WC	Also see sketch in field notes:	
Survey Date:	20-09-2004	FN11Ch140303RP	

Note	Student	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Y	Jacinta	3	4.5	3.5	3.5	4	4	3	3.5	4
Y	Ian	4	4	3	4	5	4	5	4	5
Y	Georgiana	4	4	4	5	3	3.5	4	3.5	4
Y	Bob	3	2	4	5	5	5	4	5	3
Y	Student 5	4	5	5	4	5	4	5	5	5
	Averages	3.6	3.9	3.9	4.3	4.4	4.1	4.2	4.2	4.2

Codes For Q. 2-8 above are student generated using a 1-5 Likert scale based on the following extremes:

1= most negative response and 5 = most positive response

Codes for Q. 1 and 9 above are researcher produced using a 1-5 Likert scale based on the following extremes:

for 1, 1 = no idea about the purpose of the activity and 5 = a clearly stated correct purpose for the activity

for 9 (Q 10 on the modified questionnaire), N = no comment 1 = comment indicates no usefulness and 5 = comment suggests activity was highly useful

Note: The survey was conducted 18 months after the activity was conducted. It is significant that each of the students was able to remember the activity well enough to make relevant comments.

Fig. 4.3.5 – Survey data for the Pilot Study (Inserted from Microsoft Excel™)

The following excerpts from the transcripts of the student interviews, conducted approximately 18 months after the role play activity, are provided to allow the reader to gain an understanding about the type of memories the students had after that time. The students were aware that they would not be identified and would be assigned either a pseudonym or a number. Four of the five students interviewed decided to choose their own pseudonym. These have been used in the transcripts and in Fig. 4.3.5. One student did not choose to use a pseudonym and has been shown as Student 5.

Group interview (SI-21904-RP-11Ch-JIB) with three Yr 12 Chemistry students.

During this interview the students decided to use pseudonyms (Jacinta, Ian & Bob). These names also appear in the table shown in the survey data above. T is used to represent Teacher/researcher (me).

T Can you remember the activities that we did in class about 12 months ago?

Jacinta: The ones on copper sulfate

T Yes

Jacinta A little bit

T Can you describe what you remember?

Jacinta I remember we did them in the lab and we – some of us were copper ions and some of us were sulfate, I think, and then we did a role play on how copper sulfate formed

Although Jacinta was a little tentative, often using the term "I think" in her responses, her ability to identify the nature of the task with details of the ions that were in play, suggests that she had a lasting memory, not only of doing the role play but also of some of the targeted chemistry concepts.

T Ok, Ian do you remember doing those sorts of activities yourself?

Ian: Yes

T	What do you remember most about them?
Ian	I remember in the copper sulfate experiment – that we used books.
T	What did you use the books for?
Ian	As electrons I think it was – yes electrons and (I remember) the stuff that Jacinta said.

Ian too, was able to recall some of the fine details from the role play; for example, using books as electrons. Of interest here, though is the affect of interviewing a group of students together. Two aspects became immediately apparent. Firstly, it encouraged students to agree with others and use phrases such as “and the stuff that Jacinta said”. Perhaps this is because to repeat it would seem redundant, but it limits the amount of actual data for that student. Secondly, though, as one student recalled and voiced, when a student was speaking, their comments seemed to stimulate the thinking of the others involved in the interview. This helped them filter their memories and then offer details not presented by the others. In the extract below, Bob agrees that he remembers what the others had said but not the details and makes an error about electrons (which were books as mentioned by Ian). Then, however, he adds additional relevant information, both about what happened in the role play and, in a metaphorical sense, he makes a significant comment relating to the “strength” of chemical bonds formed in the reaction.

T	And Bob what do you remember about those activities?
Bob	I remember the copper sulfate activity where the books were electrons but I actually don’t remember the details.
T	That’s OK that’s fine – Do you think at the time –the activities encouraged you to talk about the science?
Bob	Yes
T	How do you know that?

Bob	When we were doing the actual models the people were referred to as say electrons or whatever and told to move close to the copper sulfate to where they were using their strengths.

This group interview provided an opportunity to assess the efficacy of focus groups as a means of gathering data. During the interview the students were quite relaxed and provided support for each other in answering questions. It identified that while students restricted their answers to some extent, because of what had already been said by others, they also seemed to feed off each others' words, adding extra detail that perhaps may not otherwise have been revealed.

Interview-Yr 12 Chemistry student (SI-22904-RP-11Ch–G)

T	Georgiana I'd just like to ask you if you can remember some of the activities we did last year and if you could just describe those activities for me.
Georgiana	It was an electrolysis with copper sulfate – that's the only role play one.
T	That's fine, yes, can you describe what we actually did during that role play activity?
Georgiana	Different members of the class were assigned different chemicals or atoms or ions and we had to show what happens at the electrodes and how they changed the compounds.

Georgiana, the top academic student in the class, had little trouble remembering the activity and provided a quite detailed account about what had happened, specifically relating to several of the key target concepts. Her recollection of the activity even extended to identifying how the *players* became involved in role play, as shown below.

Georgiana	I think we chose a leader sort of and with the help of the teacher – it was-some people said "Oh yes-I'll be the oxygen" but other people had to be said – right "you're doing this" so it was a combination of telling people what they were and other people just said "I'll be this".

When asked if she thought the activity was a good one, Georgiana agreed that it was, but also indicated that it had its “down side”, suggesting that she had difficulty gaining “an overall perspective”.

Georgiana It was a good activity because it was different to reading text books – because if you read everything it doesn’t always like stick in your mind. Where – the thing I found a bit – sort of a down side of it – when you are doing the modelling you are actually part of it and so you can’t sort of look back and see the overall thing because you are part of it and so that’s where Molymods™ – you can see the overall thing and you can say “this is what happens” where as a role play you’re part of it – so you can’t sort of look back, you are more – you can’t see it from an overall perspective.

It was good because it was different – because – which – like, I can remember it now-where if you asked me something I had read in a text book at about the same time ago I wouldn’t have remembered it.

T Yes

Georgiana And so I suppose it does stick in your mind.

Georgiana thought she got a better overall perspective using a different modelling process. Of significance here, is her metacognitive realisation that the role play activity was, for her, a powerful mechanism towards lasting memory. Perhaps this was because she was “part of it”.

When Georgiana was asked whether she though the students were having fun during the role play activity, her response provided a different perspective to Lincoln and Guba’s, (1985) ideas relating to building trust through prolonged engagement (see Section 3.7.3.1) between the participants and researcher. In her statement below, Georgiana identifies that in this unique school situation where students come together from a variety of schools, building trust among themselves is also an issue.

T So do you think people were having fun?

Georgiana At the time when we were doing it-we were still like new and didn't know each other and so there was the problem of you [the students] not knowing people's names and you were still like basically strangers and so you still had your own personal space that you wished to keep and so if we probably did it later on in the year it might have been a bit different where we were more – become more friendly to one another -so being at the beginning when we didn't know each other it was a bit more stand offish.

This flagged the importance of trust in working with subsequent groups of students. To help reduce a lack of trust among students being a barrier to productivity, when the intervention required students to work in groups, the students were encouraged to form their own groups.

Transcript Extract-Yr 12 Chemistry student (SI-23904-RP11Ch – S5)

The fifth student (S5) interviewed, similarly recalled using books as electrons in showing understanding about chemical bonding, but was not able to recall the nature of the reactions involved in the practical activities and represented in the role plays. She did, however, recall in general, what happened.

T Can you tell me anything about the role play activity or a role play activity you did from last year?

Student 5 I remember we did lots of them and I remember using books to represent the bonds and the electrons and I don't remember exactly what reactions we did but we represented different things. Sometimes the boys represented certain molecules or atoms and the girls represented different ones

I don't know what else to say – I do remember a bit now though.

T That's good

Student 5 I didn't think I would. Yes and I remember one time when there was a board and I wrote stuff on the board and I told people what to do

T You were the director.

Student 5 Yes. I remember that.

This student freely admitted that in order to remember things for a long time, she needed to write things down. Here then is a case where the role play activity was recalled but the target science was at best only scantly remembered. Importantly for this student, the role play activity seemed to aid her understanding at the time, enabling her to write down what was happening.

T Do you remember that it helped you at the time or not?

Student 5 Yes, I think it did at the time and then because afterwards I went and wrote it down – That helped-I need to write things down to remember them for a long time but I think it was good to be able to see something and to be involved so that – like I can remember I did this and this person did this and yes it helped to be able to do that instead of just reading from the text book.

When asked if she could comment about the level of student engagement, Student 5 identified a number of pertinent features.

- The reluctance on the part of some students to be involved, (as did Georgiana see above).
- The leadership/controlling role taken on by some students.
- That discourse between students was an important part of working out what to do.
- That those who were discussing may have learnt more from the activity than those who were not.
- That students who did not say much were still involved.
- That the group nature of the activity helped to make it enjoyable.

Student 5 I think most people were (focussed) – I think some people weren't 'cause they sort of stood off to the side and didn't really want to be involved but I think because they were focused they were involved and they – like people were saying like do this and do this which showed they were thinking about it and that they wanted to work it out and be a part of it and so there was lots of discussion between people and people going, "you stand here and I'll stand here" and – but then there were a couple of people that sort of didn't say anything and they just stood there – but I guess they probably were focused they just didn't know what to say.

I think the people that had the discussion would have got a lot out of it because they were involved in talking about how it should work and so while they were discussing it they were learning.

T Did you like doing it?

Student 5 Yes I did

T Yes – why did you like it?

Student 5 Oh because it helped me to understand – and because I like doing group activities. Most of the time. Sometimes I like to work by myself but in science I like to do group activities.

In answering a question about the use of technical terms, Student 5 recalled that the input (though minimal) from the teacher (me), provided stimulus for student discussion during the activity. This co-constructive role was an important aspect in helping students to focus on the terms of the target science. It became a specific design feature of the teaching experiment and was used in all subsequent episodes of the intervention.

T Do you think the activities made you use the language of science?

Student 5 I think sometimes but not all the time – because sometimes I noticed that when we were doing it you would say "Oh what does this represent" and really bring it out of us rather than us talking about it by ourselves. But sometimes because we had to say "Oh this is going to represent an electron and you're going to represent copper and you're going to represent – then those are scientific terms and we will use those while we were doing it

Of interest here, is that at this point in the interview Student 5 began to mention chemical aspects of the role play. It seemed that talking about the role play activity stimulated her memory of the science concepts that were the learning targets 18 months earlier. This led into the next content specific question which then yielded even more specific details from the student, identifying that she still could map relevant features of the role play with features from the target science concepts.

T Do you think it helped you understand the difference between things like atoms and ions and electrons and molecules?

Student 5 Yes I think so, yes I think because we used them in different ways like this is an atom and then we made molecules out of the atoms – and represented electrons with books so we could see there are electrons and they joined these molecules together.

The questionnaire and interviews showed that the students could remember the role play activities and at least some relevant target concepts, for a long time (18 months).

In addition, the activity was considered an enjoyable and positive learning experience by the students. This is reflected in the students' ratings (numbers as answers to the questions). The overall average of ratings for all questions was 4.1 (5 being the most positive value).

Their written comments to the last question (9):

Please write a brief comment about the usefulness of the activity in helping you learn the science you were studying.

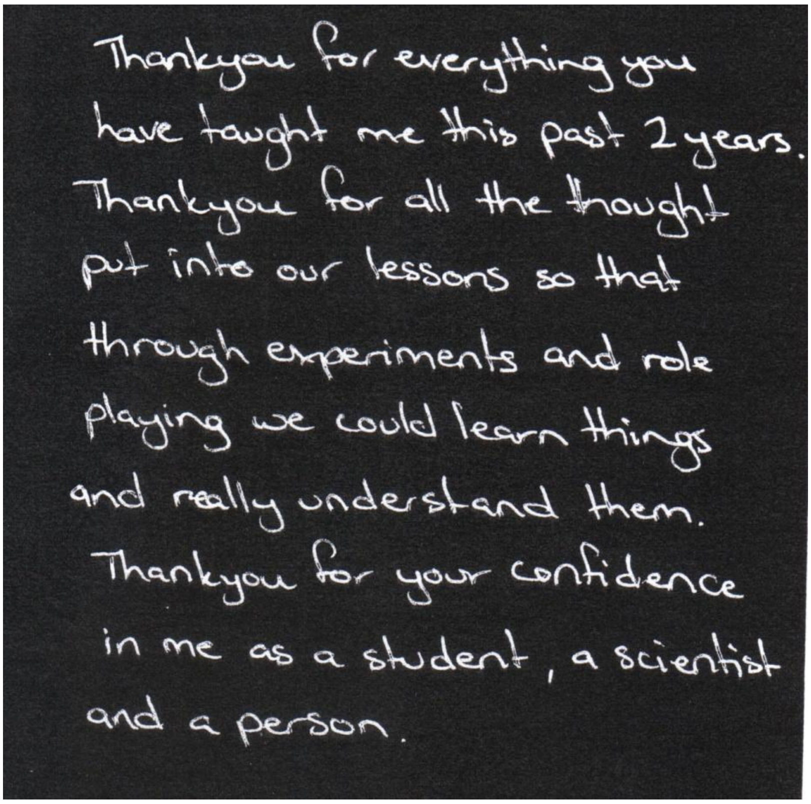
shown below, identify that the students valued the activity as a learning experience.

Jacinta The activity was helpful as it helped me to picture what was happening better in my mind and thus I was able to understand it better

Ian	Because it’s a different teaching method I will remember that science example for a long time.
Bob	It helped me understand the concept but the detail of the concept did not stick in my head.
Georgiana	This was a good alternative to reading a text book. Then writing in your own word allowed a better understanding. Very useful for someone who learns by doing.
Student 5	I thought this activity was very useful as it allowed me to be involved in an activity where as a group we represented atoms/molecules/bonds and so helped me to remember how things worked. Also, it helped me to be able to write a description about what was happening in the reaction.

This positive sentiment was also apparent in their enthusiasm and positive comments during the activity 18 months earlier and again during the interviews.

For one of these students (Student 5) there was a lasting impression that the role play activities were significant in facilitating her learning of science. This is highlighted in what she wrote on a thankyou card presented on completion of her course (Fig. 4.3.3).



Thankyou for everything you
have taught me this past 2 years.
Thankyou for all the thought
put into our lessons so that
through experiments and role
playing we could learn things
and really understand them.
Thankyou for your confidence
in me as a student, a scientist
and a person.

Fig. 4.3.3 Thankyou card – Student artefact – SA-230904-S5

4.4 Reflection of light

Year 11 Physics

Vignette Two

This vignette describes and elaborates on data from three episodes of the intervention. In these episodes the intervention was a role play development activity used to help students understand the behaviour of light. In this sense the intervention was applied as a heuristic activity.

The intervention was conducted with three Year 11 Physics classes in 2005, 2006, and with modifications in 2007. In addition, in 2007, another teacher from the same school trialled the intervention with her class and provided feedback on the experience. The students were 16 to 17 years of age and came from a variety of cultural backgrounds. In the classroom, students sat at tables, clustered to accommodate up to six students. The seating was arranged to facilitate discussion. Role play practice occurred in the classroom, the adjoining laboratory and in open area outside of the classroom.

As part of the Physics unit, students were expected to:

- Perform first hand investigations and construct diagrams, about reflection.
- Be able to describe and apply the law of reflection and explain the effect of reflection from a plane surface.
- Explain that refraction is related to the velocities of a wave in different media and relate this to changes in direction.
- Identify conditions necessary for total internal reflection.
- Present information using ray diagrams to show the path of waves reflected from plane surfaces. (Physics Syllabus BOS, 2002, p. 26)

The role play activity was designed to facilitate the students' understanding about:

- The reflection of light from glass and mirror surfaces;
- The law of reflection;

- The law of refraction; and
- How light can behave inside a glass medium;

with the overall purpose of leading them towards an understanding of internal reflection that would later be applied when learning about communication using optical fibres.

Background

Prior to the intervention, students learned about the refraction of light. During the lessons on refraction, I introduced the classes to role play, by asking them to perform a role play that I had designed. The role play introduced students to role play methods such as; using themselves to represent features of a scientific model; walking through a dynamic process as a group; using inanimate features of their surroundings in the role play; and mapping features of the role play to targeted science concepts.

This initial activity also tested the effectiveness of using role play with the students involved and helped to show them that role play was indeed a method that could be used to facilitate their learning. Based on the relative success of these lessons, the intervention was applied in the following week.

Applying the intervention, involved using the three phases of the FAR guide (Treagust, 1995); focus, action and reflection. Each of these is described below for the 2005 and 2006 groups. The 2007 group is reported separately because, while the overall process was essentially the same, the lead-up lessons were different, producing noticeable differences in what the students demonstrated.

Focus stage – Seeing the image and discussing observations in groups

In the lead up or focus stage of this activity, the students in each class were given a homework task. The task required them to observe and sketch the reflection from the flame of a candle (or match) as seen in a mirror when viewed from an oblique angle in a darkened room (see Figure 4.1). It was expected that this would spark interest in the phenomenon; allow students to identify that the physics they were studying had real world applications; and realise that reflection was more complex than perhaps they had previously imagined.

Fig. 4.4.1 Candle and its reflection in a mirror. (Photo taken by author)

Fig. 4.4.2 below, drawn by one of the students, is typical of sketches drawn by the students. It clearly shows that students could identify that multiple images were formed.

As part of the homework exercise, students were also challenged to consider the cause of what they saw and to be ready to discuss their ideas in class during the next lesson.

In the next lesson, students were asked to form into groups of about six students, to discuss their ideas about how the multiple images of the flame had been produced and to decide how to present their explanations in the form of a role play.

Students in the 2005 and 2006 episodes had participated in a teacher directed role play approximately one week prior to the intervention when learning about the concept of the refraction of light as it enters a medium. However, this intervention was the first time each of these classes had been required to develop their own Physics role play.

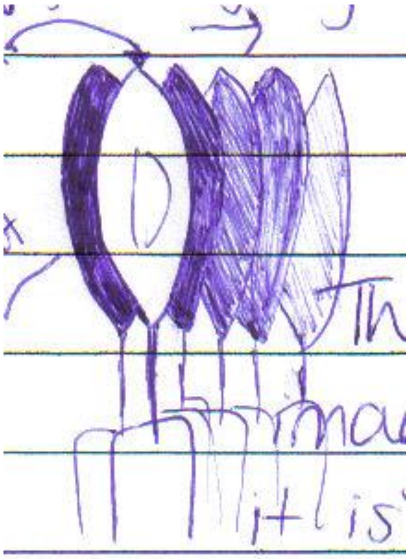


Fig. 4.4.2 Student sketch of the reflection from a candle as seen from an angle in a mirror located in a dark room (SA180506RP-11Ph).

To discuss their ideas out of earshot from each other, the groups spread themselves apart using the adjoining laboratory, the classroom and the picnic table just outside the class room. During this time, I circulated among the groups to listen to their ideas and provide encouragement.

The students were fascinated by the multiple images observed, however, they seemed baffled and while there was some discussion, none of the groups offered an accurate explanation. Relating to constructivist theory, they could not readily access adequate prior knowledge/schema to explain what they saw.

To encourage the students' thinking in a suitable direction I asked each group to tell me what a normal household mirror was like – that is, to describe its structure. Most students had some ideas and after only about one minute of discussion, members of each group agreed that a mirror had thickness and a silver reflective surface on the back. Adding to their descriptions of a mirror, I explained to all groups, that a typical household mirror is manufactured by condensing aluminium vapour onto one surface of thick plate glass and then painting the back to protect the aluminium from being damaged. I also hinted that they consider how the structure of the mirror might help to create the images they saw. Helping the students to identify relevant prior knowledge, created an enthusiastic response and they spontaneously started developing ideas. This led into the action stage of the intervention.

Action stage-Analogical modelling of the reflection

Construction of their role play analogies occurred through group discussion, drawing diagrams and attempting to represent ideas by walking them through.

In each of the 2005 and 2006 teaching episodes, the role play analogies were initially developed in or near the classroom. Performance and revision of the role plays occurred in an open concreted area at the front of the college grounds. Students opted to use brick lines and patterns in the concrete to represent the mirror. This was not unexpected. A week earlier, a brick line had been used to represent the boundary between glass and air in their performance of a given role play about the refraction of light.

During the 2006 episode I used a mobile phone with an inbuilt camera to capture 22 one minute videos (V150406-11Ph-RP-Internal reflection of light) while the students were working in groups. On the next two pages is a series of annotated screen shots captured from several of the short videos. These are provided to highlight several aspects of the processes through which the students worked. The reference for each video which includes the time, shown under each screen shot, is a unique code. The codes are automatically assigned to the video by the software on the mobile phone. These times show that the images were taken over a period of about half an hour. During this time, the students progressed from a limited (if any) understanding to being able to demonstrate high level understanding about the observed reflection phenomenon The screen shots (V2-V11) depict the progress made by one of the groups. Similar progress was, however, made by all three groups during the lesson. Codes beginning with the letter S followed by one or more letters have been used to distinguish the students in transcript excepts from these videos.

Screenshot (V1) was taken from a video of a different group and has been included because it shows a diagram (similar to Fig. 4.4.2 above) from the homework task-observing and sketching the reflection of a candle. Each of the groups typically referred to and pointed at their diagrams when discussing their ideas.

Screenshot (V2) is the first attempt by the group at showing what might be happening with the light to form the multiple images. The multiple light rays and single reflecting surface show that the students have some ideas about reflection. Despite having time over night, to think about what they observed, their collective thoughts did not result in accurate explanations (see Fig. 4.4.3 (V2)).

Fig. 4.4.3 (V1) V0406_141549(8:40 am) Observation diagram (Homework)

(V2) V0406_135755(8:32 am) A first attempt at an explanation

However, while they could not adequately explain the multiple images all six students were engaged in the task, hypothesising and discussing their ideas. The following dialogue from this one minute video (V2) highlights the fervour of four of the six students to present what their group thought was happening.

SG [Pointing to their diagram] What we think is happening is that the light spreads out as it goes out and as it hits the reflective surface it spreads out even more. So as it hits on an angle it becomes weaker as you look into it because -

SAb The surface will be there. [pointing]

SAm The light is - the side you're looking at is close to – looking at an angle – [pointing] brighter – the other side.

SAb Yes so the wave is not as concentrate; the light wave.

Most [General laughter]

SG Pathetic [laughing]

SAb Well, I just don't like that I dont' know what I'm talking about.

SG Yes-That's what we have so far.

SJ And it gets lighter because it's the same as when you-

SAm [Interrupting] because you're at an angle

SJ Yes, and when it gets lighter – that's because the light's travelling further to hit it.

These students were then asked to consider the structure of a mirror. Screenshots (V3) and (V4) are from the next one minute video. Almost immediately they began sketching new diagrams and discussing new ideas. The images show two different students redrawing to show their emerging ideas. SAm had a go and SG took over.

Fig. 4.4.3 (V3) V0406_140430 (8:33 am) (V4) V0406_140430 (8:33 am)
Sketching, describing and modifying initial ideas based on new information – their knowledge about the structure of a mirror.

The students were left to work on their new ideas and within a few minutes they had come up with new diagrams; Screen shots (V5) and (V6); and ideas about how they would role play them.

(V5) shows SAb showing the light being internally reflected from the inside front surface of the mirror glass. (V6) shows SG further refining these ideas. He added the inital reflection from the front surface of the mirror glass, identifying the first faint image. He also drew the first main reflection from the miror in a thicker line to indicate more light being reflected. This accurately explained the stronger main (second) image in the series of rflections.

Fig. 4.4.3 (V5) V0406_141854 (8:41 am) *(V6) V0406_142013 (8:42 am)*

Refining ideas while considering their role play analogy

These much more scientifically plausible ideas resulted from discussions between the students and multiple iterations of their ideas drawn on paper and then on a whiteboard.

The three groups were asked to move to an open, concreated area at the front of the school to work on their role play ideas.

SG used his shoes (V7) to represent the candle and the eye. The group decided to use the brick lines as reflective surfaces and a darker concrete area between them as the thickness of the mirror (V8). Discussion between the students resulted in several minor modifications to their role play before it was performed for the rest of the class.

Fig. 4.4.3 (V7) V0406_143241 (8:48 am)
Positioning the candle (shoe)

(V8) V040_143821 (8:51 am)
Pointing to the brick line (the reflective rear surface of the mirror)

Fig. 4.4.3 (V9) V040_143821 (8:51 am)
Walking the path taken by light.

(V10) V0406_144821 (8:51 am)
Other groups watching the role play

Students had about five minutes to work on their role plays before performing them in turn, to show their ideas to the other groups (V8), (V9) and (V10). While performing for the others (and me) the students walked through their role play ideas – speaking aloud to let others know what they were doing. The students had been encouraged to; identify analogical aspects of each role play that they might be able to use to improve their own and; to identify any critical errors that might be apparent. They appeared to watch carefully (V10) as the performances were made.

After only a brief discussion, this group decided they could show their ideas better if they had more students and so the whole class agreed to perform the role play under their direction.

Fig. 4.4.3 (V11) V0412_105932 (8:56 am)
All members of the class joining in

(V12) V0412_1010056 (8:57 am)
A second attempt with the whole class
Single file to refine the first attempt

On the first attempt (V11) members who generated the role play analogy, quickly identified mistakes (actions that did not match their ideas) made by other members of the class. For example, they had correctly hypothesised that the multiple images resulted from multiple reflections of the same beam of light. For this reason it was important in their role play analogy that all students walked from, or at least passed over, the first shoe which represented the candle and hence the source of light. It was also important that they all then either passed through or were reflected from the first point on the mirror. As soon as it was noticed that some students moved directly to multiple points on the mirror (along the first row of bricks) directly from the candle (shoe), SG called out, “We all have to go through the first point” (V0412_105932, 8:56 am).

The students avoided this mismatch, in a second run through by ensuring the whole class walked across the candle (shoe) in single file (V12). Only the first person reflected from the first point on the mirror (brick line) and the rest walked through to begin a sequence showing the multiple reflections and multiple images.

The sequence of screen shots compiled for this group covers a time period of just 26 minutes, showing that the students were able to develop, show, modify and share their ideas quickly.

During this time two other groups simultaneously worked on their own role play analogies. Each group developed role play analogies that showed appropriate understanding of internal reflection. There were interesting variations on how the details of their observations and prior knowledge were displayed. For example, the group described above, had a good understanding of refraction as a velocity phenomenon. They were careful to include a change of direction as they walked into and out of the area designated as glass; and they walked slowly or ran, to represent changes in the speed of light in the different media.

A very multicultural group, made up from six male students whose skin colour varied in darkness, opted to use the differences in their skin toning to represent the variation in image brightness. They explained that the differences in image brightness was caused by there being less and less light to produce an image because “half of the light” (student comment 2006) available each time was internally reflected.

Reflection phase-Performing and discussing the role plays

During the *reflection* phase of the intervention, class discussion about how each group had represented various aspects of their model led to identification of ideas that were more consistent with science and those that were not. Asking the students questions such as: “If you were to include good ideas from other groups in your role play, how would it change?” stimulated further discussion and led students to modify and refine their role plays. Ideas that were inconsistent with correct science were discredited and discarded. One group for example, hypothesised that the reduction in image brightness with distance from the primary reflection (see Fig. 4.4.1), was because the light lost energy each time it was reflected. They represented this in their role play by having the people representing successive reflection, walk more and more slowly. This flagged a possible misconception that a reduction in intensity meant that the light slowed down. For the sake of what Hancock and Onsman, (2005, p. 2) call, “essential integrity” (see Chapter 2), this needed to be challenged.

The discussions during the final phase of the intervention presented further opportunities to identify students’ individual conceptual issues and provide support that facilitated the discarding of personal misconceptions in favour of more scientifically acceptable ideas. If necessary, students then worked with their groups again to further modify/rectify their role play analogy. When they could not adequately show all that they wanted with only the members of their small group, they enlisted the support of additional students from the other groups. Interestingly, the other students were typically easily able to play a role in a role play analogy that was different from their own. This gave them another perspective from which to view the science concepts being studied.

A Final cycle

In March 2007, I decided to conduct a final episode in the teaching experiment-using the reflection role play. I wanted to see the impact of not doing the teacher directed refraction role play first. I wanted to observe what the students would invent and plan to do on their own volition. That is, without having first had an experience in which I directed how they could role play various aspects to model how light might behave when it strikes a glass surface. I also wanted to provide an opportunity for a newly appointed, yet experienced teacher who had not previously taught Physics, to observe and code the lesson before considering using the strategy with her own class.

The NSW quality teaching and learning coding scale (DET, 2003) is a well validated instrument “designed to be used when observing teaching practice” both in and out of the classroom (Ladwig, 2005, p. 75); and has been widely used in Australian schools. Furthermore, both the observing teacher and I were familiar with the instrument and had used it frequently.

Once completed, the coding record provided a base for further discussion. The coding sheets provide a 1-5 Likert scale based on the SOLO taxonomy (Biggs & Moore, 1993), for 18 criteria. Each of the numbered boxes contains a statement describing observable student outcomes. While these outcomes cover a broad spectrum of possible observations, several aspects of the teacher’s observations are relevant to, and provide support for, the trustworthiness of this teaching experiment (see Peer Observations below).

During the *Focus* phase of this episode of the intervention, students were asked to view the image of a candle at home, to sketch it and to think about how the image might have formed. During the *Action* phase, I encouraged each of two groups of six male students to develop role play analogies to explain what they thought was happening. This time however, when students said or implied they had no ideas – I walked them out to the same concrete area where previous students had worked and encouraged them to work it out together. I used a small digital video camera to record some of their actions and conversations. The observing teacher moved between the groups, watching from a short distance (about 3 metres – see Fig. 4.4.4 below) and coded the lesson.

Fig. 4.4.4   Group One being observed by another teacher.

After a short while (approximately 5 minutes) I asked each group to tell me what they were thinking. It was evident from the data that none of them had recalled the structure of a mirror and they were unable to identify an appropriate cause for the multiple images.

Each group had invented analogies in attempting to explain the phenomenon. All of these analogies suggested incorrect alternative conceptions. Excerpt from the video (V170307-11Ph-RP –Reflection) (see below), identify that their ideas were based on the students prior knowledge; such as multiple images formed when a person stands between two mirrors. Both groups had similarly and incorrectly hypothesised, that the light returned to the flame and bounced from it repeatedly to produce the multiple flame images. A student in Group One suggested that "the fumes [from the burning] make it [the light] reflect". Another student in Group One immediately came up with an idea related to his observation on hot days, that "the ground looks like it is shaking because of the heat" and suggested that "the heat can change the light". Two other students in that group immediately responded with acknowledging comments "heat wave" and "you can see the heat coming up". A student in Group Two (Fig. 4.4.6 below) explained that "the flame uses the carbon dioxide to create an artificial atmosphere to reflect back the light".

Based on the observation that the images were more easily seen from an angle, both groups identified that the multiple images were probably present even when the person was standing in front of the flame. Reasons given for why the multiple images were not visible from directly in front of the mirror included; "the images overlapped", hence they would be seen as one; and "the light was too bright when looking straight at it", "the images were bouncing back into the flame and it's so bright you can't see it".

Explanations were also being created for why the images were visible at an angle. Fig. 4.4.5 below shows one of the students in Group One using his thumb as the flame and looking from the side on position, indicating with his other hand where he thought the light was travelling to form the images.

Fig. 4.4.5 The student on the right is demonstrating that multiple flame images can only be seen from a side-on position. (V170307-11Ph-RP –Reflection)

One student attempted to relate the phenomenon to the curvature of the Earth however, the puzzled looks on the faces of the other group members showed that his peers did not grasp what he was saying. In a second attempt he said “it’s like sound waves – you know how it spreads out” and he used one of the other students and hand gestures to show where he thought the light might travel. This was identifiably more acceptable to the group as several members exclaimed their agreement.

During these discussions in both groups, students were taking a leading role while others interjected when they had something to contribute. Fig. 4.4.6 below shows a series of four screen shots of Group 2’s initial discussions. The first three shots show one of the students explaining his ideas and moving other group members into possible role play positions. The fourth shot shows a point in the discussion where, as suggested by Onsman (2005), the students had accepted this first idea-that perhaps seemed to make sense to them. Several students were talking and pointing at the same time while they were working out who would be what in their role play analogy.

Fig. 4.4.6 Group Two (2007) Working on the idea that light bounces back and forth between a mirror and a layer of “artificial atmosphere” composed of carbon dioxide that surround the flame.(Student comment-V170307-11Ph-RP –Reflection)

The students were happily engaged in thinking about how light could form the images they had seen. During the discussions, there was considerable laughter as ideas were offered and rejected. They were working hard and their mental gymnastics became visible to all as they tried to explain their ideas to each other and to me.

Each group had recognised that multiple reflections must somehow be involved in the image formation and had invented some ways to role play their ideas. This beginning stage of the intervention showed me that none of their ideas were referenced to the concept of partial internal reflection of light from the front surface of the mirror.

After listening to several explanations, I asked each group a single question. “What is a mirror?” At least one student in each group was able to answer this question. As answers were being uttered by some students, spontaneous discussion began. In group Two, one student remembered an electronics lesson from two years earlier at his former school; “I remember once in electronics we peeled a sheet off a mirror”. (Fig. 4.4.7 (a)) When I asked how thick the glass was, this student held his fingers up to demonstrate (see Fig. 4.4.7 (b)).

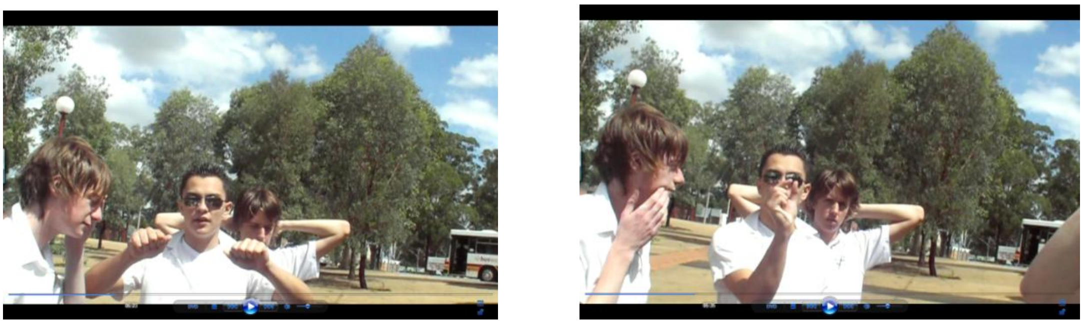


Fig. 4.4.7 (a) Demonstrating the removal of a sheet of aluminium from the back of a mirror and (b) showing the thickness of the mirror’s glass

The student who had first thought of the artificial atmosphere around the candle acting like a second mirror, reacted with “Ah-yes – light bounces back between the silver and the glass”. Another student enthusiastically said, “Remember Joseph had a laser and he put it through the fish tank”. One of the others also remembered that moment, earlier in the year, in the laboratory and said “Yes-light went everywhere – there were about five dots”. And then yet another of the students intuitively asked, “So you wouldn’t see it (the multiple reflections) if it (the mirror) was stainless steel?” These students had, in a matter of seconds, rejected most of their previous ideas. They immediately began developing more scientifically accurate models for what they had seen and then quickly modified their role play analogy to suit.

During the next 10 minutes I visited the groups, watching and listening to what they had to say. Occasionally, I would asked a question such as; “How would you show that?” and the students had a brief discussion before inventing a way to show that particular aspect. Rarely, I offered a solution to an identified problem such as, “We don’t have enough people” (to be the mirror, the light and the images) (Group Two comment). To my response - “Could you use the bricks here as the mirror?” one of the students said humorously, “Yes that’s what I was thinking”. Then with a quiet hint of collective agreement (“Oh Yes”), the group immediately went to the spot and enthusiastically continued to develop their ideas.

After several minutes during which students developed and refined their ideas, the two groups performed and discussed their role plays as had been done in the episodes of the previous two years.

Peer Observations

As stated above, another teacher observed and coded the 2007 reflection role play lesson. She identified the following aspects of the lesson by circling them on the coding sheets (TA-060307-11Ph-RP)

1. Most of the content knowledge of the lesson is deep. Sustained focus on central concepts or ideas is occasionally interrupted by superficial or unrelated ideas or concepts.
2. Most students provide information, arguments or reasoning that demonstrates deep understanding for a substantial portion of the lesson.
3. Knowledge is seen as socially constructed, with multiple and/or conflicting interpretations presented and explored to an extent that a judgement is made about the appropriateness of an interpretation in a given context.
4. Students primarily demonstrate routine lower order thinking a good share of the lesson. There is a least one significant question or activity in which most students perform some higher-order thinking.

5. Substantive communication, with sustained interactions, occurs throughout the lesson, with teachers and/or students scaffolding the communication.
6. No explicit statements [by the teacher] regarding the quality of the work are made. Only technical and procedural criteria are made explicit.
7. Serious engagement. All students are deeply involved, almost all of the time, in pursuing the substance of the lesson.
8. All students participate in challenging work throughout the lesson. They are encouraged (explicitly or through lesson processes) to try hard and to take risks and are recognised for doing so.
9. Social support is strong. Supportive behaviours or comments from students and the teacher are directed at all students, including soliciting and valuing the contributions of all.
10. All students, almost all of the time, demonstrate autonomy and initiative in regulating their own behaviour and the lesson proceeds without interruption.
11. High Student direction. Students determine many significant aspects of the lesson either independent of, or dependent on, teacher approval.
12. Students' background knowledge is consistently incorporated into the lesson, and there is substantial connection to out-of-school background knowledge.
13. Students from all groups are included in all aspects of the lesson.
14. Students recognise and explore connections between classroom knowledge and situations outside of the classroom in ways that create personal meaning and highlight the significance of the knowledge.
15. Narrative is used for a significant portion of the lesson to enhance the significance of the substance of the lesson.

These observations support my own observations and videotape data that show students were actively engaged, working together to develop and show a scientific understanding of a phenomenon with minimal input from their teacher (me).

Every student who participated in the role play episodes over the three year period was able, at the completion of the episode, to produce a ray diagram and an explanation that demonstrated understanding of the concepts of internal and partial reflection. Many of the diagrams drawn by students from the 2005 and 2006 classes, also accounted for changing direction of the light (refraction) as the light entered and left the glass of the mirror, (see, for example, Fig 4.4.8 (d) below). Hence, as a teaching strategy, the intervention successfully allowed students to meet particular learning outcomes of the Physics course.

As mentioned earlier, the 2007 group did not have the same sequence of lessons as those in previous years. Expectedly, they did not refer to or show refraction during their role plays and their diagrams (see Fig 4.4.8 (c) below) did not show refraction. Instead, they typically referred to the light passing through the glass or out of the glass. This highlights that students can only call upon what they already know when developing their own explanations for new phenomenon and supports the constructivist view of learning taken in this teaching experiment.

Transferability

In educational research, Geelan (2003) identified the worth of teachers researching teaching, and elucidated the need for that research to be useful to other teachers. In this vein, it would be of some use to identify a measure of transferability in the intervention of this teaching experiment. Transferability is shown if an intervention applied in one situation provides similar findings in another (see Section 3.7.6). The reflection episodes provided opportunities to put transferability to the test in three ways. Firstly, I used the intervention with three different classes over a three year period and so an overall perspective can be gained by comparing those classes. Secondly, each of these classes worked in smaller individual groups. This allows comparison between groups within the same class. Thirdly, the teacher who observed the 2007 lesson repeated the intervention with her own class (Class B) in the following week. Triangulating data from these four classes provides a way to check similarities and differences among the findings. It also helps to identify aspects of and issues in the transferability of the intervention and assists in defending the trustworthiness of the research.

In my three classes all groups needed support to consider the structure of a mirror in seeking an explanation for the reflection phenomenon. After that support was provided each group was able to produce a role play that identified three key concepts: (i) partial reflection from the front glass surface as light entered the glass, (ii) complete reflection from the back mirror surface and (iii) partial internal reflection of light back into the glass from the internal front surface, as some light was leaving to produce an image.

In narrating their role plays, each group of students spoke about the reduction in light intensity of successive reflections and all but two of the four groups (in the 2006 cohort), attempted to represent this observation in their role plays.

For the first two cycles (2005 & 2006), the teacher generated refraction analogy provided students with a model, from which they could and did extract attributes to use in producing their own reflection analogies. In the third cycle (2007), students displayed that they could develop their own analogies despite not having experienced the refraction role play. As was found by Roth (1995), however, even good students "construct propositions which are at odds with canonical science" (p. 276). Here, some students' initial ideas included bizarre and scientifically inaccurate relational structures. By listening to their conversations, watching their actions and asking simple, supportive, yet pertinent questions, it was possible to stimulate their thinking and direct it in more appropriate directions.

All groups of students were able to identify areas of mismatch in their own ideas and this helped to promote productive discussion during which they readily rejected analogies that they identify as being inadequate. In addition, the 2007 students readily accepted suggestions, such as using features of their surrounding and quickly incorporated them into their role plays in similar ways to the earlier groups.

Student responses to examination questions provided opportunities to make comparisons and generalisations based on the students' individual understanding. In the 2006 Year 11 final exam, I set a question that asked students to describe how total internal reflection was used in optical fibre technology. This was the follow-on concept that the role play activities supported. In answering the question, the majority of students were able to recall and present accurate information. Many (66%) students presented good diagrams which showed a series of internal reflections, to support their descriptions. As this exam was six months after the role play lessons in class, the responses indicated that the concept of total internal reflection in optical fibres was well understood and retained by most students.

Further similarity of findings over the three years can be seen in the diagrams drawn by students in each of the four classes, several weeks after the application of the intervention. All of the students drew their diagrams under test conditions as part of their answers to a specific question. The 2006 group and the two groups in 2007 completed the same questions (see Appendix 6) presented as an unannounced writing task. Both of the classes in 2007 completed the writing task on the same day. For Class B, the task was five weeks after the intervention and for Class A it was six weeks after the intervention. The task required student to explain scientifically, why a person saw multiple images of a candle flame in a mirror reflection. For these three classes, a second question asked the students to explain how the physics involved in forming the candle images was significant to the development of the structure of optical fibres. This second question was asked because the work had been covered in the previous weeks and pedagogically, the concepts learned during the reflection role play activities were designed to facilitate their subsequent learning about optical fibre technology.

All of the 12 students in Class B drew light ray diagrams in their answers showing reflection inside the mirror glass. Only two of these students, however, had excellent explanations and good diagrams, which included the initial reflection from the front surface of the mirror glass and light escaping the glass after each successive internal reflection (see Fig 4.4.8 (a)). Five of the students represented total internal reflection in the thickness of the mirror. That is, with light entering the mirror, but no light escaping (see Fig. 4.4.8 (b)). Hence their diagrams did not account for the multiple images.

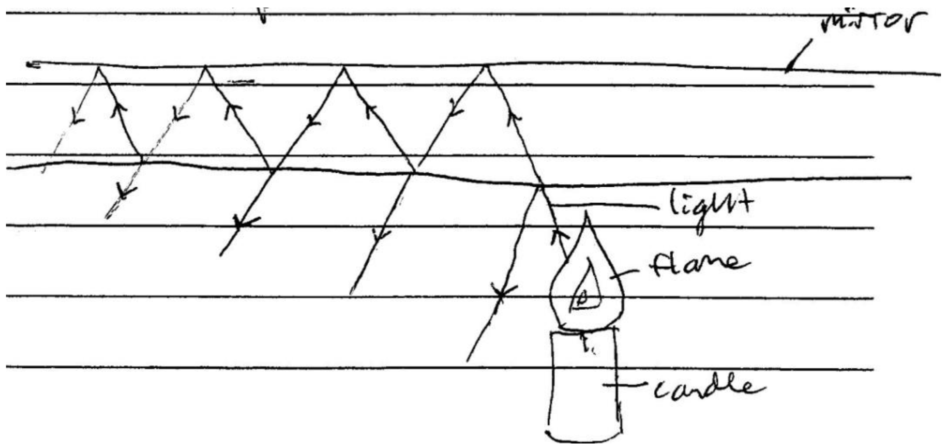


Fig. 4.4.8 (a) A correct diagram drawn as part of a response by a student in Class B (2007), about how multiple images are formed in a mirror.

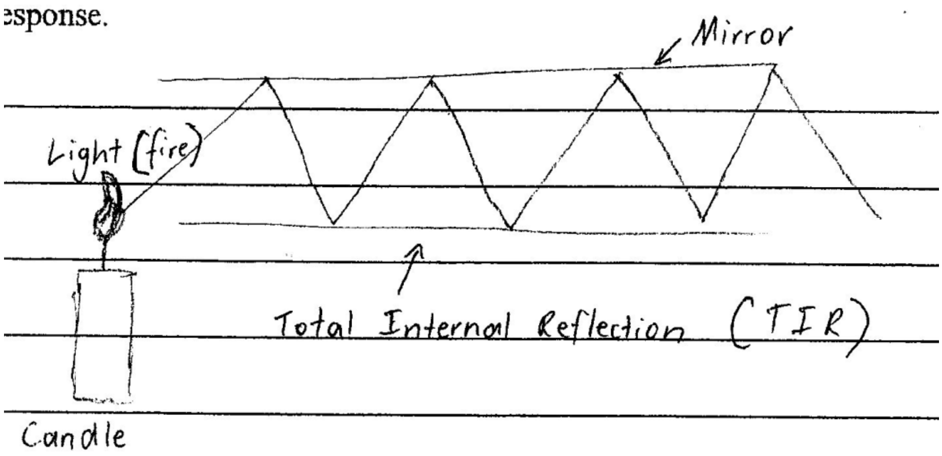


Fig. 4.4.8 (b) A partially correct diagram drawn as part of a response by a student in Class B (2007), about how multiple images are formed in a mirror.

A greater proportion of the students in the Class A produced diagrams that more correctly showed the path taken by the light in forming the observed multiple images. For example, 6 of the 12 students correctly showed the first reflection from the front of the glass. Fig. 4.4.8 (c) is one of these diagrams.

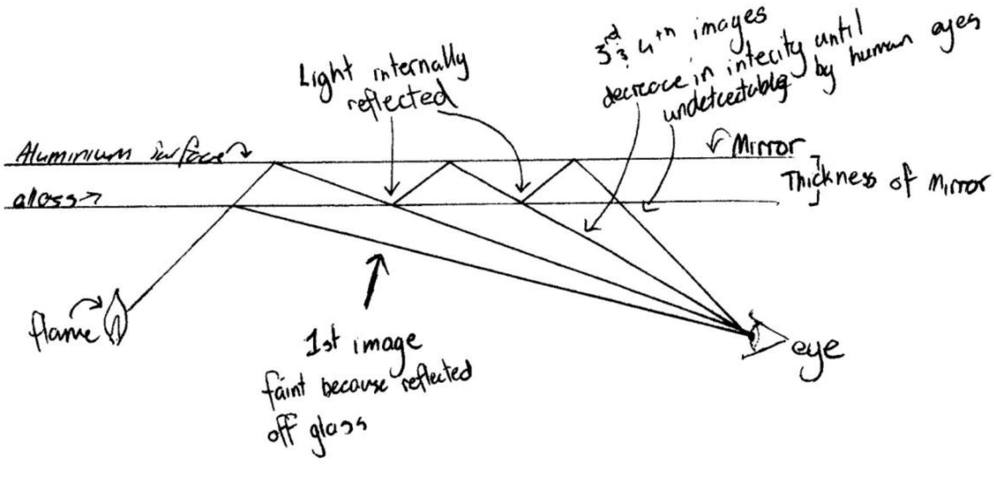


Fig. 4.4.8 (c) Drawing completed during under test conditions showing the path of light when candle light strike a mirror forming multiple images (Class A-2007) (notice – no refraction of light rays).

The 2006 students who completed the same questions under similar conditions performed even better with 13 of the 17 students producing good light ray diagrams which included the first reflection from the glass (Fig 4.4.8 (d)).

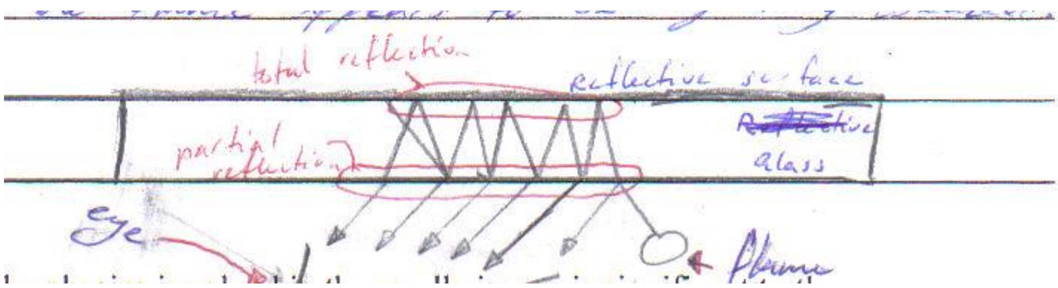


Fig. 4.4.8(d) *Student's drawing completed under test conditions (2006) showing the path of light when candle light strike a mirror forming multiple images. (SA190506RP-11Ph-G)*

Similar diagrams were drawn by students in the 2005 class (Fig 4.4.8 (e)) when they were asked to explain how the images were formed.

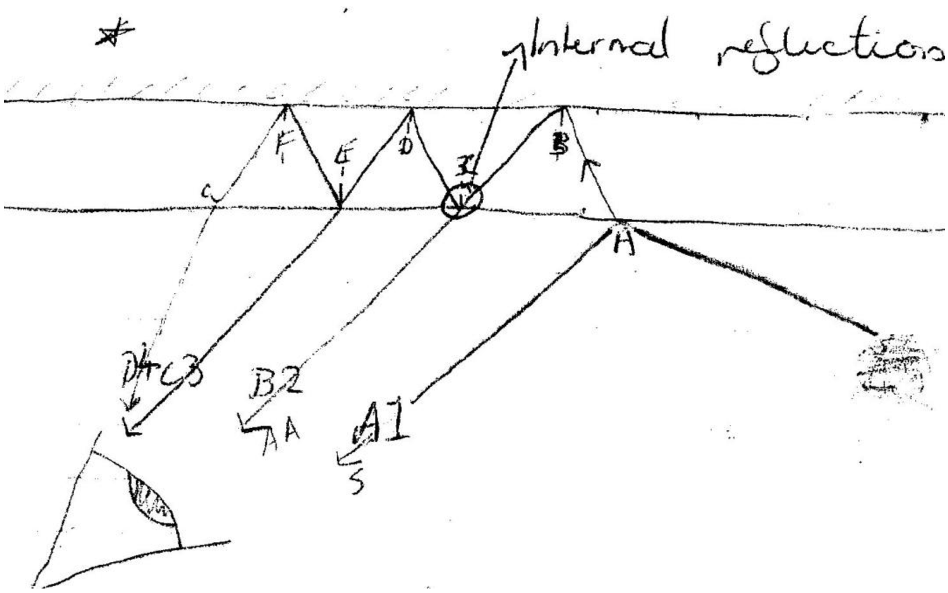


Fig. 4.4.8 (e) *Student diagram (2005) drawn as part of an answer to the question "Show how Come?" referring to the multiple images. (SA100305-11Ph-RP-E)*

Despite inaccuracies shown by some of the students in their diagrams for the question asking for an explanation of the multiple images in the candle reflection (Fig. 4.4.8 (f)), these students were typically still able to provide reasonable answers and/or diagrams to the question about the physics involved in optical fibres (Fig. 4.4.8 (g)).

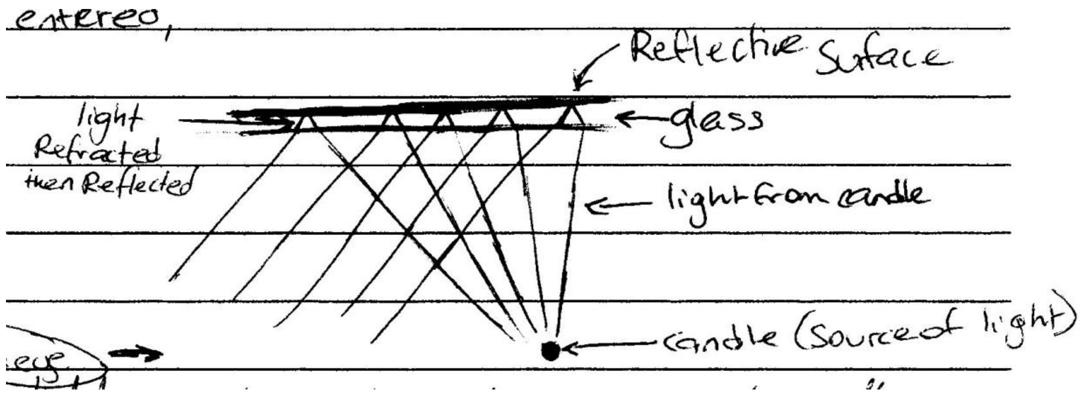


Fig.4.4.8 (f) *Student's incorrect diagram in his partially correct answer to explain the multiple images (SA180506-11Ph-RP – AE-H)*

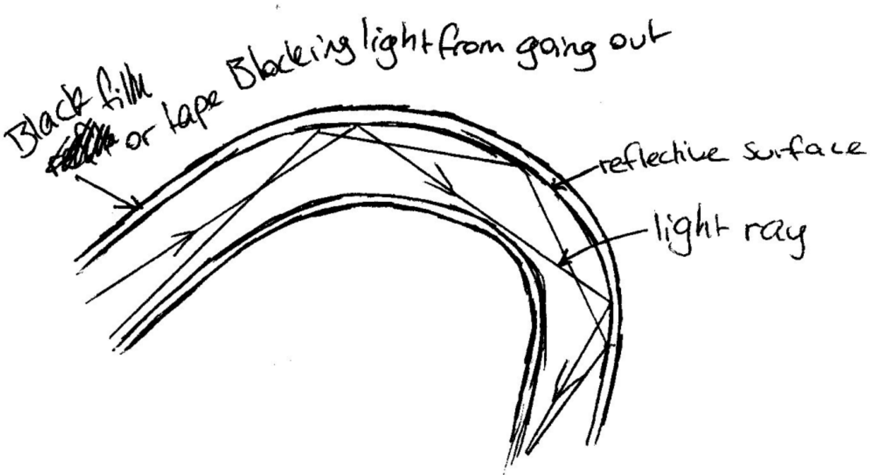


Fig. 4.4.8 (g) *Student's partially correct diagram in his answer to explain how information is sent through an optical fibre (SA180506-11Ph-RP – AE-H).*

A more formal comparison was made between the levels of understanding of the students in the two 2007 physics classes. To assess the students' levels of understanding a five point Likert scale based on SOLO levels of understanding was used. The answers were graded from excellent (relational) understanding (5) to no apparent understanding (1). Grading of understanding was based on several possible features of their diagrams, including:

- cross sectional ray diagram used in the explanation;
- partial reflection of light from the front glass surface of the mirror;
- total reflection from the back of the mirror;
- partial internal reflection of light from the front inside surface of the glass;
- light escaping from each subsequent reflection from the mirror surface;
- refraction of shown at surfaces;
- multiple reflections related to multiple images;
- indication of reduces image intensity with subsequent reflections; and on
- supportive information provided in the text of their answers.

The results showed that from the majority of students in both classes (11 of 12 in Class A, and 8 of 12 in Class B), were able to display satisfactory understandings of optical fibre technology. In addition, all students in both classes wrote about and drew ray diagrams that correctly showed the direction that reflected light would travel. In this sense, the intervention was a suitable and successful teaching strategy for both classes.

The levels of understanding displayed by the students in class B on the first question were, however, statistically, significantly lower than those for Class A (my class) [($F_{(1,22)} = 8.04$, $P<0.05$)]; (See Table 4.1 below).

A semi-structured interview with the teacher of Class B, she revealed that she had followed a similar procedure to that followed with Class A. She also mentioned several observations about her students that were a reasonable match for what had happened during the intervention for Class A. For example, she said that after completing the homework activity, her students had, in a similar way to students in Class A, displayed little idea about how the multiple images might have been formed. They also developed some strange analogies prior to being asked to consider the structure of a mirror. After being given clues about the structure of a mirror her students too, were able to develop reasonable ideas that included partial reflection from the inner surface of the mirror glass. The teacher indicated that she believed her students understood the concept of internal reflection after the activity and that the “activity made it a lot easier for them later, to understand the concept of total internal reflection” (IT040507RP – Line 131).

Groups	Count	Sum	Average	Variance
Class B	12	38	3.17	1.06
Class A	12	52	4.33	0.97

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.17	1	8.17	8.04	0.0096	4.30
Within Groups	22.33	22	1.02			
Total	30.5	23				

Table 4.1 ANOVA: single factor comparison between two Year 11 Physics classes' understanding of multiple image formation from a candle reflection displayed in written answers completed under test conditions 5/6 weeks after the intervention.

However, what she said in a subsequent lesson may have caused the difference in performance of her class in the writing task. She said, "I could go back and say this is what you saw in the mirror. This is how the multiple images were produced and this is how total internal reflection takes place" (IT040507RP – Line 136). This statement was of particular interest, because it identified an error in what she had told the students. The two situations (mirror and optical fibre) are similar but they are also quite different. By suggesting to her students that the image in the mirror was formed in the *same way* as in an optical fibre, which is only partially correct, it is likely that she misled some of them. This is also suggested by the data. As mentioned earlier, 5 of the 12 students in Class B drew a light ray travelling in the thickness of the mirror with none of the light escaping (see Fig.4.4.8 (b) above); as would have been appropriate, if it had been drawn for an optical fibre.

Harrison and Treagust (1998) identified that, "expert teachers use models to stress and explore important and difficult aspects of a concept, and this is best achieved by oversimplifying the model to emphasise key ideas" (p. 424). In addition, Harrison (2006) urges that "expert and creative teachers carefully plan their analogies and understand the[ir] limits” (p. 62). The teacher of Class B, who was new to co-generating analogies with her students, had not accentuated the differences between the partial reflections in the mirror and the total internal reflections of optical fibres. By oversimplifying too far, she is likely to have misled some of her students.

Factors such as difference in the experience of teachers highlight the difficulty in the replication of qualitative research. During the intervention however, all groups of students in the four classes were able, with help from their teacher, to generate their own role play analogies to show how light reflected in a mirror could produce multiple images. They could also demonstrate in diagrams, correct understanding about the phenomenon immediately afterwards. Several weeks later most students were individually able to remember details of what they had learned. They could show understandings related to the intervention in a new, but similar, situation relating to optical fibre technology that they had studied in the mean time. The data presented in this vignette suggest that the intervention helped students to develop deep understanding. In addition the similar findings for Class B by their teacher, identifies a measure of transferability (see Section 3.7.6) for the intervention; and this supports the trustworthiness of the research.

4.5 Medical Imaging Techniques

Year 12 Physics

Vignette Three

This vignette describes and elaborates on data from a single episode of the intervention. In this episode the intervention was a role play development activity with 11 Year 12 students, in a school in Western Sydney, NSW, Australia. The students were 17-18 years of age and emanated from a range of cultural backgrounds. These students had been involved in a range of analogical activities during their Physics and Chemistry courses. During this activity, the students demonstrated their understanding about a variety of medical imaging techniques studied during their Physics course. The intervention occurred in the last double period lesson (100 minutes) of the course. As a post-festum (Wilbers & Duit, 2006) application, students were in general, demonstrating learning from previous lessons. As the intervention was applied as a revision exercise, it was expected that students would enhance their understanding and increase their ability to remember what they had learnt. Evidence that this had been the case was revealed during the lesson and after an examination, held six weeks later.

Data are presented in this vignette as screen captures from video tapes and excepts from transcripts. In describing the various situations and in analysing the data, letters and numbers have been used to distinguish the students and the teacher. T, refers to me (the teacher/researcher and interviewer). Students are identified by the letter S and a number from 1 to 11.

The students developed and performed role plays to represent understandings about, gamma scans, ultrasound and MRI. The intervention revealed areas of student understanding, and misconceptions that needed correction. It also created opportunities for elaboration about concepts studied during the Physics course.

The Intervention

The students were in good spirits when they arrived at the classroom. This lesson, was not only their final Physics lesson, it was their last lesson at high school. One of them asked (in jest) if we were having pizza and a party for our last lesson. I explained that I would rather help them to do some revision and reminded them that we had decided in our previous lesson to finish with some role plays to help them remember their work – so that they might gain an extra mark or two in the coming examination. I also thanked them for agreeing to provide me with an opportunity to gather information about their use of role play for revision. They happily agreed that revision would be more appropriate than pizza.

As a warm up, the students were asked to form into groups and to develop short role plays to show their understanding of some aspect of gamma scanning. They were reminded about the trolley at the front of the room on which there were butchers paper, felt pens and a random collection of objects. It was suggested they should have something ready in about ten minutes. These students had previously been involved in role playing during their Physics course and quickly and confidently began discussing ideas.

As the students worked on their ideas, I used a video camera to capture their progress. Below is a series of annotated screenshots from video footage taken during this first part of the lesson.

The students shown in Fig. 4.5.1 wrote large tags to label themselves (see Fig. 4.5.2) as components of a radiopharmaceutical that would be absorbed by the body. At the instant shown in Fig. 4.5.1, the two students were engaged in animated discourse with the third member of their group. They were discussing how one of them (S1), representing an atom of Technetium 99m (Tc99m), would throw the tennis ball to represent the emission of gamma as it decayed to the very much more stable Technetium 99 (Tc99).

Fig. 4.5.1 *Year 12 students (S1 & S2) developing a short role play about a gamma scan.*

A few minutes later these students performed their short role play for the class. The two students (S1 and S2) together in the foreground (Fig. 4.5.2) were role playing a radiopharmaceutical, Tc99m tagged onto a calcium compound that had been absorbed by a bone cell in the body of a patient suspected of having bone cancer. At the instant shown, S1 playing Technetium 99m, threw the tennis ball to a third student (S3)

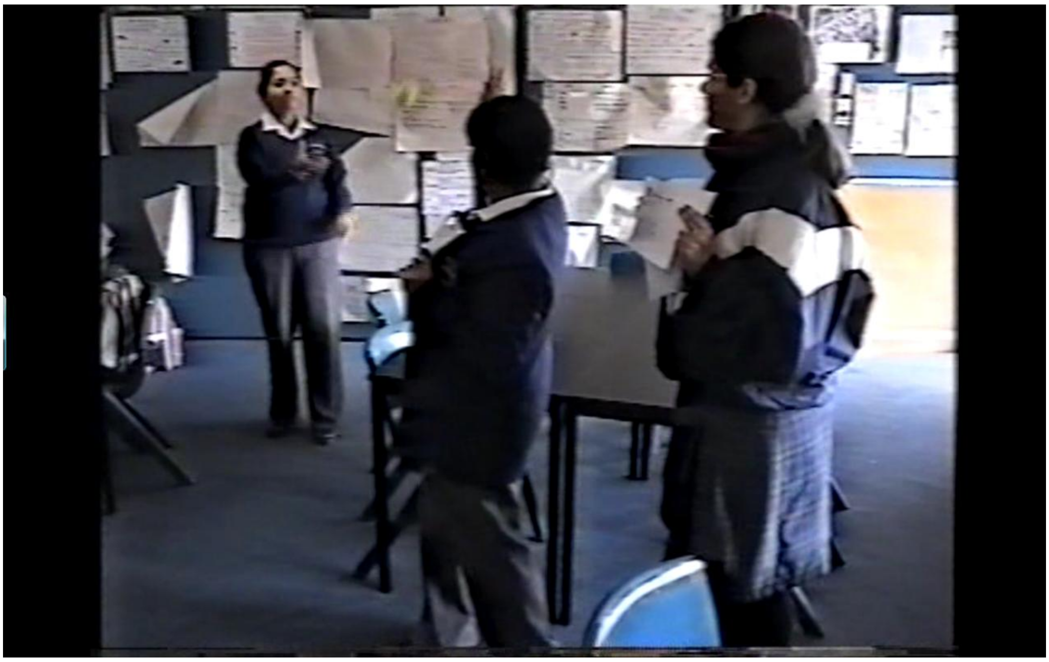


Fig. 4.5.2 Year 12 students (S1, S2 & S3) performing a short role play about a gamma scan.

standing behind. S3 who caught the tennis ball was representing a photomultiplier tube in the gamma camera, positioned outside the body. After catching the ball, S3 threw a different object to the table. This transfer of objects represented that she (the photomultiplier tube) had "converted it [the gamma] to an electrical signal" (S3). The table represented the computer that would receive and process the electric signals in producing an image.

In this brief role play the students had demonstrated clear understanding of several aspects of medical imaging. They:

1. Showed that suitable chemicals which are readily absorbed by the body are tagged with a radioactive substance – and showed understanding of the term 'tagged'.
2. Identified that specific chemicals were selected to be absorbed by targeted body tissues; providing a clear example.
3. Demonstrated that it was the technetium component of the absorbed radiopharmaceutical that underwent radioactive decay, emitting a single photon of gamma radiation.
4. Identified how the gamma camera functioned, referring specifically to the energy conversions in the photomultiplier tubes it contains.

5. Demonstrated that the energy of the gamma photons was converted to electrical signals that were then sent to a computer which produced an image showing where the radiopharmaceutical had been absorbed.

A second group of five boys were simultaneously discussing which features of gamma scanning they would show. When I went to their tables and asked them to describe what they would do, one student (S4) led the discussions while the others listened and interjected at various points. When S4 was finished talking, one of the boys (S5) said to me, “Do we have to show the stabilisation”. To which I responded “You just have to show me what is happening”. S4 then described how S5 was going to be the technetium and would be shaking during the stabilisation as a gamma photon was released. S5 interjected saying, “Gamma and beta particles” were emitted from the Tc99m. When I asked S5 if he was sure, he was quite certain, stating that he had “read it yesterday” in a chemistry text and went to the front of the room to find the book. S4 had, only moments earlier, correctly explained that only gamma radiation was emitted by the Tc99m. However, as S5 was going to get the book, S4 said, “I remember” (VT-20092005-RP-12Ph) and began writing; incorrectly describing a nuclear equation that included the emission electrons.

The brief discussion with these boys revealed a misconception that S5 had developed and thus provided an opportunity for correction. I reminded them about the physics as follows:

Tc99m decays to Tc99 only by gamma emission and the half life of Tc99m is about six hours. Tc99 does undergo further decay becoming a different element, by releasing electrons, however, the half life of the Tc99 (beta decay) is hundreds of thousands of years. Tc99m and Tc99 are water soluble and are eliminated from the body within approximately one hour after injection. Therefore, the number of potentially damaging electrons (beta particles) released by the tiny amount of Tc99 created by the Tc99m decay, while it was still in the body would be extremely small and therefore insignificant.

A few minutes later these boys performed their role play, demonstrating a more accurate understanding of the process, while the class (and the camera) watched.

Identifying an error during the drafting of the role play had enabled a critical misconception to be corrected and halted the spread of the misconception to others in the class. Interactions such as this highlight the importance of the teacher's role when allowing students to generate their own analogies. Without teacher support, students' personal misconceptions that have a serious impact on learning outcomes may well be reinforced and indeed may become 'contagious'.

Fig. 4.5.3 *Yr 12 students (S4, S5 & S6) role playing the use of Tc99m in gamma scanning.*

The students further developed their ideas as they were performing and narrating their role plays. A few seconds before the instant of the screen capture above (Fig. 4.5.3), the boy standing on the right (S6) said, pointing to S5 to his immediate right, "You're technetium and I'm calcium". S4 (on the extreme left of the image) said, "Yes, you're the calcium because you have a white shirt". The image shows S6's spontaneous removal of his jacket to expose his shirt to the rest of the students.

The statement that calcium atoms are white supports criticisms that representing various atoms with colours, as they are in molecular model kits and in colourful animations of reactions and molecules in solutions (Tasker & Dalton, 2006), may lead to the misconception that atoms are coloured. However, in the role play the misconception about the colour of calcium is likely to have been a useful link to prior knowledge. The students identified that they were aware that calcium compounds are typically white and referred to milk as a substance that contained calcium. Such links may help the students recall important/relevant information. In this case, using white probably provides an everyday common knowledge link by which students may remember that a radio-pharmaceutical contains calcium, could be used when imaging bones. The common everyday knowledge is that milk, which is shown as a source of calcium in nutrition information on most cereal boxes, reputedly promotes the maintenance of healthy bones. Hence, the spontaneous white shirt analogy, may have helped students to recall that some calcium compounds are useful when performing a gamma scan to investigate bone abnormalities. Extending from this, in a more general sense about medical scanning, is recalling the idea that particular isotopes are attached to particular substances that are readily absorbed by particular target organs within the body.

Following this warm-up activity, the students were provided with a note that listed four role play topics. These are listed below.

Concept one – Ultrasound – reflection, refraction and Doppler shift

a. Show what happens when ultrasound wave pulses meet a boundary between two soft tissues with different acoustic impedances.
b. Show what happens to ultrasound wave pulses when they reflect from a moving source (as in Doppler ultrasound used to measure blood flow in arteries).

Concept two – MRI – proton precession and relaxation time

a. Show what happens when hydrogen nuclei are subjected to a very strong magnetic field and what happens to these hydrogen nuclei when a radio pulse is applied.
b. Show how MRI can detect the difference between grey and white brain matter (or cancerous soft tissue).

Students were told that they could work in groups and to select a role play area to work on (Ultrasound or MRI) and choose to do one or both tasks.

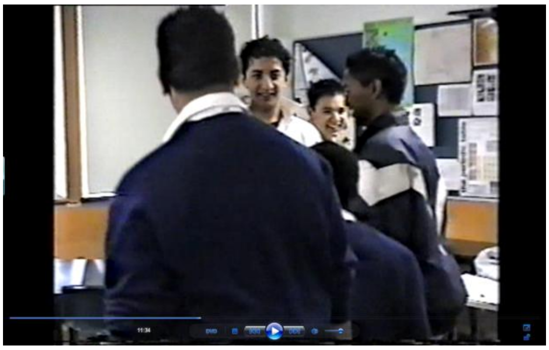
One student (S10) requested to use the video camera to record events and the remainder spontaneously formed into two groups. Group One (S4, S5, S8, S9 & S11) chose to develop the two role plays on ultrasound and Group Two (S1, S2, S3, S6 & S7) chose to develop the MRI – (b) role play (see above).

Each group was given a small portable tape recorder with a new tape and batteries to record their discussion leading up to their role plays. The tape recorders were placed on the desks where they were working. The students were also encouraged to refer to their textbooks if they needed to clarify points of specific detail.

4.5.4 (a) Group 1- working in the classroom (b) Group 2 -working in the laboratory

Group 1 remained in the classroom while developing their ideas and Group 2 worked in the attached laboratory. About 30 minutes was allocated for the groups to plan and practice their role play(s).

Group One spent considerable time discussing their ideas sitting down at their desk and then refined their ideas during several rehearsals. In one of their early rehearsals, two students (S4 & S6) stood next to each other, representing a tissue boundary within the body. Three students (S5, S8 & S9) representing ultrasound waves, bobbed up and down as they moved towards the ‘body tissues’ to a tune sung by S4. The following four images are from two different rehearsals performed as the developed their role play.



(a) Pulse of waves moving into the body

(b) Some of the pulse (S8) being reflected

(c) Pulse of waves moving into the body

(d) Some of the pulse (S5) being reflected

Fig. 4.5.5 Group One rehearsing a short role play to demonstrate how some ultrasound energy is reflected from a tissue boundary while the rest is transmitted into the tissue.

The wave motion of ultrasound moving into the body was shown by the three boys bobbing up and down as they walked towards the other two students (S4 & S9 – shirts only) who were being two different body tissues. In the first attempt, the last student (S8) playing the partially reflected wave reflected as he reached the first 'tissue' student. To represent a wave, he moved his arms in a wavelike motion, as he walked backwards.

During this first performance of the draft role play shown above (Fig. 4.5.5 a & b), it was evident that the students had good understanding of the processes involved with ultrasound. In demonstrating the partial reflection of an ultrasound pulse, however, the student that represented the reflected ultrasound, reflected (changed direction) when he reached the first student, rather than from the boundary between the two students (tissues). When I asked the question, "Where did you reflect from?" one of the boys

(S9) immediately realised the error and they repeated their role play. In this second rehearsal, the ‘tissues’ (S4 & S9) stood further apart providing a clear gap from which, a different student, S5 more correctly showed the reflection of some of the wave pulse.

The students were also having considerable fun, as indicated by much laughter and smiling (Fig 4.5.5), and still, they were actively involved and focused on the tasks most of the time. Given that this was the last lesson that these students would have prior to leaving school, this application of the intervention in particular, supports the notion that teaching with analogies has a certain “allure” and “power” (Harrison, 2006, p. 51) to facilitate interest in learning.

Fig. 4.5.6 Group Two students having fun whilst drafting a role play about the reflection of ultrasound

In a second role play about the application of the Doppler Effect to measure blood flow with ultrasound waves, S4, S7, S8, S9 and S11 used chairs to represent a major blood vessel (Fig. 4.5.7a).

Fig. 4.5.7a S9, on the left, describing that the chairs were an artery and that he was going to play the role of the blood cells in their role play about how Doppler Ultrasound is used to detect the speed and direction of blood flow.

Fig. 4.5.7b Students demonstrating that the wavelength (distance between the students) of the reflected ultrasound increased when it reflects from blood cells that are moving away from an ultrasound transducer.

Fig. 4.5.7b shows S9, walking between two rows of chairs which were positioned to represent an artery. S4 and S10, who have reflected from S9, are further apart than S8 and S5 who were still travelling towards the blood (S9). This role play was a brilliant working model that accurately showed both the Doppler Effect principle and how it can be used to measure blood flow.

When the Group One students were discussing their role play and responding to questions from Group Two, their collective understanding was further demonstrated. Their confidence in demonstrating their understanding about what happens when the blood is moving towards the ultrasound transducer, is shown by the exuberant, multi-voiced segment from the transcript below.

S4	As you can see it increases in frequency
	[laughter while the role-play progresses]
S9	As you can see they were further apart – the wavelengths – but when they hit the red blood cells the wavelength shortens
S4	Relative motion coming towards us
S8	Because they were coming towards us
S1	[Group 2] Why is it different ?
S8	The Doppler effect
S4	Doppler effect
S9	Because of the relative motion of the
S8	It's like when a car comes with a siren and you hear it and as it leaves
S9	Because it pushes the waves together
S4	Yes (AT-200905-Ph-RP-MRI (b))

This MRI role play topics were suggested so that the students could show (and perhaps further develop) their understanding about what happens to the hydrogen nuclei (protons) within the body, during an MRI scan; and to reinforce the importance of water in the scanning technique. Group Two students who selected the MRI topic, decided only to do the second part. In trying to develop the role play, they had difficulty verbalising ideas associated with the water content of different tissues within the brain. Despite this they struggled on, developing their ideas as they went. In the process, they revealed their misunderstandings.

Fig. 4.5.8 Five students in a laboratory, actively discussing how to role play an aspect of MRI.

The two images (Fig. 4.5.8) which are just four seconds apart show an active discussion between the five Group Two students while developing their ideas to show how MRI can distinguish between different types of brain tissue. In this discussion the students were checking and clarifying ideas with each other. This free and animated discussion was held out of earshot from the members of Group One who were working on their own ideas in the attached classroom.

The rapid interaction between the Group Two students during their discussion is evident in the transcript of their discourse, which is riddled with truncated and incomplete sentences. These students displayed a limited understanding about some basic principles associated with MRI and only little understanding about water content in body tissues. However, through their efforts they made considerable progress. The following excerpts from the transcript are provided to highlight particular aspects of their confusion and progress.

Group Two Transcript section while the students were performing a draft role-play about MRI of the brain.

S3 OK what do we do?

S2 Well we are standing here as the grey matter and you're the white matter and cancerous tissue – and you, the hydrogen, are going to the white matter.

The reference to hydrogen going to the white matter shows that the students may have confused hydrogen with water.

S1 You love each other

S5 [laughter]

S1 you have to be the thing [cancerous tissue] – you are cancerous – you need water

It seems here that the students are not acknowledging that water is an integral component of all of the soft tissues and instead have assigned a 'need' for water rather than a difference in water/blood vessels.

S3 Stand like that – in between us

S1 OK – and you get absorbed more because you are cancerous

Here again, is the idea of water being absorbed more by cancerous tissue as opposed to cancerous tissue having a higher water content than surrounding healthy tissues.

S2 Who's cancerous – whoever is cancerous you look like

S3 I'm cancerous

S2 The cancerous tissues – so you move closer to cancer

S5 I'll just stand away [laughter]

S1 And you just say it

S3 Yes – I am staying here – S1, the hydrogen, is standing closer to the cancerous tissue – that's me – and yes.

S1 And you're giving out more hydrogen.

S3 I'm giving out more hydrogen – so you [S5] can go away now.

(AT-200905-Ph-RP-MRI (b))

These last statements that include comments about giving out hydrogen are wrong. It is the emission of radio waves from hydrogen nuclei that is used during the MRI scanning process. Interestingly, S3 accepted the idea of the hydrogen being given off – as spoken by S1.

S7 So am I classed as water or hydrogen.

S1 You're water.

S6 Water has hydrogen in it.

S1 So the hydrogen is what is utilized.

S6 Yes.

S3 Water is absorbed by the whole brain.

This excerpt shows that while the students were able to clarify some points of concern, others remained. It seems here that they could reconcile that it was the water that contained the hydrogen, however the idea of water absorption was yet to be resolved.

The next excerpt shows how the students attempted to resolve the problem they had in finding a term to describe the interaction of water with the different body tissues.

S2 I don't like to say the word absorbing-it doesn't really get-

S1 Isn't that where-

S3 Coagulated?

S1 Gets used.

S3 Accumulates more.

S1 Yes.

S6 Accumulates.

S3 Accumulates.

S7 Oh, so it uses more -

S4 It's more like the radio isotope [referring to their studies on PET] – it just accumulates.

S2 Accumulates.

S7 Accumulates.

S3 It [the text] says cancerous tumours contain different amounts of water from normal tissue.

S1 Yes.

S3 Or are surrounded by watery tissue

S6 So, say it accumulates more water concentration.

S3 Yes so it's not really being metabolized.

S1 Yes. Because it's not an isotope.

S2 Yes.

S3 Yes.

S6 Metabolized is like the brain takes it in so it's not metabolized-you could say accumulates more-

S2 Yes-I wouldn't say metabolized-you could say concentrates! – concentrates – concentrates.

S3 Concentrated-yes concentrate's a good idea.

S7 So cancer – so the cancer has a more concentrated amount of water.

S2 Yes.

S1 Yes that's why it has more hydrogen.

S3 It has more concentration of water than grey matter and normal white matter.

S7 Than grey matter and normal white matter.

S1 And you give out more hydrogen.

Their reading of the text and discussion seemed finally to have led to a reasonable understanding about water content in the different tissues. However, S1 persisted in incorrectly saying that the hydrogen was given out.

The following excerpt is a segment of another attempt by Group Two at performing and talking through their role play while they checked their physics textbook for clues.

S7 I am walking and I am attracted to the white matter.

S1 - I am having fun [referring to the water moving] – You are not attracted.

S2 You are not really attracted-you are not attracted – you're just accumulated.

S7 I am more accumulated to the cancerous white matter compared to the normal white matter. So I'm more like -

S3	Concentrated.
S7	Concentrated around the-
S1	The grey -
S7	The grey matter – but not as much as -
S3	Cancerous white matter.
S7	Cancerous white matter.
S3	I think it says it is surrounded by watery tissue.
S2	Bound in the brain in different ways – OK so we are bound in different ways.
S2 /S3	[chorus] – Bound in a different way.
S1	Bound.
S3	It's bound – so yes we're bound in a different way.
S7	So the water is bound to the cancerous -
S3	Tissue.
S7	Tissue more than the normal white matter.
S1	No no no no no no.
S3	In a different way.
S7	Is the water bound to them differently or are we bound to it differently?
S2	No no, he is bound differently.
S3	He is bound to you guys differently.

S7 Jesus how many words are we using?

While S7 openly expressed his frustration with the range of words being used, it seemed as though the matter had been resolved and they would use the term *bound*. However, when S2 attempted to put a definitive statement together, her use of *absorbed, bound* and *attracted* in the one sentence indicated that the terminology was still a matter of concern; as was the confusion between water and hydrogen.

S3 I'm hydrogen – I am absorbed by grey and white matter and S7's the white matter that's cancerous and there is a difference in the way the molecules are bound in the grey matter and the white matter and I'm walking in the blood stream and I'm coming in and I am standing in between the white matter but I am more attracted towards the cancerous tissue.

S3 Where at the same time, if I am going to the grey matter I am going to the side of S4 and S3 which is a different way.

S2 To standing in the middle.

S3 To standing in between the white matter .

S1 Because you're bound differently.

S3 Bound differently and that's how an MRI distinguishes between-

The final statement by S3 in the above excerpt is the first link between water/hydrogen and MRI.

At this point the students were asked some questions in the hope that it might help them clarify some perspectives.

T So are you showing that these things have different amounts of water in them?

S1 Yes.

S3	Yes –we're showing how differently it is bound – 'cause these are the white matter and he is the cancerous – I am standing in between them so it is a different sort of binding.
S1	Yes.
S3	Whereas I'm standing to next to S3 and S4 not in between them which is another different sort of binding and they are grey and they are white.
S1	But also there's different concentrations of water.
S3	Concentrations of water.
T	How are you showing the different concentrations of water?
S2	Standing closer.
S3	Yes.
T	OK, so if you're closer there's more water.
S3/S2	Yes, yes – the further away-
T	So you are having distance represent concentration?
S3	Concentration – yes.
T	That's important for people to know when you are doing it.

The students seemed clear about the idea that different tissues contained different amounts of water and that is what they were trying to demonstrate.

During the performance of the role play to the rest of the class, it was apparent that these students had still not clarified some of their ideas and were still struggling to find appropriate words to describe what they had correctly worked out about the differences in water content in the brain tissues.

S7 I am the water I am travelling through the blood stream-I am heading up towards the brain and I meet white matter. I am attracted to this-more accumulated to this white matter and I am more accumulated towards the cancerous white matter because it contains more water. And in the second instance I am more accumulated towards grey matter but because of its different structure of its molecules I am still accumulated around the grey matter but not as much as white matter or the cancerous white matter.

S1 And the amount of concentration of the water in each of these instances is shown by the distance – so the more distance between us the less water concentration and the less distance between us there will be more water concentration.

Fig. 4.5.9 *Group Two answering questions after performing their role play for Group One*

During the performance, some of the Group One students appeared confused and they asked several questions.

S8 What's the actual MRI part?

S4 I don't understand – how does MRI detect the difference – how does MRI detect the difference between grey and white matter?

At times, while students in Group Two were justifying what they had shown in their role play (Fig. 4.5.9), some of the students in Group One were identifying more detailed mappings of MRI concepts, than Group 2 had considered, and attempted to help link what had been done in the role play to additional MRI theory. They did this by asking quite specific questions or making suggestions about modifications to the role play. In the following section of the transcript from the discussion between the two groups, a measure of friendly conflict is evident. This seemed to arise because Group Two had focussed on showing differences in the water content of different types of brain tissue; while from their questions, Group One students expected Group Two to show how MRI detects the different types of tissue.

Despite the competitive nature of the discussion, the following transcript shows that the underlying atmosphere was one of searching for a shared scientific understanding (see especially Lines 6, 8, 18-20, 33-39, 46-48 & 51-52). (For ease of recognition, the presenting group (S1, S2, S3, S6 & S7) codes are in bold text)

S9 So what is the difference between white and grey on the image?

S1 Well the white and the grey – the white comes up as white and the grey comes up as the grey.

S4 But why? But why?

S1 Do you mean what is the actual difference between the two?

S4 Well you said one contains more water

S2 The white is brighter

S4 Because?

S1 The grey matter is grey.

S4 Oh really?

S2 The answer is because it contains more hydrogen because of lots of water

S1 And it gives off more hydrogen protons

S4 Why, is there more water?

S2 Oh [laughing]

S9 You can’t get a brighter light

S3 Oh, because the cancerous cells are growing – they need more water

S9 So I can tell the difference between say the white matter of S6 and the white matter of cancerous tissue

S4 And the MRI can detect this – how?

S1 Because hers will be brighter – his will be bright and hers will be brighter.

S6 I was standing more further away so the concentration was less

S2 So it’s cancerous – so it contains more water which has more hydrogen.

S1 Because there is more cell division.

S2 And the brightness would be greater – more brightness.

S4 So show how MRI can detect it.

S7 Yes MRI can.

S3 [A little frustrated] We just told you MRI detects the concentration of water in the grey and white matter and the way

S4 How ? How?

S3 It’s an image.

S4 OK-How?

S1 OK – say, me and S7 are the water

S4 So you’re saying there’s more hydrogen atoms there.

S1 Yes

S4 So more spin and therefore concentration of radio frequencies being given off.

S1 We’re going to be two hydrogens given off and here I’m going to be one hydrogen given off.

S5 Yeahrrrr?

S4 So that’s what you are saying.

S9 Is the hydrogen given off uh [facetiously].

S1 Yes, from the water.

S4 So there’s a concentration of radio frequencies being emitted from that particular point and that’s how the computer recognises that there’s white matter and that’s grey matter – is that right.

S9 The hydrogen come out. [multiple voices]

S2 Didn’t say that.

S4 I get it now – that’s good.

[Clapping]

During the role play and the discussion, Group Two students showed that they had further developed their understanding. They related the different water content in the tissues to brightness on the image (Lines 7,9, 16, 21-22 & 27) and provided a causal link between high water content and cancerous cells (Lines 17 & 24-26).

Several of the issues raised by Group One during the Group Two role play discussion, related to the first of the MRI tasks that had not been attempted. To address these issues, the students were asked, as a whole group, to quickly pull together a role play to address the MRI task (a); Show how radio waves are used in the production of an MRI image.

The excerpt below, from the transcript (AT-20092005-RP-12PH) shows how teacher interaction led to the students constructing a role play in which they used an extended analogy that mapped well with key aspects of the target MRI physics. Students were only given a short time to come up with the role play (See Lines 15-18). The discussion about, and performance of, the role play, provided opportunities to address misconceptions that were noticed during the earlier part of the lesson. For example; S1's repeated mentioned that hydrogen was given out (Lines 24-35) and a subtle but important misuse of the term atom instead of nuclei, when referring to precession (see Lines 41-42). During the role play, the more correct views were reinforced.

T OK now – nobody sit down – nobody sit down-we have seen three of the four things on the sheet – and I think to do part (a) of the MRI probably needs all of you – so can I – in the last 15 minutes – look I think there was a lot to be done in that – I can see lots of good questions – and some pretty tough ones. Where's S6?

S6 Behind you.

T And that's the thing – we were not necessarily trying to show the whole process and that's pretty hard to do anyway. You know, if we said OK, show everything you know about ultrasound in one role-play, it would be too hard – I was trying to pick out some particular things with these [4 topics on the handout] that were probably a bit confusing all right – and so I wanted you to have a go at – making it not so confused. And I think you have done that reasonably. I think you did that. I wasn't unhappy to hear some giggling – I like you guys with your up and downs. I want you in the next ten minutes – yes in the next 10 minutes to try as a whole group – now this is hard - try as a whole group to do part (a) of MRI.

S4 Yes we can do that.

T OK as a whole group – you probably need a few different parts to that. So you might want to break it up into different things and you can work on that. And then we will finish off with actually trying to do it.

S1 I know the first part.

T The question was, did you think that the hydrogen ions actually came out. You know how you were talking about the hydrogen – and I was saying that hydrogen nuclei were the ones that give off the radio frequency.

S1 No No no.

T But I think they [Group 1] had some confusion about what you meant there.

I think this next part- this last part that says, show me what happens – really is addressing that kind of thing – It is really saying – what is actually happening to the hydrogen and something about the radio frequencies emitted.

So if you can try – I mean-I don’t know how you are going to do that – you have got magnetic field to contend with you’ve got radio waves to deal with – precession to deal with – in 10 minutes – see how you go.

[Lots of noise-singing and laughing]

S4 [Directing] Hydrogen atoms-this is easy, this is easy – hydrogen atoms all line up in the magnetic field as the radio frequency hits we all flip – then with relaxation time a frequency wave and we step back there.

[Lots of laughter and chatter - Words such as precession, parallel, anti-parallel, radio pulse].

[A few minutes later]

T Are you going to be ready in about three minutes.

S9 Four of us should do that-one of us can be the radio frequency.

S2 We’ll be the radio frequency.

Within a few minutes the boys had formed into a group of precessing protons (hydrogen nuclei), rotating an extended arm either parallel or anti-parallel to their specified magnetic field direction. The girls had decided to be the radio frequency/waves that would be absorbed by the protons causing them (the boys) to flip (raising their rotating arm) and then release their energy (the girls – as radio waves) again when they spontaneously un-flipped (relaxed). They showed this relaxation by lowering their raised arms. The role play developed by the students in just a few minutes was quite detailed and mapped very well against the science of MRI.

The collection of annotated images below (Fig. 4.5.9 (a) – (f)) are from a short video segment during which the students were developing and performing the MRI role play (Concept 2 (a)-see above). The students showed how the axes of spin for hydrogen nuclei line up either parallel or anti-parallel in the strong magnetic field inside the MRI tunnel by pointing an arm in a north or south direction; demonstrated precession of the axes of spin for the individual protons within the hydrogen atoms by holding out one arm and rotating it a little; demonstrating the change in proton precession when energy from the radio pulse is absorbed, by lifting their arm to a 90^{o} position; and what occurs when the energy is given off again, by lowering their arm to the horizontal position again (see Fig. 4.5.9) and releasing the absorbed energy as radio waves.

Fig. 4.5.9 Annotated images from a short role play about MRI (VT-200905-RP-Ph)

(a) Students helping each other understand the concept of parallel and anti-parallel alignment of the protons' spin in the strong magnetic field. Here, S4 was helping S8 clarify the difference between parallel and anti-parallel alignment.

The next part of the role play revealed that the students had not quite understood a key feature of the MRI process-the absorption and re-emission of the radio pulse energy by the protons of the hydrogen atoms. This was consistent with the difficulty shown earlier in the lesson when Group Two were trying to show how MRI could be used to distinguish between certain types of brain tissue.

(b) *Students (hydrogen nuclei – protons) demonstrating the absorption of energy by raising their arms. Here an error was made – they raised their arms before the radio pulse students had reached them.*

At this point the students were asked to stop, and during a brief discussion, the error was identified and they restarted from the beginning.

(c) *S4 'flipping' (raising his arm) as S2 reaches him, while the others wait a few seconds for a pulse to reach them before 'flipping'.*

(d) *When the students representing the radio energy reached their proton student, they stood next to them to show the energy they possessed had been absorbed. (About 5 seconds after image (c)).*

In response to a comment by S2 about the radio pulse 'hitting' the protons as she reached S4 causing him to 'flip' (see image (c)), S3 (female) flung S5's arm into the flipped position when she reached her proton.

(e) When the pulse energy (S3) was being re-emitted by the proton (S5), he gave S3 a little push. S3 responded by turning around and gently pushing him (S5) with both hands.

(f) To this S9 said "Hey, you can't treat a proton like that!" The whole group cracked up with laughter as the role play continued.

The students were having fun while demonstrating and reinforcing their understanding about the physics of MRI. The comment that referred to a 'proton' correctly identified and reinforced to all that it was the nucleus of the hydrogen atoms that they had been role playing and which emitted the energy as radio waves.

In the last five minutes of the lesson I was able to use the students' MRI role play, getting them to do it again and to demonstrate and reinforce one more difficult concept – the increase in relaxation time when there is a greater number of protons (e.g., due to a greater amounts of water) in particular tissues.

During the second performance one of the girls walked into the group of precessing boys and was absorbed by one of the boys (she stood next to him), causing him to flip and then un-flip as he released her (she walked away). As she walked away, representing the emitted radio wave that would normally be detected almost immediately through a radio-receiving antenna, I asked her to demonstrate being absorbed by a second precessing proton (boy). She caused him to flip and stood by his side and as he spontaneously un-flipped she demonstrated being released again – by walking away again. During the very brief discussion that followed, students seemed to understand that a second absorption would delay the reception of the radio frequency. Hence, if there were more water molecules in a particular tissue, there would be a detectable increase in proton relaxation time because there would be a greater amount of re-absorption of radio frequency previously emitted by relaxing protons. The resulting time differences could thus be used in the production of the image.

Most students had not hitherto developed a good understanding of variation in relaxation time for different tissues, during the course. By directing one small aspect of their walk through role play analogy, I was able to better explain the idea of re-absorption of emitted radio frequencies. Role playing the explanation within the framework of what they had developed, allowed the students to see and interpret the idea for themselves; and by correctly performing the analogical explanation, they demonstrate their understanding. Thus, making a difficult part of MRI accessible, especially to those, who may previously not have grasped the idea.

This modification of the students final role play, also supported the earlier role play about brain tissue, constructed and presented by Group Two. It addressed the confusion about the different amounts of water in different tissues and provided an opportunity to reinforce, that it was the hydrogen nuclei that absorbed and emitted radio waves. This was a purposeful attempt at correcting the misconception about hydrogen being given off, that S1 had stated several times.

At the end of the lesson I proudly commended the students on the positive way they had approached the tasks; for their efforts and their interest in learning over the previous two years; and for their support as participants in my research. I also invited any that might wish to do so, to participate in a final interview on the afternoon of their physics examination.

A follow-up interview

Approximately six weeks later, shortly after the HSC Physics examination (Board of Studies, 2005) had finished, three students (S4, S8 and S9) arrived at my door to participate in an interview. The interview was conducted in the classroom where they had studied the Physics course. The students were asked questions about whether the role play activities had an impact on their ability to answer questions in the exam. All three students commented that they had recalled the MRI role play when they were answering the examination question on MRI and indicated that it had helped them in constructing their answers. One student said that after he had answered the question, he remembered aspects of the role play and realised he had made a mistake; which he then corrected.

Prior to beginning the interview, the three boys independently completed a questionnaire about the MRI activity (SS-041105-12Ph-RP-MRI).

All three students' responses to the survey questions were in the moderate to very high positive range (average score 4.1 out of a possible 5). This identified in general, that they felt they were actively engaged, cooperating with their peers in an enjoyable task in which a high level of meaningful discussion led to the development of an acceptable product and an increase in understanding.

The students written responses for the last item on the questionnaire supports their comments about a development of high levels of understanding.

10. Please write a brief comment about the usefulness of this activity in helping you learn the science you were studying in class.

The students' written comments were as follows:

S4	It allowed me to turn the theoretical knowledge I had into practical knowledge which we role played and allowed me to remember the functionality of an MRI much more. I could also recall the role play during the HSC physics examination.
S8	I found it useful, especially in the understanding of MRI and how it works. I even recalled it during a question in the Medical Physics section in the '05' HSC.
S9	The activity helped me to remember and understand the concept of MRI.

During the discussion that followed, comments made by the students supported earlier observations and provided further evidence that the intervention had helped the students to remember aspects of their course during the exam.

When I first spoke with the students on their arrival after the examination, S8 excitedly told me about his recall of the MRI role play during the examination. He indicated that after he had written an answer, he thought about the role play and changed his answer to “make it better”. (FN-041105RP-12Ph-MRI). S8 elaborated further during the interview (see Lines 20-34 below).

Comments made by these students during the interview (SI-04112005-12Ph-RP) are discussed below, with examples from the transcript.

Excerpt One

This first excerpt identifies that the students remembered the final MRI role play activity while they were in the exam. In particular, the recollection of the part of the role play that showed the resonance ‘flipping’ and relaxation of the precession of the hydrogen nuclei due to the absorption and emission of particular frequencies of radio waves, allowed the students to produce what they believed to be reasonable answers to the following question that appeared in their examination (see lines 12-14, 16-17 & 20-34).

> Q. 29 (d) State the function of the superconducting magnet assembly and the radio frequency (RF) coils in the MRI system. (BOS, 2005, p. 30)

T: Did you guys think about any of this role play stuff when you were in the exam?

S4: Well actually I did – during the exam – I remember-the Medical Physics question – the MRI question – I specifically recalled the role play we did in class with the students acting as the hydrogen nuclei flipping as the radio frequencies – the Larmor frequency, hit them and then as the relaxation time – they flip back to the original orientation – emitting weak radio frequencies back. And so I just rephrased that and put it down on to the exam paper.

T: So actually you remembered that?

S4: I remembered – I actually remembered the actual – [over-talking].

T: Is that the only place that you remembered something like that? – have a think about that while S9 tells me. Did you have a think about that [to S9]?

S9: Yes. Same as what S4 said. When I had the MRI question I was remembering flashbacks of what we did in class with the role playing and that helped understanding.

T: What part actually did you remember the most?

S9: The radio waves coming in – so when it asked what do the RF coils do I was able to answer the question.

T: That's good. [To S] Did you do the same thing – did you remember or not – [laughing] you didn't have to?

S8: [Laughing] No, I did. You see, during the question I recalled the flipping of the actual hydrogen nuclei during the radio waves being sent to it. I actually initially put it that the magnetic field was turn on that they aligned and flipped, then I corrected myself in remembering the-what was it called –

S4: Role play.

S8: Role play-that they don’t actually flip. They only flip when the radio waves are sent to it, so I just said they align when the magnetic field was applied. So that was the purpose of the [slight pause] superconducting magnets [also chorus of-magnets-from the other two as he spoke]. And then also for the radio trans – coils, that is-was the-that they were sending the radio frequency to flip to the higher energy state.

T: Do you remember what part of the role play that was?

S8: I remember the flipping. I remember our hands going up and down. And I remember when-some of us were disorientated and you say – “magnetic field on” and some would be parallel and some anti-parallel.

S4: Yes. I remember that as well.

T: You guys worked that part out. I don’t know who in the role play did it – but some of you guys were talking about parallel and anti-parallel.

S4: Yes I think it was us (referring to S8 & S4).

S8: Yes I think that was me.

S4: I’m sure it was you [referring to S8].

T: Do you remember what caused you to flip in the role play?

S4: Radio frequency. S2 and them would walk through and hit your [the student’s] arm up.

Excerpt Two

After watching a segment of the video of their final lesson in which Group One had performed their role play about water content in different brain tissue, I asked the S4 who was in Group Two about his “But why?” question. The ensuing comment from the students confirmed that: they were confused (Lines 54-55); had their own thoughts about what should have been done by Group One (56-65, 74-76); ideas about what the others could have done differently (Lines 76-82 & 88-102); and indicate that the role play at least encouraged their thinking about the topic.

T	Alright, you were asking “But why?” can you tell me about that?
S4	Oh well um. Because –the overall – as S8 said the role play wasn’t- they didn’t say at the start – at the beginning-what they were doing. So right from the beginning we had no idea what was going on. We didn’t even – until he [S7] started talking about grey and white matter – like OK it is in the brain. He didn’t discuss about the magnetic field at the beginning.
S8	True.
S4	The strong magnetic field which was lining up with – and then he didn’t.
S8	Radio waves.
S4	He didn’t go on to the radio frequencies and so on – but then he was mostly talking about how it’s absorbed -how the hydrogen – how the water in the body is -so I don’t know if he was talking as much about functional MRI.
S8	He was talking about . .
S9	It wasn’t related to MRI at all.

S4 I was more like between PET than MRI – because he was talking about the rate of consumption and it as getting used more there.

T I think they were trying to say why it is - that the MRI can distinguish. The MRI does distinguish between grey, white and cancerous tissue. So what is it about those tissues that allows the MRI to do the distinguishing.

S4 Well they should have been like as in One [Referring to the first of the MRI topics – which became the final role play] there's a concentration of hydrogen nuclei in the cancerous cell. And so they should have said – that in that – more because there is a concentration in that – more radio frequency waves are being emitted from that particular point and that's why, and that's why the MRI knows that the cancerous cells that, and then compares that to the other receiving information which is the white matter and the grey matter and distinguishes between them.

T After watching them, do you think they were actually trying to do that?

S9 Yes.

S4 No. Ohr?

S8 Yes.

S9 But they could have done it better. Like they had one person representing white matter, one representing cancerous white matter and two people representing grey matter and like they could have showed the concentration of water – instead of having one person being the same concentration for the both and having to tell us that it was different concentrations because there were two people doing grey matter, one of those people could have showed that there was more water in one than the other.

96 S4 Exactly – or they could have used the tables.

97 S9 Anything.

98 S4 So it shows more of concentrations, then we - I recon we'd notice
99 that easier. 'Cause you have two people next to grey matter, one
100 person next to the white matter [chorus from S9] then have the rest
101 of them on the cancerous cell. And shows the ratio and then you
102 understand. I think that would have been clearer – definitely.

Excerpt Three

The following except identifies that these students had developed perceptive understanding about the analogical process. The understanding included: that students may get it wrong (Lines 109-110, 116); that one person can affect a group (Line 110); that students will believe others who are expected to be correct (124-131 & 139-141); that discussing both wrong and corrected ideas is important (118-123); that not identifying errors could be a problem (130-131); and the necessity of having someone (a teacher) who can recognise errors, if the learning is to be accurate (141 – 143 & 148 – 152).

103 T If I ask people to do this and they are not quite sure how to do it, or
104 they try and they make mistakes, is that a good thing to find out?

105 S4 Yes, because most people in the class will have probably similar
106 mistakes to that person, and so by we finding one person has that
107 error we can rectify that error. Finding what's wrong with it and the
108 rest of the other people go, 'Oh yes, that's what wrong with it'.
109 And they remember 'Oh yes, we talked about what's wrong with
110 that'. Because when you have one person that has like – a group of
111 people that explain the whole thing wrong, then the probability is
112 that most of the students don't know what's going on either. They
113 believe the same thing.

T When you were listening and talking and seeing what they did and thinking about that – and you have just seen it again – did that help you think about it and think about your own ideas.

S9 Yes, like

S8 It was important that like the mistake was shown, but it was more important that we actually corrected it. So I found like actually making sure that we actually make-like remembering which one was correct and which one was wrong, was important. Knowing that yes, that's wrong – so that is the correct method of determining like how to do the image.

S9 I believe it is a good way to remember, but if they. If you are listening and you pick up the mistakes and you remember those mistakes and you don't remember the corrected mistakes then you are going to remember the wrong things. So it would be a good way to learn if what they were doing was right. And so that's what I thought the practicing in the beginning was, was getting it right to show the other people. But if that's not corrected then and the rest of the class could pick it up wrong.

T: Do you think people remembered wrong things from that role play or do you think we discuss it enough afterwards to fix them up?

S4 I reckon we discussed it enough afterwards to rectify the problem. Cause after we did the role play - on MRI with the group, and that helped, I reckon everyone – would help the majority of the group to remember it.

S8 It was effective.

S9 Because you're uncertain as well – and everyone was uncertain – you'd take what they said as true. Like because you are uncertain, you weren't confident enough to know otherwise – so if you weren’t the teacher to pick up on that, we wouldn’t have rehearsed it.

S8 Of course.

T So you think I had an important role?

S9 Yes.

S8 In rectifying the problem.

S9 And then going and doing it again to fix up the problem helped by. But if there was no teacher who was capable of knowing the wrong things then it would have gone by unnoticed and then we would have learnt the wrong things.

S4 Obviously.

Excerpt Four

Towards the end of the interview, the students were asked if they thought that being involved in the intervention activities was worthwhile and if it helped them to focus on their work. While two generalised answers were provided (Lines 159 – 161 & 167-171) examples specific to the MRI role play were used to elaborate understanding (Lines 163 – 164 & 172-173). There was a consensus that the active participation and sharing of ideas, assisted to improve understanding by identify errors and clarifying concepts. The students indicated that the types of activities we had done were particularly good for the harder concepts and recognised that the time involved would make it impractical to use for learning all concepts (Lines 176 – 180).

T: About being involved – about the whole process – of these kinds of activities. Is it better to do it?

S4 Yes.

S9 Yes.

T	Why?
S8	Its more interactive. You actually being part of the actual learning process. So like you can get a better understanding if you are actually taking part in it.
T	Yes. Does it make you focus on the work better.
S8	Yes especially like - I remember like the flipping – that was like the main thing in correcting one of my main problems. So yes, it was good.
T	S4?
S4	Similar to what you [S8] said. Allowing like - to recall what you already know. Your knowledge. So what you learn in the books then you can put into role plays. And you can exchange ideas with the other students – and maybe you're leaning the wrong thing – maybe you're reading the right thing but you're interpreting it wrong. So in the role play you can – like oh yes – that's how it actually happens, that's why it flips.
S9	Yes it's good in helping to understand and remember – but um - for like the harder to grasp concepts like MRI, and say the photo-electric effect it would be good. But it takes up a lot of time and so it couldn't be used for like all sort of sections of each topic.
S8 & S4	[Agreeing noises]

After the interview, about two hours later in the day, S9 came back to the school to return his English textbooks. He dropped in to say goodbye again and was interested to chat a little more. I asked him why he thought he was still able to remember the MRI role play so well. When he said he was not sure, I suggested that it might have been because it was the last thing they had done at the end of their course. Surprisingly he said "no it's not that" and stretching his arms and hands out to his sides, said "I still remember the light refraction one", which had been done about 20 months earlier, at the beginning of the two year course. When his friend who was with him and who knew about the activities said "maybe it's because people got involved", S9 agreed but said "it was more than that". But he could not say what it was. (FN-041105RP-12Ph-MRI)

Four months later, S3 visited the school to speak to her teachers about her examination results and the course she had started at university. In her conversation with me, she spoke at length about the Physics role plays (FN-130306-RP-12Ph). She said that doing the role plays "really helped" her to understand the work and helped her to gain the high mark (85%) she received for the Physics examination, which she said, helped in securing a place in her university course.

Like S9 (see above), S3 remarked on being able to remember the first role plays about light refraction. She said that at the time she "didn't really like doing the role plays – but they were kind of fun and did get everyone involved". She said it made them, and her, "think about what they were doing". Referring to the role plays in the final lesson, she recounted speaking with others in her group and checking understandings with me and text books to "make sure they got it right before presenting it to the others". She said it was an "emotional experience" and that she remembered after being "put on the spot" by S4, having to "justify various points of her group's role play". She said this had helped her to remember the details in the Physics examination – "because she remembered S4 asking". She concluded by saying: "You should keep doing it [the role plays and modeling] because it really helped to developed good learning skills that I am grateful to have now at uni – especially the thinking about the work" (FN-130306-RP-12Ph). These positive comments, made months after the intervention, highlight the significance of the research to these and future students.

Conclusion

In this episode, conducted during a 100 minute lesson, students had minimal yet important support from the teacher. Yet they developed, performed and discussed six role plays covering a range of medical imaging techniques. The students appeared to enjoy consolidating their understanding through this analogical ending to their Physics course. In the process, they made their personal views visible and subjected them to the scrutiny of their peers and their teacher (me). Openly giving and accepting criticism in an atmosphere of cooperation and co-construction identified they had developed a high level of trust within the group.

This culmination activity demonstrated the students' skills and metacognition about learning science through analogies, developed through their participation in this research. The students liked analogical activities and rated them highly. They were used to sharing ideas and seeking assistance where needed. As reflected in comments such as those following, however, they were aware that analogical activities were attempts to model the science and that while doing so, was scientific, there were their limitations to what could be shown. That is, they knew that the analogies could not account for all aspects of the complex situations.

S7: [To the teacher (me) during rehearsal] You want this to be as correct as possible?

S3: [To members of Group 2 during a sharing performance] We are not being physicists - well we are – but this a role play.

and

S6: [Tongue-in-cheek comment to Group 2 following a sharing performance] You have not accounted for the fact that the ultrasound enters at an angle.

S4: [Reply to comment by S6] Yes, well I could just fly up into the air – [lots of laughter].

These students developed a good working relationship with their teacher (me) and gained significant abilities to use and develop analogies over the period of 18 months while completing their Physics and Chemistry courses.

Producing the role plays, actively engaged the students in group-work that facilitated collaborative discussion, resulting in the co-generation of extended analogies. While doing so, the students shared and tested their personal ideas. In selecting and revising their ideas to best fit the evidence, the students were engaged in the scientific process.

By observing the students’ analogical representations, I was able to recognise confusion and misunderstandings as they became evident in their conversations, questions and representations. As a participant in the process, when necessary, I provided clarifications so that the students’ could identify errors and make modifications to their ideas. The correct science was thus more appropriately represented and the students were able to demonstrate their understanding of the correct science. The episode thus identifies, that careful attention, by the teacher and the students, to the imperfections of the analogies developed, can have a significant positive influence on learning correct science. Students were able to draw on the experience and the revised concepts in an examination and during an interview, six weeks later (and beyond). The learning that results is thus accessible to the students long afterwards and is therefore persistent.

The role play activity and its associated analogical reasoning, was both intellectually and affectively engaging. It led to robust and profound learning in which the analogical experiences formed a significant part of the students’ cognitive framework. This episode provides strong evidence that activities involving students in the co-generation of analogies are useful as pedagogical tools for engaging students in developing deep understanding of complex/difficult science concepts. It shows that under appropriate circumstances, students, learning science through the co-generation of analogies, can achieve significant learning outcomes in relatively short periods of time. In addition, there is some evidence to suggest, that involving students in learning science through analogy development, may enhance their metacognition, which may be useful to future learning situations.

4.6 A model for a solenoid valve

Yr 11 Physics

Vignette Four

This vignette describes and elaborates on data from four episodes of the intervention conducted with four different Year 11 Physics classes in a school in Western Sydney, NSW, Australia. The students were 16-17 years of age and emanated from a range of cultural backgrounds. The episodes were conducted at approximately the same time in consecutive years from 2004 to 2007. The teaching approach, used in each of the 100 minute log episodes, was essentially the same. It involved the students in considering electrical appliances that might use solenoids and then modeling how a solenoid might be used to control water flow in devices such as washing machines and dishwashers. The task was a heuristic application of the intervention, designed to help students learn about the use of solenoids. The repetition over four years, provided opportunities for: refinement of the lesson; the collection of a wide range of data; and the identification of consistencies across groups of students.

As part of a unit called Electrical Energy in the Home, in the Preliminary Higher School Certificate Physics course in NSW, students are expected to learn about and be able to "explain one application of magnetic fields in household appliances" and "compare the nature and generation of magnetic fields by solenoids and a bar magnet" (p. 30) (Physics Syllabus, Board of Studies, 2001).

Towards meeting the syllabus outcomes above, the modelling activity was designed to facilitate the students' understanding about:

- The behaviour of magnetic poles when they are brought close together;
- The right hand grip rule for determining magnetic field directions in conductors;
- Solenoids (electromagnets) and their related magnetic fields; and
- How magnets function in household appliances.

Background

Prior to participating in this teaching episode, the students had built solenoids by winding a long piece of insulated wire around a cylindrical iron rod about 20 centimetres in length. They had performed an experiment in which they mapped the magnetic field patterns around a straight wire, bar magnets and the solenoids they had constructed (see Fig 4.6.1 below). Hence, they were aware that a solenoid was an electromagnet.

(a) Field around a wire   (b) Field around a bar magnet   (c) Field around 2 solenoids

Fig. 4.6.1 Students mapping magnetic fields (V-170605-M-11Ph)

The Episodes

Four episodes of the intervention are reported below. Data for three of these episodes has been reported first under the headings Focus, Application and Reflection to highlight aspects in the episodes that relate to the FAR guide (Treagust, 1995). The fourth episode is reported separately because it only provides additional information about the nature of the models when the students were given more time to build them. It otherwise provided no additional perspectives on the first three episodes.

Focus

Prior to beginning the solenoid valve modelling activity, the students were asked to answer one or more questions. This was done to: ascertain their prior knowledge about solenoids and electrical appliances; establish the idea of a solenoid valve; and to initiate interest in finding out about such devices.

In the first two episodes (2004 & 2005), the students were verbally asked, to answer a question – “How could a solenoid be used as part of a tap to turn water on and off?” None of the students were able to answer the question. While they knew what a solenoid was, they were not aware that solenoids could be used in a tap like device let alone what sort of appliances, found in the home, might have such a tap. Their lack of responses and perplexed facial expressions indicated that this was something they had not previously considered. They were unable to link their knowledge of solenoids or their knowledge of household appliances to the question.

During the 2006 episode a video camera was positiond on a tripod and the lesson was recorded. These students were asked to write answers to the following questions which were asked one at a time to stimulate group and class discussion.

1. Describe your level of understanding about solenoids in household appliances.
2. List electrical appliances found in the home that probably include a solenoid.
3. For one of these, describe the function of the solenoid.
4. Name a device that would use a solenoid as a tap.

Responses were written in A5 sized booklets (SA-290606-11Ph) and are presented in Table 4.6. Some of these students (06-1, 06-3 & 06-4) correctly identified that solenoids could be found in electric motors. In general, however, the random nature of examples provided by most students and the large number with no response answers, indicated that this group of students were also largely unaware of how or where a solenoid might be employed in household electrical devices. This view was reinforced by the video evidence. When the questions were asked, the students who were directly in front of the camera, displayed that they had no idea. To the second question (see above), this same group sat, puzzled, obviously searching for answers. One of them said to others in his group; “I can’t think of any”; and soon after “I’m lost”. (V-290606-M-11Ph). This lack of knowledge about the use of solenoids was typical at the beginning of all four episodes.

The written answers to the questions were stimulus for the class discussion. To Question 2, the 2006 group brainstormed a full range of electrical devices. The range of appliances could well have been an answer to a different question – Tell me some electrical appliances found in the home? It suggested that few if any of the students were clear about which appliances had solenoids and which did not. Comments such as "I can't think of any appliances that would use a magnetic field" (V--290606-M-11Ph) and then a suggestion from the same student, that a kettle used to boil water might be such a device because it had a heating coil, identifies that the concepts were new to them and links to prior knowledge had not been made.

During the discussion the students were asked to consider how a solenoid might be used in appliances as a tap. Perplexed facial expressions, together with questioning responses – "As a tap?" (V-290606-M-11Ph), further emphasised that while these students were aware that a solenoid was an electromagnet and could draw labelled diagrams of them (Fig. 4.6.2), they had little if any idea that they were commonly used in household appliances.

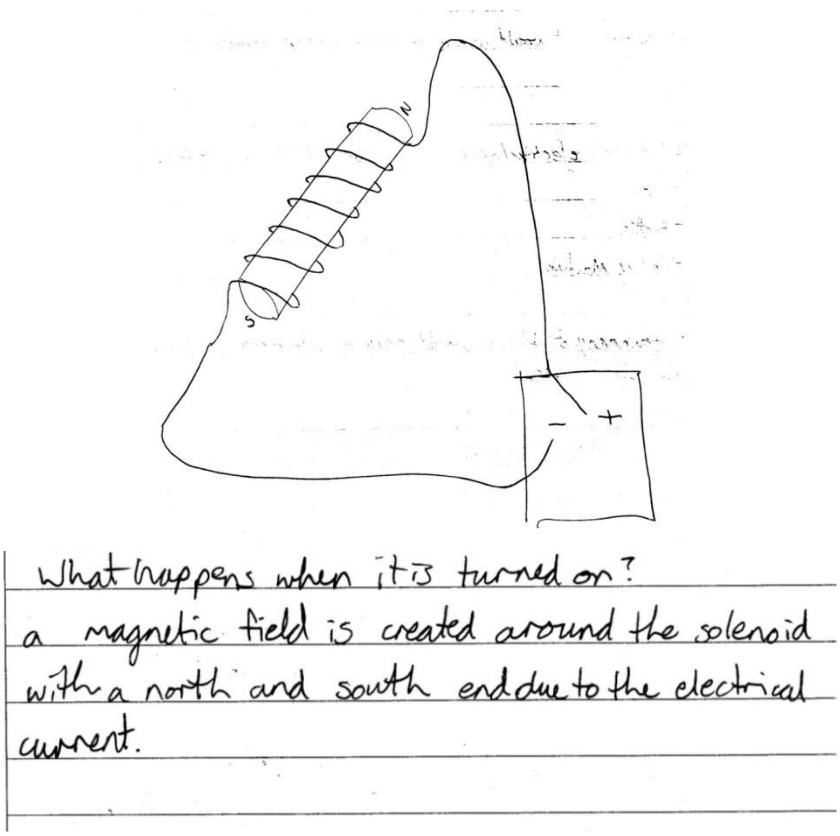


Fig. 4.6.2 Typical student response to "Draw a solenoid and describe what happens when it is turned on" SA-290606-M-11Ph-S5.

Table 4.6 Responses to questions asked during the Focus Phase of the Solenoid Modelling episode in 2006 (SA20060611Ph)

Student	*Question 1 (Current understanding)	*Question 2 (List)	*Question 3 (Function of solenoid for one)	*Question 4 (Tap)
06-1	I know a fair bit	Fan, washing machine	The electrical fields around the solenoid magnetise so when they come across a magnet, the solenoid like ends repel the magnet. And surrounded by magnets of like ends will rotate	No response
06-2	I have little understanding of solenoids	I don’t know	No response	Hot water
06-3	There’s room for improvement	Fridge, heater, air conditioner, toaster, electric tooth brush	In the electric tooth brush the solenoid is used in the motor to spin the head	Hot water system
06-4	I know a fair bit about solenoids, what they are and how they are useful.	Washing machine, air conditioner, heater, TV computer	Washing machine, the solenoid in the motor spins the washing machine	Washing machine
06-5	Not a lot (very little)	Microwave, fridge	No response	No response
06-6	Just knowing what a solenoid is but not knowing a lot of appliances that uses solenoids and why they use each other.	Washing machine, fridge, compass, TV monitor, motors	No response	Washing machine
06-7	I know a bit about solenoids but not much about their uses in the home.	Fridge	No response	No response
06-8	I have attained little understanding about solenoids at the moment.	Don’t know.	No response	Hot water, kettle
06-9	I could know more-right now – not much.	Fridge, oven, dishwasher, electric mixer, toaster.	The solenoid could release the spring loaded latch on the toaster	Dish washer, washing machine
06-10	Solenoids can be used to provide electricity but can have a hollow interior.	Fridge, kettle	No response	Hot water system
06-11	No response	Microwave, fridge	No response	No response

* The bracketed words in the table headings relate to the four questions.

The identification of this general lack of understanding established a need for the learning activity. To establish that the students already had some background knowledge that would be useful, the students were asked two guiding questions. The first, “What electrical devices that use water might a person have at home?” was readily answered by the students. They mentioned familiar devices such as irons, air-conditioners, washing machines, dishwashers, swimming pools with timed filtering systems and automatic sprinkler systems.

The second question, “How might the water be turned on and off in these examples?” led to a brief discussion. The discussion elicited responses by some students that the turning on and off of the water would be controlled using electricity. Others agreed. In the discussion that followed, a consensus was reached that there were many devices in which water was most probably turned on and off electrically using an electromagnet (solenoid) during some automatic/timed cycle. All students agreed that they had at least one such device at home. The students still however had little idea about how a solenoid could be used to control water flow. In fact most had little idea how a conventional tap functioned. One student recalled that a tap has a washer but could not explain how it functioned in the tap. Providing a sketch and a description of how the conventional tap was turned on by unwinding a screw using the tap handle, which moved the washer to open a gap allowing water to flow, assisted the students. They were then able to begin making sketches, hypothesising how a solenoid might be utilised in a solenoid valve (see Fig. 4.6.3 a & b).

Fig. 4.6.3 Student proudly showing his initial sketch of a possible solenoid valve design to the camera. (V-290606-M-11Ph)

Despite their confidence to begin the task however, some students displayed misconceptions about magnetism. During the classroom discussion, several students made comments suggesting they thought all metals were magnetic. Another student said “I get it – the solenoid pulls the water” (V-290606-M-11Ph). He made reference to the solenoid attracting the water in a similar way that an electrically charged rod does and was keen to test the idea. Interestingly, so were two other members of his group.

The questions had helped to establish a familiar base from which students could identify personal relevance and meaning in the task. In the process, students levels of understanding could be assessed and some misconceptions revealed.

As a lead into the *Action Phase,* a final question was asked: “In a washing machine, would the solenoid tap need to be on or off for the water to flow?” All students agreed that the water only flows into the machine when the machine was turned on and hence the tap inside the machine that used a solenoid must be closed when the electricity was turned off.

Action – Developing the models

Students were challenged to produce a model that would simulate a solenoid operated tap (solenoid valve); to show how water could flow when an electric switch was turned on and not flow when the switch was turned off. To maximize the ‘hands on’ feature of the task, the students were told that group sizes were not to exceed four.

Students were then directed to a trolley (Fig. 4.6.4) that had on it; their previously constructed solenoids, bar magnets, some connecting wires, and an assortment of other materials including cardboard, paper clips, sticky tape, iron rods and rubber bands. They were told that they could use any of the usual equipment found in the laboratory (transformers, retort stands etc.) and that they had a time limit of just 20 minutes.

While the students in 2005, 2006 and 2007 were constructing their models, video records were captured. The 2005 images were taken using the camera of a mobile phone and the 2006 and 2007 images were captured on a high quality digital camera. While the

2005 images are quite poor in quality, they provide an accurate record of at least part of the groups' activities during the episode.

Fig. 4.6.4 Students collecting materials for their model solenoid valves (V-290606-M-11Ph).

Groups had different ideas and constructed a variety of models. During the model development the students were actively involved. Group 05-S created a vertical model with a bar magnet suspended by rubber bands below a solenoid, clamped on a retort stand. Much of their time was spent constructing an elaborate web of rubber bands to support the magnet. Their fervour was especially noticeable when they were testing its operation. All three students were working on their model and at the same time they were talking and making suggestions about how to make it work better. At the moment shown in the Fig 4.6.5, the student on the right said, "OK wait. I'm putting it [the magnet] a bit lower".

Comments such as "cool" and "too good" amongst beaming smiles, indicated that the members of this group were elated when lowering the magnet helped to get their model working (V-170605-M-11Ph).

Fig. 4.6.5 Group 05-S building a model solenoid (V-170605-M-11Ph)

While there were similarities among the models constructed by each of the 2005 groups, they were all different. For example, two groups used two test tube racks to guide the movement of a bar magnet (Figs. 4.6.6 and 4.6.7) yet their method of controlling movement, when the electromagnet was switched off, were different. Group (05-E) simulated the stoppage of water flow using rubber bands which forced the magnet to return to the solenoid when the switch was open (Fig. 4.6.6 b).

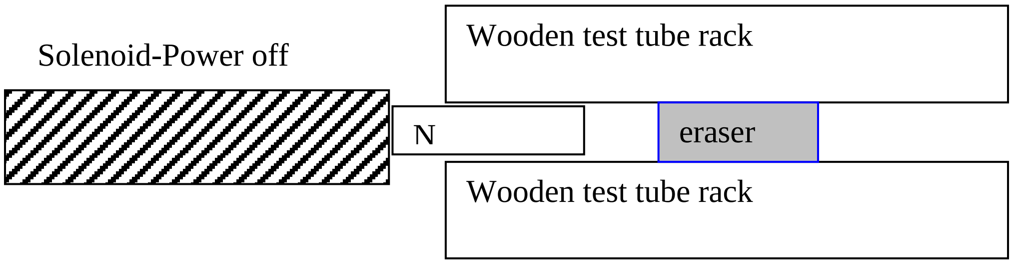
Fig. 4.6.6 (a) Group 05-E testing an idea (b) Group 05-E's more refined model (V-170605-M-11Ph)

Group (05-K/N) took a different approach. Like the others, they had identified that they could apply the concept that like magnetic poles repel, to get the bar magnet to move away when the solenoid was turned on (simulating that the tap was turned on, thus allowing water to flow through the gap). However, they used an eraser to restrict the movement of the bar magnet and adjusted the size of the gap so that when the solenoid was turned off, the attraction between the bar magnet and the iron core of the solenoid caused the magnet to move back, closing the gap when the solenoid was turned off (Fig. 4.6.6 and Fig. 4.6.7).

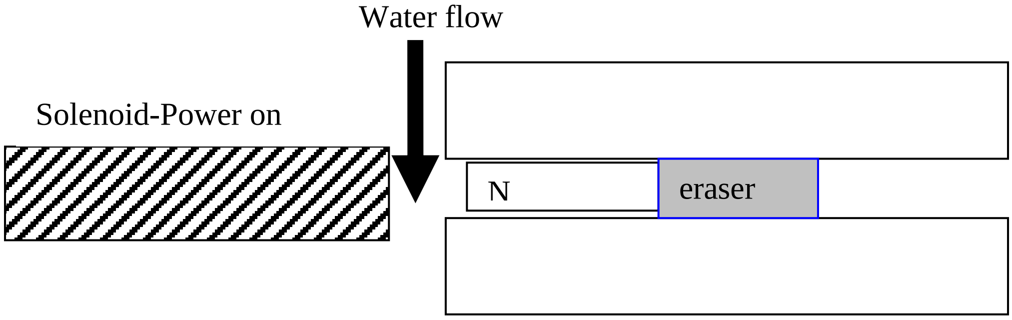
Fig. 4.6.7 (a) Solenoid on-tap open (b) Solenoid off-tap closed (V-170605-M-11Ph)

These students worked quickly and had time to produce a labelled diagram showing how their model worked. Fig. 4.6.8 below is a computer generated representation of their labelled diagram.

One student (05-Si) working independently, persevered through several modifications to produce a model in which a bar magnet was suspended below a solenoid in a similar way to that of group (05-S) (Fig. 4.6.5). His model however, had the bar magnet suspended from the solenoid itself (Fig. 4.6.9). During his progress this student demonstrated his model (to me) several times and sought support for his suggestions and improvements.



When the power to the solenoid is off, the magnet is attracted to the iron core of the solenoid. This closes the gap between the solenoid and the magnet – turning off the water



When the power to the solenoid is on, the magnet is repelled by the solenoid. This opens the gap between the solenoid and the magnet – turning the water on

Fig. 4.6.8 Group 05-K/N Solenoid model – diagram

Fig. 4.6.9 A model that used gravity (V-170605-M-11Ph)

Within the 20 minutes, the 2005 students had constructed, tested, revised and improved a range of different models, all of which demonstrated aspects related to the targeted science domain.

The lesson was immediately before a short morning tea break. Typically, students are keen to move from the classroom to the school yards and eating areas at the end of the morning lessons. However, at the end of this lesson, there were no students hurrying and four students (Group 05-E and 05-Si) who were keen to improve their models, remained and continued working for approximately 10 minutes.

In 2006 the students were similarly keen to build and show get working their analogical models. The images below show two very different models. One is suspended on retort stands. It includes a magnetic flap as its opening device and has two separate outlets. The other is taped to the table, has a single pipe for water flow and a plunger style magnetic valve. Both models, however, demonstrated that a solenoid could be used to open and close a pipe.

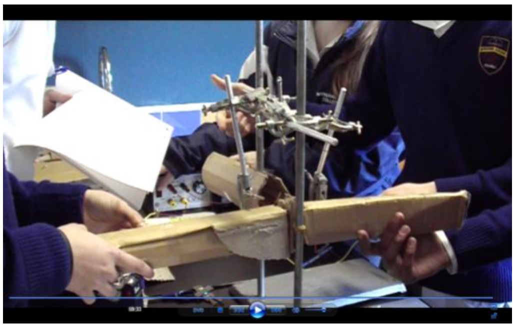


Fig. 4.6.10 Two groups working on their model solenoid valves (2006) (V-290606-M11Ph).

The model building process resembled the iterative micro-cycle model development reported by Nunez-Oviedo and Clement (2003). The students constructed, assessed and modified their models, oscillating between action and reflection in the process.

Reflection

At the beginning of the week after the models had been built, the 2005 students were asked if they had noticed anything about their washing machines or dishwashers over the weekend. Several students indicated they had taken an interest and had listened to the devices while they were in operation. One student (05-S) remarked that she had noticed the "clunking" of the solenoid valve as the water suddenly turned off when the washing machine was full. Another student, (05-Si) said his parents were astounded when he had asked if he could stack the dishwasher. He "wanted to turn it on and listen for the solenoid valve operation". This discussion provided an opportunity for students (and me) to reflect on their models and compare them to the real devices. In sharing their thoughts and experiences the students provided positive affirmation that the model building not only helped them learn about the physics, it exposed them to the relevant science that was in their homes.

Focus group interviews

All members of the 2005 class were invited to participate in a focus group interview during a lunch time break in the following week. While eight students expressed some interest, only three students came. Prior to the interview, these three students completed a questionnaire. Results from the completed questionnaires (SS-170605-M-11Ph) indicate that these students:

- Felt they were actively participating in the task;
- Felt the task help them understand the science they were learning;
- Enjoyed the task;
- Worked well with other members of their group; and
- Were reasonably happy with their models.

During the focus group interview (students made several comments indicating that they:

Enjoyed the activity;

- It was a fun experience
- It was quite interesting
- It was good
- It was really exciting
- We were all interested in making the solenoid valve

Were challenged by the task;

- We wanted to make a better one than everyone else.
- We wanted ours to work first.
- Pretty hard but we finally got there.
- It wasn't a success at first.
- It was frustrating, but at the end we got it.
- I was a little confused at times – I found it a little challenging to make what I wanted to with the resources provided.

Had ownership of their learning;

- We put our own ideas into it.
- We are not being told what's right and wrong – we are discovering for ourselves.
- It helps you remember when you do it yourself.
- Allowed us to look at our own ideas and see what is wrong with them and try to refix how we think about things.

Felt successful;

- We were really happy with the final invention.
- You feel proud of yourself.
- It helps us understand a lot more than just reading.

Observations, supported by several short video recording made during the activity (V-170605-M-11Ph), showed that students were:

- Willing to generate and test ideas;
- Within groups students were actively discussing ideas-listening to each other and testing ideas by building and modifying models.
- There was a keen sense of friendly rivalry between the groups – all seemed to be working towards being the first to produce a model that would show the concept.
- Sometimes there was considerable laughter from a group especially when their model fell apart or behaved in an unpredictable manner.
- Some students asked if they could to work into the morning recess break to refine their models.

Proud of their achievements;

- Groups who made successful working models cheered when the models worked
- Elated comments such as “Too cool” “Ours is cool” and “Oh look at that skill” when their model worked.
- Groups were willing to demonstrate their models for others

The intervention was implemented again in 2007. During this revised intervention the students were more specifically encouraged to show on their models, where the water would flow. Expecting that the models would therefore be a little more elaborate than those build in previous episodes, the students were given twice as much time (40 minutes) to construct their models. One of the models was videotaped while it was being tested (see Fig. 4.6.11)

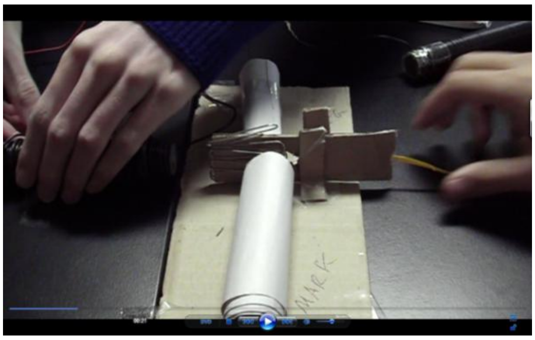
 

Fig. 4.6.11 (a) Students adjusting their model (b) The solenoid turned on, pulling the hole into place – showing where water would flow. (V-270407-M-11Ph)

In the model pictured and in others produced during this episode, the students depicted the water pipes using rolled up paper and created actual openings that coincided with the pipes when the solenoid was activated. This provided an added dimension of realism to the models and helped to focus the discourse on the physics involved.

Analogical discourse was evident during the model building process for all groups. During the building of the 2007 models which included the water pipes however, the students more specifically referred analogically to sections of their model. For example, (see Fig. 4.6.11) they referred to the section including the electromagnet and the cardboard slider with paper clips attached, as the solenoid valve and to their cardboard tubes as the water pipes. When they switched on the transformer to power their electromagnet, they spoke of turning on the washing machine and allowing water to flow through the hole. Typically, however, the students in all groups in all episodes were actively engaged, thinking in context and trying hard to apply physics to get their models to work.

None of the models mapped perfectly to a real solenoid valve, however, when the discussion continued in class, the students were able to comprehend a diagram drawn on the board that showed the main features of one.

These episodes highlight a particular aspect of the intervention as it relates to models. An analogical model does not have to be accurate to facilitate learning and understanding. In this case, the model solenoid valves did not have to accurately show what was inside a real solenoid valve. The students' 'inventions' merely had to show the concept of using an electromagnet (solenoid) as part of a mechanical device that could open and close a gap. Through the analogical application of the physics to the idea of a solenoid valve, the students developed a high level of understanding about controlling water flow in appliances such as dishwashers and washing machines. In the process, they appropriately applied the physics of magnetism in ways that provided meaning about real life situations: and, as will be identified below, they could remember and apply what they had learned.

A specific question was included in the 2004 topic test. The question was: "Explain one application of magnetic fields in one household appliance. (Use a diagram)". Copies of the answers were collected as artefacts for this research. An analysis of the answers revealed that the learning from the intervention was accurate and persistent. 14 of the 17 students had reasonable explanations including appropriate diagrams representing a solenoid valve. 13 of these students used the example of a solenoid controlling water flow in a washing machine and one, controlling water flow in a dishwasher. Of the other three; one correctly applied the concept to an electric can opener, one applied it correctly to an electric door and one student did not attempt the question.

Two examples of answers relating to washing machines are shown below.

Student response (1)

> One application for the use of household appliances is a solenoid in the washing machines. A solenoid is an electrical magnet which can be switched on by the use of electricity. This concept can be used to control the water flow in a washing machine. When the washing machine is turned off – the spring pushes the iron bar across the channel, thus restricting water flow. When the electricity is turned on, the solenoid is then an active

magnet, and attracts the bar to the side of the channel, allowing water to flow past. (SA170604-11Ph AC)

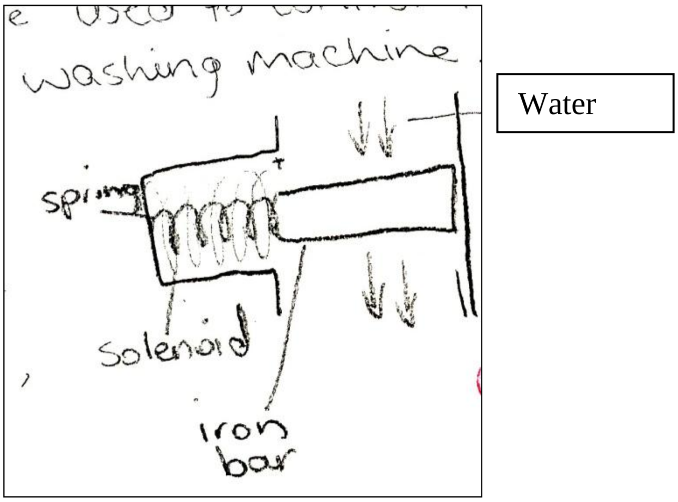


Fig. 4.6.12 Diagram for Students response (1)

Student response (2)

This solenoid valve is used in the household electrical appliance, the washing machine. This valve is used for letting water from the tap into your washing machine at the required time. The machine does this automatically thanks to this valve which is made from three main components; the solenoid, the spring and the piece of iron. The solenoid is an electric magnet which when turned on produces a field which counter pulls on the spring and piece of iron to let the water enter the machine. When the solenoid is switched off the spring pushes the piece of iron back in place so the water can't get through. This is a good example of a magnetic field in that it doesn't just use a permanent magnet but uses an electric magnet (solenoid) that can be switched on and off at required times. (SA170604-11Ph JM)

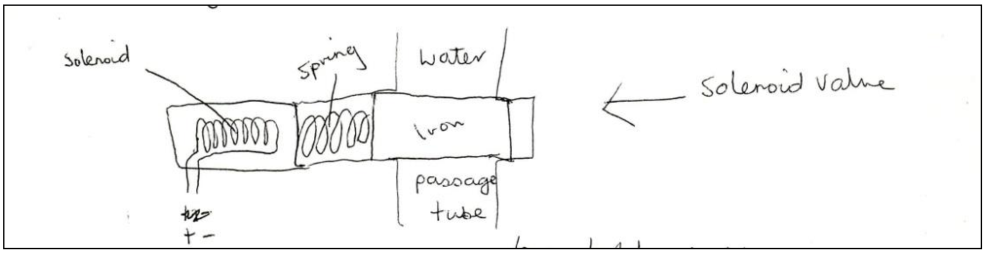


Fig. 4.6.13 Diagram for Students response (2)

While the written responses for these two answers are more typical of the better responses, most students had diagrams which were similar in detail to Figs. 4.6.12 & 4.6.13). It is noteworthy that the diagrams represented real solenoid valves and not the students' models.

Conclusion

During the episodes reported in this vignette, the students in four different physics classes were able, with minimal help, to develop working analogical models that accurately demonstrated a scientific principle. In doing so they progressed from a very limited understanding to being able to display high levels of understanding about a target concept. The models were not accurate representations of real solenoid valves. Nevertheless, correct scientific understanding of the principles involved was developed through the co-construction of these imperfect models. During the activity, all students appeared to be happily and actively engaged with their peers in a scientific process. They were applying, testing and modifying their ideas to find a solution to a problem. The understanding gained, was developed during the activity; accurately shown at the end of the activity; and demonstrated several weeks later under test conditions. This episode has thus shown that the co-generation of analogical models can engage students in effective learning resulting in persistent understanding.

4.7 The photoelectric effect

Yr 12 Physics

Vignette Five

In Chapter 1, an example of an analogy was provided in order to foster the understanding of terms relating to the use of analogy. The example described how John, a Year 12 Physics student, was assisted in his development of understanding about the photoelectric effect by referring to a real life situation that was of particular relevance to him. This led to the first of four episodes of the intervention in which the 14 other Year 12 Physics students in John's class were encouraged and supported in developing their own understandings about Lenard's photoelectric experiment (see Appendix 7) by co-generating analogies.

This set of episodes which occurred over four years with four different classes has been selected for presentation for several reasons.

1. Each student developed their own personal analogy by choosing their own base from prior personal life experiences.
2. The narrative form of the analogies is different from those presented in the other vignettes.
3. The sharing of personal analogies among students revealed implications about the learning.
4. As a set, the episodes show developments in the implementation of the intervention.
5. Multiple applications of the intervention, in similar ways with different classes, reveal commonalities which support the trustworthiness of the data and findings.
6. The final episode was observed by my doctoral supervisor and his observational notes verify processes used in the intervention and provide support for the findings.

The Episodes

The students were in their final year of schooling and had been subjected to thousands of analogical models in texts, video tapes, movies and lessons over their previous years. Even so, because the concepts being developed were difficult, requiring complex "concept-process models" (Harrison & Treagust, 1998, p. 22), and because the students had not previously developed their own analogies, care was taken during the *Focus Phase* of each episode to:

- Introduce students to the concepts of mapping features (attributes and relations) of a model with its target science (which itself is often a model);
- Identify that no model is perfect;
- Allow students to choose part of the concept for analogical development – and to modify their ideas as they went – especially after discussion and/or practice; and
- Allow and encourage students to work in groups and to share their ideas with others before presentation.

During the *Action Phase* of each episode students developed their analogies with support, when needed, from others in their group and from me.

During the *Reflection Phase* students discussed, refined and presented their analogies. After listening to the analogies developed by their peers some students made further refinements to their own analogies. In this respect, there was some oscillation between *Action* and *Reflection* during the final part of the intervention.

The headings *Focus, Action and Reflection* are used in reporting the first episode, to show the structure of the intervention lessons which were essentially the same for each of the episodes. Repeating the episodes provided opportunities to explore ideas and seek clarifications through the collection of specific data.

Episode 1-2004

Focus

After working with John on his personal analogy, the 14 other members of the class were encouraged to develop their own analogies. The students had not previously developed their own analogies in Physics and so it was necessary to explain and discuss the idea before we started (see above). This was achieved by recounting John's analogy to the rest of the class and introducing terms such as target, base and mapping. Mapping the given analogy to the photoelectric experiment with the students, facilitated discussion about which features (attributes/relations) were included and which ones were not. The students were told that in developing their analogies, it was unlikely they could deal with all features of the experiment; that they should, however, try to include as many features possible; but not worry if certain features were not accounted for. It was also suggested that they should develop their analogy based on something familiar to themselves (chocolate bars and movie tickets were given as alternatives to cigarettes). They were encouraged to go beyond a mere matching of the given example to their own and to include additional features of the experiment where possible.

Action

The students were allocated about 20 minutes of the lesson to draft their analogies and they worked hard to include many features of the photoelectric experiment. One student, for example, who used the purchasing of chocolates as the analogy, wanted to include the feature that different metals have different work functions (W) and therefore threshold frequencies (f_o) (see Appendix 7, Fig. 11.18). He mapped this feature of the experiment to purchasing chocolates of different costs. The different costs of chocolates mapped well against the work functions of the metals.

While the students were developing their analogies, they identified areas in which they needed help and asked questions to seek clarification.

Reflection

Most students were able to select a personally familiar situation on which to base their analogy, however, the analogies developed were typically similar to the sample given.

Discussion with the students about their analogies required them to clarify their points of comparison and enabled areas of misrepresentation and misconception to be identified and corrected. This led students to further refine and sometimes extend their analogies. For example, discussing how the cost of chocolates could be determined from the amount of change given for a variety of notes ($5, $10, $20 etc.), fostered additional mapping from a student's analogy to several aspects of the photoelectric experiment (the photon energies, the work functions for different metals, and the kinetic energy of the photoelectrons).

During the development of their analogies, students shared ideas with others at their table group and towards the end of the lesson with other members of the class. This sharing of analogies allowed students to evaluate their own analogies and the analogies produced by other students, further helping to facilitate their understanding. Developing the analogies had allowed the students, in a short period of time, to show, clarify and enhance their understanding of the target science.

Episode 2-2005

The following year, when the next Year 12 physics class (11 students) were at essentially the same place in their learning, the intervention was repeated using the same FAR phases. Hence, I told the students John's story (see Chapter 1); asked them to invent their own analogies; and provided time for discussion about and sharing of their analogies. During the *Focus phase* however, greater emphasis was placed on the students choosing personally memorable bases for their analogies. This was done to encourage a broader, more personal range of student generated analogies, in order to explore the effect on long lasting memories of the target science.

During the lesson, some students still used examples similar to the one provided, involving the purchasing of something (chocolate, biscuits, slushy ice drinks and birdseed). Several others, however, came up with more personal ideas. These included; people on a dance floor; evaporation of water; and a religious situation in a mosque. Some of these more personal analogies, however, created a challenge for me in providing co-generative support. While I could readily identify the mappings for most of the students' analogies, some were so unique to the culture of the students (see the mosque example, lines 51-88 in the transcript below) that the base needed to be explained very carefully to me before I could understand how the student was mapping attributes and relations to the target science.

The process of the students sharing and explaining their personal analogies revealed their understandings and aided the co-generative process.

A revision lesson

The checking of lasting memory was of particular research interest and as part of this episode audio data from a revision lesson conducted two months after the intervention is presented.

During the revision lesson, the students were asked to recall their analogies for the photoelectric experiment and to discuss them in small groups. While the pedagogical objective of this revision activity was to strengthen their understandings of the science concepts involved, the research component was to identify if the students could recall their analogies and/or what they had learned and could remember about the photoelectric experiment. Students worked in three groups and the discussions were audio taped.

The following transcript section is from one audiotape (AT-120905-A- 12Ph3) recorded during the lesson. It is provided to reveal some details about the students' recall of their analogies and to highlight the nature of the students' discussions. Pseudonyms are used for the students involved.

Alex	So when a photon hits a metal surface – what kind of surface was it?
Jeffrey	Yes it was – when a light photon hits a metal surface.
Alex	It will emit ah-kinetic – it will emit energy if that frequency –
Mohamed	Won’t the metal emit the electron thingy – is that what happens?
Alex	When the metal (lots of over talking).
Jeffrey	When the light photon hits the metal.
Alex	Yes.
Jeffrey	The electrons will absorb the energy and gain enough energy therefore breaking free from the metal and creating current.
James	Creating current.
Jeffrey	Called photo-current.
James	Oh – photo-current OK.
Alex	And that has to – and that photoelectron has to be a what – below a certain?
Jeffrey	Has to be of a certain frequency.
Alex	Frequency yes – which is the threshold frequency.
Jeffrey	Yes.
Alex	If it’s not [laughter] – so if the – if the frequency of that hertz exactly equal to the threshold frequency – no energy will be emitted.

Background No, no.

Alex That's right - No – it will be emitted but it won't be able to reach the surface.

Background Yes, yes.

Zac What analogy did you use?

Alex Let's see.

James Cigarettes.

Alex No I'm not a smoker – oh.

James Dance floor.

Alex Dance floor? Please explain about the dance floor.

Lots of excitement and noise. Dance floor! – Dance floor! Dance floor!

Mohamed Well the people were the -

Alex What were you saying about the dance floor.

Mohamed Well the people were the electrons in the metal surface and the dance floor was the metal surface and the music came on – that was the light that will make the people start moving –

Alex Oh so if the music was good enough –

Mohamed Yes.

Alex Because the threshold frequency – then they would be – start dancing –

Mohamed Yes.

Alex	When they start dancing that’s then emitting the energy from the
Mohamed	Yes.
Alex	Metal surface.
Mohamed	Yes.
Alex	That’s a good analogy.
Alex	So Zac wasn’t your’s about chocolate or?
Zac	Oh I can’t remember.
Alex	Weren’t you going to the mosque and if you were?
Zac	No that was Eddie’s – Eddie made that up [the group laughing].
Eddie	No that was mine that was mine [visiting the group after hearing his name].
Zac	I can’t remember – all I remember – it was just on slurpies – and that was it.
Alex	Yes it was slurpies – go –
Zac	I can’t remember – going to Seven Eleven that’s it.
James	[Flicking through his notes] – Oh here I –
Alex	You go to the mosque - the mosque is the metal surface-
James	[Finding his analogy in his notes and interrupting excitedly] – Analogies – it’s right here – [reading and explaining] you got the money – you got the money or the note which is the E = hf – you got the shop which is the metal – you got the drink which is

	electrons – the price which is the threshold energy-and the change which is the er -
Others (almost in unison)	energy - kinetic energy – yes yes – so that –
Alex	You go to the mosque – which is the metal surface. If you were of a good – if you had been a good Muslim – which would be your frequency – and if the – What is the person there called – at the mosque?
Zac	Imam.
Alex	What? Yes - the person that [lots of noise and some laughter] - Imam. [More laughter and ‘ya mum’ in the background]. Yes if you had been good - of a good Muslim and that’s your thing and he thinks you have been of a good Muslim - which would be his threshold frequency – you would receive the blessing?
Zac	Yes. I would receive the blessing [in the background agreeing].
Alex	Which would be the kinetic energy – that was mine.
Jeffrey	Will you quit relating religion to the photoelectric effect – come on [laughing].
Alex	Well actually the thing wasn’t actually the metal surface – the
James	Ya mum.
Alex	Yes, the Imam was the metal surface –
James	That guy you know – ya mum – eh! [laughing]
Eddie	It was good though –
Alex	It’s quite different from the others as you can see.

87 Mohamed No mate-The dance floor was the best.

88 Zac Yes the dance floor was pretty good – I reckon.

89 Mohamed Yes that was good (AT120905-A-12-Ph3).

This section from the transcript is typical of the full transcript and highlights the rapid and overlapping nature of the discussion that occurred during the revision session. While some students needed prompting from their peers (e.g. Line 48) and at least one student had to refer to his notes (Line 60), in general they were able to remember their analogies and were able to map features back to the photoelectric experiment discussed in class approximately two months earlier. Interestingly, Alex who was a Muslim remembered the mosque analogy in more detail than the student who created it; and Zac was able to recall more details about other students' analogies than his own.

The revisiting of analogies, during these discussions provided another opportunity for *Reflection.* Through comparisons made between multiple bases, the students were recalling the target science and assessing the effectiveness of the analogies they had generated (e.g. Lines 47, 85 - 89).

The discussions also provided me with opportunities to further identify and help correct misconceptions about aspects of the photoelectric effect. In the example below (Excerpt 1), the use of the phrase "were heated enough" identified a probable misconception relating to photons.

Excerpt 1: An evaporation analogy for the photoelectric phenomenon

> Personally I used evaporation to sort of model it where I used a water body or a lake as the metal body and the sun heat coming as the source of light. And so when the water molecules or particles were heated enough and gained the energy needed to escape the water, which is like, equivalent to the threshold frequency, they escape in the way of evaporation. (Student 2-AT120905A-12Ph1)

Discussion with this student about his analogy revealed that while he could accurately map aspects of what happened in the experiment to his analogy and he could discuss many aspects of the photoelectric experiment with accuracy and confidence (see Excerpt 2 below), he had not fully understood the quantum nature of light as a key aspect of the photo electric phenomenon.

Excerpt 2: An accurate description from memory, relating to the graph from the photoelectric experiment (see Appendix 7, Fig 11.18).

> Mathematically or graphically, when E is graphed against frequency we can determine the work function. Graphically, when the graph cuts the E axis – it falls below the frequency axis, negative – so graphically we can determine the work function; which would be where the graph cuts the energy axis to the frequency axis; the difference – which is negative. And then we can also determine the threshold frequency graphically where the graph cuts the frequency axis. (Student 2 – AT-120905-A-12Ph)

This example shows that the intervention was useful to the student in remembering specific minute details of the target science for a long time. It also provides an example of how the use of a student generated analogy helped to reveal a subtle misconception which would otherwise have remained uncorrected.

Episode 3 – 2006

Episode three was conducted with a Year 12 Physics class of 10 students, at a similar time during their course using the *FAR phases*, as in the previous two episodes. It provided opportunities, however, to further refine and explore aspects of the intervention. These included:

- Checking students' abilities to recall aspects of the photoelectric experiment at the beginning of the intervention;
- Providing a template to support the students in mapping their analogies;
- Gathering students' opinions about the intervention; and
- Gathering data from an examination-relating to individual students' long term understanding about the photoelectric effect.

Extracts from field notes, questionnaire responses, artefacts from students' class work and an analysis of examination answers, resulting from the above opportunities are discussed below.

Prior to the intervention being used with this class, the students were given a lecture style lesson about the discovery and further exploration of the photo electric effect and how Einstein had interpreted the results The students made notes and copied diagrams, drawn on the whiteboard during the presentation. At the end of lesson I asked the class if they thought they understood the photoelectric experiment and what it indicated about light. All of them indicated that they understood. This was evident because they were then able to chant snappy, correct answers to a barrage of questions about all aspects of the experiment. (Field notes-SA080606-12PH)

Examples of questions that I asked the students while referring to a diagram and graph on the white board (similar to those shown in Appendix 7), are shown below.

- Why was a quartz window used? How did the scientist know to use this?
- What is the purpose of the galvanometer; the variable voltage supply?
- What will the galvanometer show when low energy light is directed onto the metal surface? Why? What happens if the frequency of the light is increased?
- Why is it that a 'truck load' of low frequency light produces no photoelectrons yet just one photon of high frequency light will produce a reading on the galvanometer?
- On the graph of photoelectron energy versus frequency, what is the significance of the; x-intercept; the y-intercept?
- What happens if a different metal is used? How is this shown on the graph?
- What happens above the threshold frequency to the energy of electrons emitted if the frequency is increased?
- What happens to the number of electrons emitted if the intensity is increased? Why?
- What do we call the voltage between the metal plate and the collector when it is adjusted so that the galvanometer reading becomes zero? Why is it called that?

This would ordinarily mark the end of teaching for this concept. About a week later, however, I asked students to recall details of the photoelectric experiments. I was expecting the students to have forgotten some of the complexities but was surprised how little they were able to recall without prompting. (Field notes-SA080606-12PH)

The poor recall of details was the prompt to begin the intervention suggesting to the students that using an analogy might help them learn so that they might remember what they had learned.

After telling John's analogy I asked the students to identify (map) aspects of the story to the photoelectric experiment. They were able to correctly map several aspects. I also asked them to identify one aspect of the experiment that was not represented in the analogy. On student said "the stopping voltage" and another identified "the different metals" and others agreed. (Field notes-SA080606-12PH)

The students were already thinking and within just a few minutes, they were well into the task and as the field note below shows, so was I.

After about three minutes a student asked me if he and another student could use the same analogy. When I asked why, he said "I really like his one – it works well". So I asked what it was about and the other student began to tell me about "going to university and how students needed a certain UAI (ranking) to get into various courses". He paused and I asked "have you thought about how to account for different metals"? As he began to tell me about different courses at the university, the first student also began speaking. He said "you would have different universities". At this point I said "OK – so now you can work on the same idea about universities but they will be slightly different". They agreed happily and continued to work. (Field notes – SA-080606-A-12PH)

The students were asked to produce a table that mapped the features of their analogy with the features in the photoelectric experiment and then to share with the class their ideas about one or more of these features.

An example of a mapping table provided by one of the students appears below (Fig. 4.7.1). The analogy, as explained by the student, worked well except for the last point. During the discussion with the student about her analogy, she identified that she was aware that her last point, referring to the bus breaking down, was a "struggle" and that she had difficulty trying to "work in the stopping voltage". She was aware that the relation between the bus door and the stopping voltage was inaccurate; however, she was able to use the concept of the bus door to provide an accurate reminder about stopping voltage. As revealed in one of her comments on the questionnaire: "By mapping the analogy bit by bit, the science part became less complicated" *(*SA-080606-12Ph- CF), personally developing and mapping her analogy had assisted this student to make sense of the target concepts.

FEATURES OF THE PHOTOELECTRIC EFFECT	ANALOGY (STORY)
• Atom	• Bus
• Electrons	• Passengers in the bus
• Threshold Frequency	• You need a certain amount of money to reach a certain destination
• Electron Emission	• Passengers getting off the bus -popular destination - more people get off - not so popular less people get off
• Galvanometer (measures number of electrons)	• Survey which is counting the number of people getting off the bus at a particular destination
• More energy	• More money therefore, reach a further destination
• Not enough energy to reach the threshold frequency	• Not enough money to get to that destination
• Different metals	• Different destinations
• Stopping Voltage	• Bus breaks down and the doors have to remain shut for a reason

Fig. 4.7.1 Student's mapping table for a photoelectric analogy SA-130606A-CF-12PH

The 10 students who participated in this episode completed a Science Activity Questionnaire (see Section Appendix 2). The responses to the 10 questions were typically positive with average scores for questions falling between 3.6 and 4.2 (1 being the most negative and 5 being the most positive). In addition, a total of 23 *Optional comments* were made by these students on the questionnaire (see Table 4.1).

Table 4.7 Optional responses to the Questionnaire (SA- 080606-A-12Ph)

Questions	Responses
Q. 2. To what extent were you participating in the activity?	(i) There was a lot of class, group and paired discussion and that helped with interpretation of the idea. (ii) Listening to other people's ideas and theories helped me understand the concept.
Q. 3. To what extent do you think the activity helped you understand the science you were learning?	(i) It can simplify the experiment, but can also confuse. (ii) By explaining the concept in simpler terms and then increasing the detail slowly it made more sense of the concept.
Q. 4. To what extent were the members of your group engaged in what you were learning?	(i) We had to think deeply and coherently – therefore needed to be engaged. (ii) We were all writing our own analogy but also discussing.
Q.5. To what extent was the activity enjoyable?	(i) As enjoyable as physics can be. (ii) A little un-enjoyable when we began but once the helping and discussing came it was more enjoyable.
Q. 7. To what extent were members of your group working well together during the activity?	(i) Mostly an individual activity but we shared ideas and improvements for the analogy – helped each other.
Q. 8. To what extent were you happy with your final product?	(i) It didn't really gel with me. I prefer to just remember the prac. Though the exercise was helpful. (ii) By mapping the analogy bit by bit, the science part became less complicated. (iii) It did not really incorporate the 'stopping voltage'.
Q. 9. To what extent were the members of your group talking about the Science?	(i) We were forced to analyse the effectiveness of each analogy, in relation to the science involved. (ii) We were trying to figure out how to incorporate certain elements in the analogy.

One student who was very keen to develop an analogy that would map to all of the features of the experiment, rated the extent to which she was happy with her final product (Q. 8), as moderate (Score of 3). Her comment that her analogy "did not really address the stopping voltage" mirrored a measure of personal disappointment at not meeting her own challenge. Her realisation, however, is positive in terms of her understanding about the physics and analogies.

The *Optional comments* (Table 4.7) identify that during the process of developing their analogies the students were actively involved in sharing ideas, discussing their analogies and relating them to the target science (Questions 2, 4, 5, 7 & 9). The comments indicate that the students, even those who found the task difficult, believed that the construction of analogies was beneficial to their development of understanding about the photoelectric experiment. This is particularly evident by comments (see Table 4.1-responses 3 (i), 4 (i), 5 (i), 8 (i) & 9 (i)) made by the highest achieving student in the class, who struggled to develop an analogy based on people doing high jump. While she "preferred to just remember" the experiment as described on the board and found that the process of developing an analogy could "confuse", she thought the activity; required her to "think deeply and coherently"; "forced [her] to analyse the effectiveness of each analogy"; and that "the exercise was helpful" (SA- 080606-A-12Ph).

While it is likely this student did not require a special intervention in order to remember the details of the photoelectric experiment, the confusion she encountered in developing an analogy for it, flagged a warning that she perhaps did not understand the target science well enough to do so. This is perhaps also suggested by the deep thinking she had to do during the activity and her judgement afterwards that the activity was "helpful".

The final question on the questionnaire *Please write a brief comment about the usefulness of this activity in helping you learn the science you were studying*, required a written response. The responses which are shown below, also confirm that, in general, the students' perceived the activity to have had positive impacts on their learning.

1. This activity did help and was relatively useful in the understanding of the photoelectric effect. It is easier to understand and this understanding can be related to the actual concept. It also was easier to remember.
2. It helped understanding different singular concepts but I am still having trouble stringing the concepts together.

3. This activity allowed the class to discuss their analogies and helped me to understand my own. The activity helped to understand, in our own ways, the topic.
4. Analogies definitely helped in understanding the more difficult concepts. I find it easier to learn the ‘good’ analogies rather than making up my own. But by changing the analogies I have heard and adopting them to suit my understanding helps me learn the science.
5. It goes over the photoelectric effect for us and helps us better understand it using normal things. It gives us something later on that makes it easier for us to remember all about what we were doing and how to understand it.
6. The activity has enabled me to use the relevant science terms related to the topic. The analogy has made it easy to understand the concept of the photoelectric effect.
7. Personally, I think that my analogy covers some parts of the scientific concept but could not address other sections. However, hearing other people’s analogies helped me understand the concept more.
8. This activity was useful, to an extent, in forcing us to think about the science involved with this experiment and enabling us to think more deeply and be able to relate the science to everyday occurrences. It did help a general understanding of the process involved with the photoelectric effect.
9. Finding our own way to understand better, the concept of the photoelectric effect. This always helps because we find our own way that will suit ourselves, could even relate to us which would help understand.
10. By making it personal we can relate it to other things that you participate in. (SA080606-12Ph)

Three months after the intervention, this Physics class (Class A) completed the Trial Higher School Certificate examination with their peers from a second parallel class (Class B). Part (c) of question 30, (shown below) in the examination, required students to recall and apply their knowledge of the photoelectric effect.

(c) Describe the photoelectric effect and outline how the results were used by Einstein to support Planck’s ideas about the quantization of light. (SA-2006-T- HSC-Q30)

The answers to the question were used to identify the students' level of understanding about and their long term memory of, aspects of the photoelectric effect and the results of Lennard's photoelectric experiment.

All 10 students from Class A and 4 of the 11 students in Class B provided answers to part (c). In Class B however, five of the students who had not answered Part (c) wrote answers for parts (a) and/or (b). This indicated that they had made a genuine attempt during that part of the examination but could not answer part (c).

The marking criteria for the question was constructed by the teacher of class B and discussed with me prior to its application. In marking the answers, care was taken not to advantage or disadvantage students in either class.

The intervention focussed on aspects of the photoelectric experiment that were identified and discussed through the use of a diagram. Mappings between the students own analogy and the experimental set-up also focussed on aspects of the diagram and the relations between its parts. In this regard, it is no surprise that the students in Class A, who recalled the experiment, drew a diagram in their answers to the examination question.

The presentation of a diagram enabled identification of the students' abilities to recall aspects of the photoelectric experiment, such as the relationship between light falling onto a metal surface being the cause of electrons leaving the metal surface. The text associated with the diagrams was also considered. Students who were able to accurately present the experiment in diagrammatic form and correctly relate to it in their supporting text, showed what the SOLO taxonomy identifies (see Section 3.8.2) as a high level of understanding.

The diagrams (Fig. 4.7.2) from the data have been emphasised here rather than the full answers because they offer a quick visual representation indicative of student understanding (refer to Appendix 7). However, not all students who understood the photoelectric effect drew diagrams. This is shown by the response by student S6-A.

> The photoelectric effect is "the emission of electrons from a metal surface upon bombardment with light (usually in the high frequency

range)”. The physicist used classical physics to explain the phenomenon, but could not get any agreement between theory and experimental results. Planck changed the fundamental terms of physics to include quantisation. Only then were the results seemingly clear, but still no explanation – until Einstein.

The results of the photoelectric effect were:

1. Intensity: As intensity increased photo current increased
2. Emission time: Emission did not always occur, otherwise it was instantaneous
3. Frequency: Emission was greatly affected by frequency, under a certain frequency, no emission occurred.
4. K.E.: This depended on frequency under the f_c no K.E. was possessed, by electrons.

Einstein used a particle approach and was successfully able to give an explanation which supported Planck’s ideas about the quantisation of light. (S6-A)

Figure 4.7.2 shows all diagrams drawn by students in presenting their answers. Students S6-A (see the answer above) , S10-A, S2-B,and S3-B did not draw diagrams as part of their answer and seven students in Class B (S4-B to S9-B and S11-B) did not answer the question. Diagrams that show both the galvanometer (G) and a variable voltage supply (V) or the equivalent circuit symbols (see diagrams presented by S1-A, S2-A and S7-A) are the most accurate. In addition, three students’ answers (see S2-A, S5-A and S9-A below) included sketches of a graph depicting the results of the experiment.

It is pertinent to reveal that student S3-A was a high achieving student who placed overall third in the group of 21 students at the end of the course. She was, however, oversees at the time of the intervention and as a self motivated learner she covered all of the worked missed during her absence by working through the text book. Her written response that accompanied the incorrect graph (see below) included several inaccuracies, including confusion between photons and electrons, frequency and energy, and material and metal.

> This [photoelectric effect] is where light of a certain frequency above the work function of a material releases a photon. S3-A

Several students were able to display cause and effect (relational) understandings about aspects of the photoelectric experiment, approximately three months after the intervention. This suggests that they had developed high levels of understanding about those concepts and transferred that understanding into their long term memory.

The data presented in this episode show that students who had participated in the intervention developed a high level of understanding about the photoelectric effect. In addition, while the purpose of the research was not comparative, data from others students of similar ability, who had been taught using more conventional, didactic methods demonstrated significantly lower levels of understanding. This supports the use of the intervention as a pedagogical method.

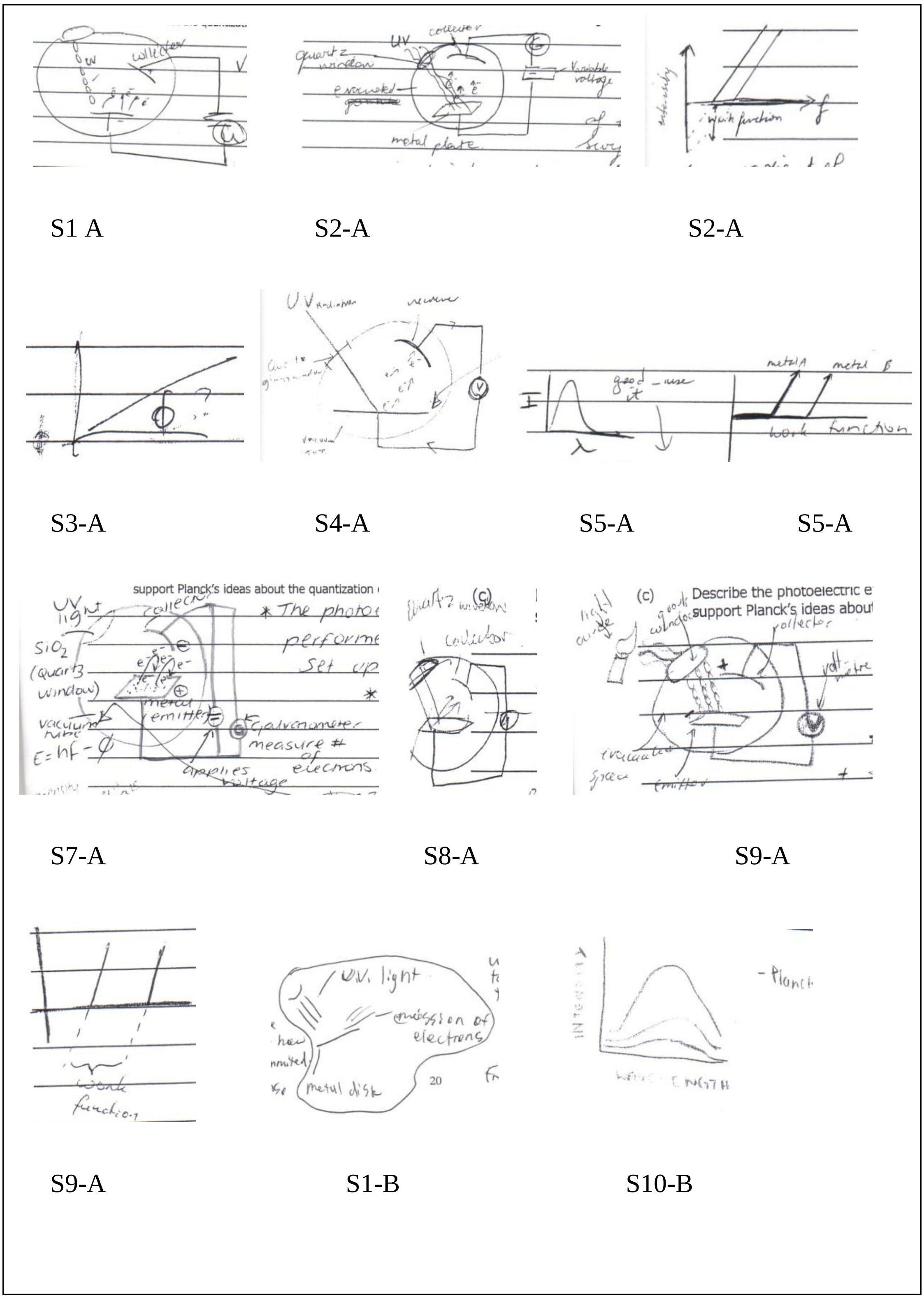


Fig. 4.7.2 Diagrams from students' answers to an examination question about the photoelectric effect. SA-092006-THSC-Q30(c).

Episode 4 – 2007

In 2007, the intervention was repeated with a fourth Year12 Physics class (17 students). On this occasion however, to enhance the trustworthiness of the research, I invited my Doctoral Supervisor to watch the lesson during which the students developed their analogies. Here the expectations were that:

- The observations would provide an unbiased critical view of what happened during the intervention;
- Observer notes (ON-01062007-A-12Ph) would supplement my own field notes and student artefacts; and
- Being able to discuss the lesson observations afterwards would foster an opportunity for "peer debriefing" (Lincoln & Guba, 1985, p. 308) (see Ch. 3).

As had been the case with the three previous episodes, the intervention occurred during two lessons. The first lesson began the *Focus* phase and in the second lesson which was observed by my Doctoral Supervisor, the students moved through the *Action* and *Reflection* phases as they developed, discussed and refined their analogies.

The following except from field notes made at the time describes the 50 minute *Focus* lesson.

> I started this lesson outside the room sitting on one of the aluminium seats with a charged electroscope positioned so that direct sunlight could fall on the electroscope. After moving into the classroom, I described how Hertz discovered the photoelectric effect. Following that, I began describing the photoelectric experiment as carried out by Lennard. Students seemed to understand the concept of how the galvanometer could be used to detect photoelectrons that had been emitted from a metal surface. During the lesson there was a brief discussion about how the electroscope worked and how it could be used to show the photoelectric effect. I encouraged student, as a voluntary homework task, to make their own electroscopes using a PET bottle, a large nail or screw and thin strips of alfoil and to bring it for the next lesson. (FN SA-010607-12PH)

This first lesson introduced students to the concepts and aroused the interest of several students. This interest was identified two days later, when at the beginning of (the next) lesson, six students placed their working electroscopes on their table and excitedly began to demonstrate that they worked.

When all of the students had arrived for the second lesson Dr. Peter Aubusson was introduced as my Doctoral Supervisor and his role as observer was briefly explained. Dr. Aubusson sat between two of the students' table groups and made notes as he observed the lesson.

After briefly testing some of the electroscopes, the students were told the same sample analogy about purchasing cigarettes as had the previous groups.

To support students' work during the *Action* phase of the intervention, the students were provided with a mapping template – a simple table of 18 cells in two columns with the headings; 'Analogy' and 'The Science'. However, before the students could use it, they needed to understand its purpose and what was meant by the term 'mapping'. To facilitate this metacognition, mapping was explained and then through a series of questions, the students were encouraged to "map attributes of smokes purchased against [the] photoelectric effect" (Observer notes ON-01062007-A-12Ph).

The students were then asked to identify aspects of the photoelectric experiment that were not represented in the example analogy.

As had all previous groups, these students mentioned "the metals" and "the stopping voltage" (Observer notes ON-01062007-A-12Ph) as attributes of the experiment that were not evident in the analogy provided.

This key aspect of the FAR guide (Treagust, 1995) was emphasised to reinforce that even good analogies rarely map to all features of the science they are being used to remember or learn. It was also a challenge to the students to develop analogies that could be mapped to more features of the photoelectric experiment than the sample analogy provided. Consistent with schema theory (Zook, 1991), it was suggested to the students that the analogy they developed would more likely be useful in helping them to learn and remember the finer details of the science if the analogy was personally relevant.

Prior to beginning the analogy development, the students were provided with a list of features from the experiment. When they were asked if there was anything missing, the students identified two features that could be added to the list; the *galvanometer* and *photons*. The group was then told "You've only got 25 minutes but I think that is enough." (Observer Notes ON-01062007-A-12Ph) and they began by thinking of ideas to use for their analogies.

While some students had difficulty in coming up with appropriate ideas and ended up by working with others, most students readily identified a suitable personally familiar situation that could be applied analogically. This group of students produced a wider variety of analogies than had the previous three groups. Examples of their topics include: an ice hockey training session; university entrance to courses based on school results; picking apples from apple trees; and passengers on a bus trip.

As had been the case with previous groups: I moved among the students; listened to their ideas; asked questions; and provided answers to their questions, to facilitate the development of their analogies in ways that were consistent with the canonical science targets. Dr. Aubusson also spoke with some of the students and listened as they described their analogies.

Consistent with all previous groups, the *Reflection* phase, involved students sharing their analogies. In this case, some of the students' mapping tables were shared by passing them around the room. This was followed by a brief class discussion.

A final note taken during the observation of this lesson by Dr. Aubusson reflects the essence of the co-generation of appropriate understanding as students constructed and discussing their analogies.

> Discussion/exchanges in story building is refining understanding – not just a means of representing understanding. Note the way that the questioning/discussion/testing of ideas results in discussion of views of the physics and changes both in view or expression of view and changes

> in story (analogy). The process is testing their understanding; [and finally], They are learning heaps! (Observer notes ON01062007-A-12Ph)

Conclusion

Several repetitions of this episode consistently revealed that by co-generating analogies, students developed good understanding about the photoelectric effect. In one episode, answers to a question in an examination held months later, were analysed. Students who had participated in the intervention were more able to demonstrate high levels of understanding than similar students in a parallel class who had not participated in the intervention. This indicated that the level of understanding developed through the analogical process was deeper than would likely occur through more traditional methods of teaching.

The oscillation between action and reflection during refinement of the students' analogies is akin to the micro-cycles of model development reported by Nunez-Oviedo and Clements (2003) in which students refined and improved models. When students developed and discussed their own ideas, they opened them to the scrutiny of the others. During this process the students had to make clear to their peers and their teacher (me), how their base domain mapped to the target science domain. In doing so they were able to test each point of comparison. If a comparison was unclear or wrong, discussion about the ideas led to modifications or additions to the analogies to facilitate a more correct representation of the science. In rare cases, the students rejected their ideas completely, preferring to use or build on another persons' analogy that made more sense to them than their own. Typically, however, students worked at developing their own ideas, refining and extending them so that they included accurate representations of several aspects of the science they were learning.

The sharing of different analogies for the same science targets required the students to consider the physics of the photoelectric experiment from a number of perspectives which were different to their own. As suggested by Harrison and Treagust's (1999), considering "multiple explanatory models" (p. 428), is likely to have a positive impact on learning, further enhancing understanding of the target science concepts.

The photoelectric experiment target domain contained several attributes and relations. In this regard, it was unlikely that any analogy developed, would map well to all parts and so, students identifying areas of the target science that they could not map to their base domain, was an important part of the process. Doing so seemed to enhance the students' abilities to recall those aspects as well as the ones that did match well. While the students were aware of this, they mapped as many features as they could.

Many of the students chose bases that were personally familiar or important. For example, one student who developed an analogy based on bird seed admitted to having birds as pets; another who wrote about monkeys said she "liked monkeys" and the two boys who wrote about university were very focussed on getting there. All of the analogies developed by the students did, however, map well to several features of the target science. However, because none of the analogies mapped well to all of the target features, all of the analogies were imperfect. Nevertheless, the analogical process of seeking a base, deciding which attributes and relations mapped and which ones did not, provided vehicles for thought, discussion and learning. During the process students were able to clarify and extend their understandings in ways that led them to correctly represent the science, months after the learning had occurred.

The episodes in this vignette provide sound evidence that deep understanding occurred as a result of the intervention. This strongly suggests that developing analogies in a collaborative classroom, conducive to co-construction, can have a positive influence on learning in science.

4.8 Summary

This chapter has presented data from 13 episodes of the teaching intervention conducted over a period of four years. Three different types of analogical activities have been highlighted; role play, written analogy and model building. While the nature of the analogical product varied for each type of activity, each activity involved students in analogical reasoning supported by their peers and by their teacher. Collectively, the vignettes provide significant evidence that when students are supported in developing, refining and sharing their own analogies, the learning that takes place contributes to deep understanding. This understanding has consistently been shown to be persistent, allowing the students to call upon the science they learned through co-constructed analogical activities, weeks, months and even years afterwards.

The data confirms that the FAR guide (Harrison & Treagust, 2006) as discussed in Chapter 2, was an effective framework for the productive use of analogies with and by students in learning science. Co-generating analogies has been shown to serve both heuristic and *post festum* purposes.

The data identifies many instances in which students have been able to move from positions of misunderstanding or little understanding, based on their own prior experiences, to being able to demonstrate correct scientific knowledge and understanding. These transformations support the constructivist epistemology underpinning this teaching experiment.

In Chapter 5, the findings from the vignettes are further discussed and conclusions, drawn from the data, are presented.

Chapter 5

How the co-generation of analogies influences students' learning of science

5.1 Preamble

Science educators often use analogies to help students develop understanding, but successful learning where students develop their own analogies has rarely been reported (Harrison, 2006). This research sought to investigate how the co-generation of analogies influenced students' learning of science. It stemmed from the author's scholarly interest in helping students understand the more difficult science concepts through analogical activities. The use of analogies as tools for learning encourages students to build on what they already know and understand and hence this research was underpinned by a constructivist epistemology.

A pilot study was conducted and this led to the development of four research questions:

a. How do students develop analogies?
b. How does the co-generation of analogies influence student engagement with science?
c. Do students develop deep understanding through the co-generation of analogies?
d. How does a teacher support students in the co-generation of analogies?

The literature that underpinned the theoretical framework for this study (see Chapter 2) brought together two main areas of interest. The first relates to the nature of learning through the construction of meaning (Duit, 1991b; Freyberg & Osborne,1985; Lorsbach & Tobin, 1992; Rosenthal & Zimmerman, 1978; Vygotsky & Cole, 1978) and the second relates to the nature and use of analogy (Duit 1991a; Gentner, 1983; Harrison & Treagust, 2006; Vosniadou & Ortony, 1989; Zook, 1991).

The literature review established that little has been reported about students co-generating and using their own analogies in their processes of learning science. An analysis of several suggested strategies for using analogies with students, led to a justification for the strategy adapted for use in the teaching experiment conducted.

A teaching experiment methodology (Brown, 1992; Confrey & Lachance, 2000) suited the purposes and context of the research in which a teacher conducted research to explore and scrutinise a teaching approach with his own students during the course of regular timetabled lessons. As justified in Chapter 3, a large amount and variety of data were collected during the teaching experiment.

The teaching experiment involved 24 applications of a teaching intervention. The intervention required students to develop analogies with the purpose of showing and enhancing their understanding of science concepts. Throughout each episode (application of intervention) students were supported by each other and by the teacher. Discussions about the analogies occurred throughout their development and were integral to the analogy refining process. Hence, the resulting analogies were co-generated.

Through participatory enquiry, the conjecture that: when students develop their own analogies (supported by their teacher) in the process of learning science, they will be able to demonstrate high levels of understanding about the concepts being studied; was qualitatively investigated. This conjecture was founded in the literature; supported by personal experience and a pilot study; and tested through several teaching episodes.

A large amount and variety of data were collected during the teaching experiment. These data have been used in providing thick descriptions of 13 episodes in which students developed their own analogies while learning science. Similar episodes have been grouped together and presented in five vignettes (see Chapter 4). Findings from the vignettes have been used to formulate conclusions.

In this chapter, a synthesis of the findings from the vignettes is presented under the headings of the four research questions. Implications of these findings for learning and teaching of science are discussed. Then the ways in which this study contributes to knowledge in the field of learning with analogies in science are specified. Directions for future research are suggested before concluding the chapter

5.2 Findings

The findings are presented in terms of the research questions. Each question will be addressed in turn with reference to specific data resulting from the teaching experiment. Limitations of this study were considered in detail in Chapter 3. Here, as theoretical and practical implications of the work are proposed it is important to consider some key limitations. The study was situated in one school and taught by an experienced practitioner. Care is required in considering generalising from the data and in applying findings or practices in other settings. Furthermore, students were knowingly involved in doctoral research. This may have influenced their patterns of behaviour. The prolonged engagement may have reduced possible effects but the potential influence should not be ignored. For example, knowing that they were participating in their teacher's doctoral research project may have enhanced their willingness to participate and become actively engaged in the learning.

(a) How do students develop analogies?

A variety of analogies were developed by students during the teaching experiment and a number of consistent factors have emerged which provide evidence to suggest how students develop analogies. However, unlike the spontaneous analogies observed in students' discourse when they explained science concepts to their peers (Sandifer, 2003), analogy development here must be viewed in the context of the teaching experiment. In this teaching experiment, students were asked to develop analogies and were guided by the teacher using processes consistent with the FAR guide (Treagust, 1995). In this sense the processes and products were not entirely owned by the students. What will be discussed here are factors within that context that stem from observations made during the episodes.

When working on a personal analogy about the photoelectric effect (see Vignette 5, pp. 217-243) individual students began the process after being provided with an example from the teacher. After working on their ideas for an analogy for a short time, the students shared and discussed their ideas with a small group of other students and with the teacher. As such, the process of subjecting their ideas to the scrutiny of others was ongoing. Several students chose to develop analogies that were based on the example given by the teacher; purchasing of an item (cigarettes, movie tickets or biscuits) from a shop. Others developed analogies from bases that were very similar to the examples provided. These bases included; people using defined amounts of money to purchase, kebabs, bird seed, slurpies and chocolates; and monkeys purchasing coconuts with bananas. These analogies could readily be mapped to the target science in very similar ways as the examples, and hence the appropriateness of relations for these bases could readily be assessed by others during discussions. A number of students, however, chose bases that were more personal and which required considerable explanation during discussion with others. These examples included; rockets escaping the gravity of different planets; athletes competing in high jump; people entering a dance floor to different kinds of music; a tutor working with various students; a tunnel ball game; and students entering various university courses.

The discourse among students and between the student and the teacher during the sharing phase encouraged critical analysis and review of the students' ideas. Students identified features of their bases that mapped well to the science target. They made modifications to their base domain in attempt to map it to a greater number of features of the target science and realised where their base could not be adapted or where only poor mapping was possible.

When working in groups to develop analogical models (Vignettes 1-4), students discussed their individual ideas with others in the group at the beginning of the process. Discussions among members of the group led to decisions about what would be developed. Observations identified that in some cases one idea was readily accepted while in other cases different ideas were tested or challenged before accepting one and sometimes multiple ideas were combined.

During the development of group analogies, students took a more or less active role. If there was only one idea suggested, the student who came up with it, explained it to the others and they all worked on the idea together. However, when there were multiple suggestions, considerable discussion ensued as all were considered. During this process students who more confidently espoused understanding and could justify their ideas tended to have their ideas accepted. Hence, the ideas that were accepted, were those that seemed to make more sense or which were identified by consensus, to be more consistent with what the group thought was relevant to the science phenomenon being modelled. In this sense, acceptance depended on a perceived positive relational mapping between at least some features of the base and the scientific phenomenon.

At the beginning of the group analogy development, some students were happy to let others lead the way. The corollary is that within some groups one student initiated the development of ideas with which others were willing to work. This was particularly evident in the episodes reported in Vignette Two. Some bizarre explanations (bases) were suggested for observations made by the students as they struggled to make sense of an unfamiliar phenomenon. One was based around a perceived back and forth reflection of light between the mirror and an invisible reflective layer of carbon dioxide gas that surrounded the flame. Another from a different group was based on a similar back and forth reflection between the mirror and the flame, but in this case the reflections came from a heated air layer surrounding the flame as well as from the mirror. In this case the student justified the idea by describing his personal observations about mirages reflections of cars seen coming from the road below cars on a hot day.

These bizarre explanations stemmed from individuals' prior understandings and identified their attempts to "instantiate" (Zook, 1991, p. 48) these prior understandings to account for the new phenomenon. It was also observed, however, that others in the groups of these leading students, unquestioningly and enthusiastically began developing the base as described: indentifying that they had readily accepted the bizarre ideas as being plausible. These instances support Onsman's (2004) warning that "people generally accept the first meaning that makes sense" (p. 3). Early detection through careful observation by the teacher, however, led to critical discussions about the misconceptions. More appropriate alternative ideas were developed by the students after they addressed questions posed by the teacher. Based on the students' new thinking, which had been guided by the teacher, all students in these groups, including the initiators, accepted that the initial ideas were flawed and readily modified their ideas to suit their new, more appropriate explanation for the science phenomenon.

In other cases, where there was a level of mistrust or general misunderstanding or ignorance of the details by members of a group, the students were observed to check with a textbook or ask a question of me (the trusted teacher). This stimulated further discussion among the students and between the students and the teacher prior to them deciding on how to proceed. Hence, akin to the micro-cycle development of models, discussed by Nunez-Oviedo and Clement (2003), as the analogy developed, ongoing discussion of aspects of the analogy occurred. Subsequent testing of ideas, led the students to make a number of modifications to their analogies and importantly, to their understanding of the target science.

A final step in the students' development of their analogies, was communicating the understanding of the science through the analogies to other members of their class. In doing so, the students subjected their ideas to the scrutiny of others and this often led to further questions about the analogical mapping and clarifications of the science.

Observations suggest six key stages (see below) associated with co-generated analogies. These are listed under the headings of the FAR guide below to show how they too fit into three main phases (see Table 2.3).

Focus

1. The teacher initiates a discussion that leads students to consider some aspect of their course. During this stage the teacher challenges the students to, solve a problem, explore a phenomenon or demonstrate their understanding, by giving analogical expression to an idea. When students are inexperienced in using analogies, the teacher provides an example to foster understanding about the analogical process needed. In cases where the students are familiar with using analogies, the teacher reminds the students about the process of constructing an analogy.

2. The students identify a base for use in developing an analogy for a science concept. In building a model, this involves the formation of initial ideas around the range of materials available. For a role play it requires the determination of parts or features need to be represented, how these would be represented and who would play the various parts for a given situation. In developing their personal analogies students reflect on their own experiences to select a base that might be suitable for mapping to a science concept.

Action

3. Students map attributes and relations of their base domain and the target science domain. This often involved a back and forth clarification of both the student's base and of the science. Active discussion, mostly among students and sometimes including the teacher, typically occur during this mapping process. Features that cannot be mapped or which are deliberately omitted from the mapping are identified. For role playing this involves making group decisions and rehearsing parts of the role play. For model building it marks the beginning of construction. When students are developing personal written analogies, this part of the process involves the students in writing down the features of their analogy and mapping them to features of the target science.

4. Sharing of ideas among students, and with the teacher, provides opportunities for students to test their understanding and subject their analogies to the scrutiny of others. Draft role plays are performed for the teacher and for other groups. Models are tested while members from other groups watch. Students working on personal analogies complete mapping sheets and explain their ideas to others. These opportunities for others to be scrutineers, often require students to clarify features of their analogies, foster further discussion among students and with the teacher, about the science and sometimes lead to suggestions for modifications to the analogies.

Reflection

5. After feedback, the students review their ideas. The sharing of ideas provides a verification of students' own ideas. It can also provide stimulus for further modifications, including the addition/subtraction of details, which further enhances the mapping between the base and target domains.

6. Students display and further clarify their learning by communicating their understanding through their refined analogy.

This teaching experiment provides evidence suggesting that when encouraged to develop analogies, students actively engage in discourse and share their ideas. If left unchecked this discourse can become unproductive, resulting in bizarre alternative conceptions for science phenomena being accepted by others. The research, however, identifies that when effectively guided, through active discussion and reflection, students will subject their ideas to the scrutiny of others. The teacher as expert, the students' peers and resources such as textbooks, play a critical role in helping students to scrutinise and refine their own ideas. Thus, the guided use of student generated analogy is a teaching strategy that, through iterative reasoning processes, can result in very effective learning; even if it stems from bizarre beginnings.

(b) How does the co-generation of analogies influence student engagement with science?

The observational, video and audio data gathered during this research provide overwhelming evidence that during the many episodes in which the intervention was applied, students were actively engaged. In general, the students were happily working with fervour to complete their tasks. Classic signs of active engagement such as, students in groups with their heads together, multiple hands on the same equipment, active discussion among students and students actively seeking answers to their own questions, support that co-generation of analogies has a positive influence on student engagement. Happy friendly discussion, typified by laughter, smiling and comments such as "cool" made during activities, support the notion that students enjoyed the activities. Data from the questionnaires identified that students rated their enjoyment and engagement as positive during all episodes of the intervention. This was further supported by several comments made by students throughout the teaching experiment, indicating that the lessons were; better than learning from books and lectures; and that it was a fun way to learn. The affective dimension of teachers using tried and tested analogies when teaching science has been identified by Harrison (2006). It is significant here that the data supports Harrison's (2006) view, even though the students were working hard to develop their own analogies. It is significant that the few students who in the beginning of interventions, appeared disinterested, did not remain so (see Vignettes 3 and 5). In this respect the intervention facilitated engagement and for these few students, perhaps it was the inescapable vicarious learning associated with a productive classroom that encouraged them to experienced some success and become actively engaged.

Arguably, the students were not only engaged in their learning about science phenomena, they were also engaging in science. The processes of thinking about phenomena, selecting bases to facilitate understanding about the phenomena, testing the bases against their observations and/or science theory and subjecting their ideas to the scrutiny of others, are very much part of the scientific process.

Addressing the *how* part of the research question, requires consideration of the nature of the tasks involved and the expectations of involvement. It was made clear through early discussions with the students that their enhanced understanding was the expected outcome: and that the tasks were designed to provide opportunities for them to build on their prior understandings and investigate novel phenomena in non-threatening ways. During these discussions in the *Focus Phase* of most episodes of the intervention (see Vignettes 1, 2, 4 & 5), it was made explicit that the emphasis was on *developing* understanding about the science phenomena through analogical modelling. In others (see Vignette 3) the emphasis was on *showing* their understanding. At all times, however, while an emphasis was placed on the importance of models in learning science, the imperfection of all models was stressed (see Gentner, 1983; Harrison & Treagust 1995). It was also stressed that the analogies they developed, did not have to account for all aspects of the science phenomena. Rather, the aim was to develop and show as good an understanding about the science as was possible from the experience of developing, analysing testing and discussing analogies. Students were encouraged to take control of their learning in a situation which allowed them to take risks and make mistakes; with the knowledge that they would be assisted to correct errors or misunderstandings that were revealed. Hence, there was the personal reward of coming to a ‘correct’ understanding; perhaps giving the students confidence about achieving better results in the course(s) they were studying.

(c) Do students develop deep understanding through the co-generation of analogies?

During the teaching experiment a plethora of data support the assertion that students will develop deep understanding when they co-generate analogies in science, with support from their teacher. Deep understanding as defined in this thesis surpasses the students’ observed abilities to recall and discuss the canonical science at the end of an episode of learning. The assumption is that if deep understanding results from the learning, students should be able to make explanations and answer questions some considerable time after the learning. This was the case for the majority of students.

In the Pilot Study, students developed and demonstrated relational understandings about chemical processes involving ions and electrons through co-constructed role plays. They were able to recall details of their chemical role play and the related science concepts in an interview held 18 months after the activity.

Students who participated in the co-construction of role plays to develop and show relational understanding about multiple images formed in a mirror, were able to use their understandings to learn about the transfer of information through optical fibres later in the topic. These students were also able to provide accurate written and diagrammatic representations of the science phenomena, several months later, under examination conditions.

Students, who developed role plays to show their understanding of some medical applications of physics, remembered key aspects of the physics phenomena by recalling their role play activities during a major external examination a month after the intervention and felt confident about the answers they wrote.

Students who built models of solenoids moved from an almost complete lack of knowledge about the use of solenoids in household appliances, to being able to present their understanding using diagrammatic and verbal representations immediately after the activity and under examination conditions several months after the intervention. The level of understanding shown by these students was not matched by their peers in a parallel class who studied the same information with another teacher who taught without using co-constructed analogies.

Finally, most of the students who developed analogies about the photoelectric effect were able, in an examination held months after the learning episode, to provide detailed descriptions of what they had learnt, supported by accurately labelled diagrams. Again the level of understanding shown by these students surpassed that of their peers in a parallel class who had not taken part in a learning-through-analogies intervention.

During the development of their understanding students typically made modifications to their ideas. This was observed to occur as a consequence of their thinking and discussions when mapping their base to the target science. The final sharing of refined analogies provided opportunities for self, peer and teacher assessment of understanding. However, several of the activities were completed in groups. To assess individual understanding, a question requiring a written or oral answer was asked by the teacher on completion of the intervention. Examples of these questions, which emphasised the science and not the analogy, are provided below.

- Describe the chemical path taken by copper in its extraction from a carbonate ore.
- Draw a diagram to explain the formation of multiple images in a mirror.
- Explain the process of image formation in an MRI scan.
- Describe how ultrasound can be used to detect the direction and speed of blood flow.
- Explain how a solenoid can be used to control water flow in a household appliance.
- Using a diagram, explain how the work function for a metal can be determined.

Answering questions such as these provided the students with an opportunity to celebrate their learning and in some cases, a final opportunity for misunderstandings to be exposed and corrected.

When students' analogical ideas were tested during and after analogy development, their conceptions became visible to themselves, their peers and me (the teacher). This visibility of personal conceptions and their modification (if needed) through discussion with others are key aspects identified through analogical processes in this teaching experiment. Helping the students to make sense of the science through analogy enabled them later, to show appropriate understandings of the science.

The development of understanding as identified in this teaching experiment is therefore consistent with the views of Zook (1991) who purported that learning unfamiliar information occurs through analogical processes. The analogical process, has however, been shown often to lead to persistent alternative conceptions (Clement, 1993). In this teaching experiment, however, the use of analogy has been a guided process, used to develop understandings that are consistent with the canonical concepts embedded in the syllabus content of the courses undertaken in a school.

Keeping in mind that "analogues are simplified or exaggerated representations of a target" (Harrison & De Jong, 2005, p. 1136), co-constructive care, through active discussion and use of the FAR Guide (Treagust, 1995) is needed to assisted in helping to maintain "essential integrity" (Hancock & Onsman, 2005, p. 2) of the science concepts during the analogical process.

The experiment showed that when students engaged in activities that required them to develop their own analogies in a supported (co-generative) learning environment, they were able to demonstrate appropriate understandings about the science concepts they were learning. This was evident, almost without exception, on completion of the intervention and several examples identified that some students could demonstrate their understanding for a very long time (18 months). This teaching experiment has therefore shown that despite the imperfections of students' analogies, the analogies and the productive discourse that they engender, can lead to enriched learning in science. Moreover, it is likely that the imperfect students' analogies stimulated much more discussion than would any, more perfectly mapped analogy, provided in a text or by a teacher.

(d) How does a teacher support students in the co-generation of analogies?

This teaching experiment identified several ways in which a teacher can support students in the co-generation of analogies. Encouraging an atmosphere in which the construction of analogies is considered to be a productive way to learn, can give students the confidence to expose themselves to the risk of being wrong. An essential part of successfully developing this atmosphere is convincing the students that they will be supported when 'mistakes' are made. Allowing the students to work in groups enhances risk taking because any 'errors' made, belong to the group, thus taking pressure off the individuals within the group. Discussing these aspects of the process in the beginning stages of analogy development identifies to the students that they will be supported throughout the process and is hence the beginning of co-generation.

Co-generation can occur in each of phase of the analogy development. Co-generation in the early phase may help to identify that difficult concepts need special attention in order to be understood and that analogies could be chosen or adapted to assist the development of understanding. Discussions in this early phase also help to guide the students in selecting features of the target science phenomena to be mapped to their base. During the *Action Phase,* students working together and/or checking ideas with each other facilitates the development of their ideas. The teacher also plays a critical role in checking for understanding and misunderstanding. This is facilitated through careful observation. By asking questions and offering suggestions, the teacher acts as an active participant, stimulating students' discussions and thinking, steering students in the direction of scientific understandings.

In the final phase, by encouraging students to share and reflect on the effectiveness of their analogies, the teacher helps students to consolidate their thinking about the science phenomena, recognising features of their analogy that map well and others that do not. Here it is important for the teacher to assist the students to identify any important features of the science phenomena that have not been mapped to the analogy. This aspect of the comparison helps the students to realise that their analogy is not complete. Focusing on the aspects of the science that their analogy does not cover may also assist the students in remembering the unmapped features. Discussing the difficulty/impossibility in mapping all features of the science phenomena to the base domain brings to the fore that while all analogies have limits they can be very useful as a tools for learning. This also reminds the students about the purpose of the activity – to develop understandings about the science.

When a teacher encourages students to compare their different analogies, they consider the science phenomenon being studied, from different perspectives and this further enhances their understanding. The processes of thinking involved in these comparisons further emphasises that the representations are not supposed to be "thought of as 'ends in themselves' but rather as tools for thinking and communicating in science" (Tytler, Prain & Hubber, 2009, p. 9).

In summary, during all phases of the analogical process, the teacher can play an active role in helping individuals develop their ideas and understandings. It is relevant to note though, that the students provide considerable support for each other in the process of co-generation.

5.3 Implications

This research implies that co-generating analogies is a powerful way of engaging students in developing appropriate deep canonical understandings of science phenomena. As such it would be advantageous for teachers of science to have in the repertoire of pedagogical content knowledge (PCK), understandings and skills associated with the effective use of student generated analogies (see Shulman, 1986; Tobin, McRobbie & Campbell, 1999). This PCK involves knowing how to enhance the positive aspects associated with students' co-generating analogies while reducing their negative potential.

This research provides data that reinforces the double edged nature analogies. In terms of co-generation, however, this double edged nature is shown to be a positive feature rather than a negative one. The usefulness of the 'negative edge' in making visible, previously held misconceptions and revealing inappropriate mappings to target science phenomena, is paramount to the effective application of student generated analogies as a pedagogical strategy in science teaching.

Care must be taken to ensure students are appropriately aware of the benefits and pitfalls in developing and using analogies. Teachers wishing to encourage their students to generate analogies need to be confident in their own understanding of the concepts and mindful of the need to participate as a co-generative partner, using a carefully planned strategy such as the FAR guide (see Harrison & Treagust, 2006). If students' ideas are left unchecked there is a strong likelihood that misconceptions will not only become entrenched but that their use in discourse among students will 'infect' the other students, corrupting their understanding (see Vignette 2).

Student generated analogies are one way in which a teacher can encourage students to make their thinking visible. The use of the Focus, Action and Review phases (see

Harrison & Treagust, 2006) may help to ensure that the negative aspects associated with the use of students' analogies are limited. The refinement of these analogies through a process of co-generation has been shown in this research to be useful as *heuristic* pedagogy to help students learn concepts 'better' the first time and as *post festum* pedagogy to enhance students' understanding while revising concepts. This research has shown that while there are significant benefits in supporting students in developing their own analogies to learn science, teachers need to ensure, that they are also mindful of, and take appropriate action to avoid, the possible disadvantages of doing so.

While more than one type of analogy activity is likely to be appropriate for learning about particular concepts, reasons for choosing a particular type of activity will be determined by several factors. Such factors could include the nature of the science phenomenon, the nature of the learning outcomes, the time available, student interest and teacher expertise.

5.4 Refining our knowledge of analogy for science teaching and learning

This research adds to the body of knowledge about the use of analogies in teaching science in several ways.

There has been little research done about students co-generating analogies to learn science concepts in authentic classroom settings. The rich descriptions of several lessons identifying what happened when senior high school students, selected, and with support, developed their own analogies provides an account of an extensive teaching experiment, thus adding significantly to the body of knowledge regarding the practical application of analogies to learning in science.

The application of the FAR guide (Treagust, 1995) to the co-generative arena and the positive learning outcomes from the teaching experiment supports its extended usefulness in a broader pedagogical perspective. The deep understanding that students gained from their involvement in the intervention suggests that when students become involved in all FAR phases of learning through analogy, including; the identification of target science domains for application of analogical processing; the selection of base domains; and the development of and reflection about an analogy; their learning will be enhanced.

The research identifies that student generated analogies provide a window through which students' understandings become visible. This visibility of students', often imperfect analogies, helps to identify both scientifically correct conceptions and misconceptions. Once known these provide nucleation sites for rich discourse that engages the students in thinking about what they know and understand and what they do not. This research shows that deep understanding of science concepts can result from building on students' imperfect analogies, including those which focus on limited aspects of a science phenomenon. Harrison (2006) asserted that teachers should use "only tried analogies that can be presented in an interesting way . . . to explain abstract and difficult science concepts" (p. 62). In a similar vein, this research suggests that if a teacher is to encourage students to develop their own analogies, to be most effective, the students' analogies must also be tried and tested. However, when working with students' analogies they must be tried and tested in the classroom because they cannot be determined a priori. It is the process of students constructing, testing, modifying and sharing their analogies that can lead to very effective learning.

Students' analogies can be a useful aid in the development of understanding despite only mapping to a small number of features of the target science. The inability to analogically map certain attributes and relations does not always identify misconceptions. For example in the Pilot Study, it did not matter to the students that they had not included the water in their analogy about the movement of ions. Similarly, none of the analogies developed for the photoelectric experiment (Vignette 5) accounted for the vacuum inside the apparatus. The students' seemed to focus mainly on aspects which they found difficult to comprehend. Sometimes it was not possible for them to map aspects that they wanted. This was exemplified when students were unable to successfully map aspects of their base domains to stopping voltage in the photoelectric experiment (Vignette 5). Students gaining understanding about the aspects they could map, however, facilitated the development of understanding of the target domain and helped to identify aspects of the phenomena which were intellectually challenging and/or very difficult to represent. These, often critical points of differences in interpretation or understanding among the students, can then be clarified through argument and critique during which students express and share their views. Analogies that allow students to correctly understand parts of a target domain may therefore help to fill the gaps in what is already known and/or facilitate understanding of aspects that cannot be included in the analogy.

In discussing areas where the students' personal analogies fail to help them represent or give meaning to aspects of the target science, students expose their thinking and levels of understanding. By helping to correct the imperfections, the teacher helps the students build on their previously limited canonical understandings. This crystallises their understandings about the target domain, helping it to become more persistently retrievable and therefore useful. This persistence in understanding was displayed many times throughout the teaching experiment in students' correct representations during tests and long term memory of both the analogical activities and the science concepts learned.

There is a tendency in the literature on analogy for teaching and learning in science, to seek almost perfect analogies, in which a base domain maps extremely well to a target domain. Through analogical processes this research has shown that students critically review their understandings about science phenomena displayed in their own analogies and in the analogies of their peers. Whether purposely discussing and sharing analogies, arguing their case or through vicarious observation of others working on analogies, students recognise imperfections in their own analogies and in the analogies of others. During discussions about their analogies, students provide co-generative support for each other's learning. This research has shown that the discourse generated through the analogical process is critical to the generation of correct science understandings. Analogies with imperfections have consistently been shown to stimulate productive discourse among students and between the students and the teacher, and hence they are likely to be more powerful learning tools than nearly perfectly mapped analogies that do not. This research has therefore shown, that the strength of using co-generation of analogies as a learning tool lies as much in the discussions that the analogies engender, as it does in the process of selecting a suitable base.

Apart from allowing students' alternative conceptions and misconceptions about the target science domain to be addressed, students making their ideas visible through their own analogies may reveal previously held alternative conceptions and misconceptions about their chosen base domain. This was exemplified in Vignette Two, by the two bizarre initial explanations provided when students began developing a role play to explain multiple reflections from a mirror. While Wilbert and Duit (2006) identified that “students usually make use of the symmetrical nature of the analogy relation” (p. 47), the oscillations in which the target becomes the base and the base becomes the target, evident in this teaching experiment, would have been unlikely without teacher support. Examples provided in Vignettes Three and Five, describe how analogy development can be used to assess students’ post festum (Wilbers & Duit, 2006) understanding. In one case, a student who could draw labelled diagrams correctly depicting the photoelectric phenomenon, revealed a lack of understanding when asked to explain the phenomenon in terms of an analogy. Another student who appeared to have an excellent understanding of medical imaging techniques, revealed a critical misconception about the decay of a particular radioisotope while developing a role play to show understanding of an imaging process. These aspects, provide argument supporting the co-generative role of the teacher in both heuristic and post festum applications; and identifies an enhanced diagnostic usefulness through which the teacher can assess and help to correct misconceptions that may otherwise remain hidden.

Students can work effectively to develop analogies that lead to lasting understanding. The discourse that occurs among students and between the students and the teacher, during the development and sharing of individual and group analogies, fosters deep understanding of the target science. Clarifications and comparisons are constantly being made by and with the students between their personally familiar base domains and the target science domain. The processes of selecting bases; testing them through mapping; sharing and refining their analogies; and presenting ideas about the scientific phenomenon; are scientific processes. Students therefore not only learn about the target science when they develop and refine their own analogies, they actively engage in and with science. In addition, students can be flexible in their adaptation of analogical ideas. In some cases the students considered the ideas presented by others as having enhanced effectiveness in representing the science phenomena being studied and they either modify their own or discard it completely. Evidence suggestive of this was especially revealed during the production of reflection role plays (Vignette 2), the building of solenoids (Vignette 4) and the development of photoelectric analogies (Vignette 5). Thus students co-generating analogies helps them develop an understanding of science as an evolving field of understanding that changes as new evidence come to the fore, by engaging in that very process. The aspect is not inherent when a teacher selects and presents a well tested analogy. The research therefore identifies that student engagement through their own analogies extends beyond them learning about the target science. The processes engage students in and with the scientific process.

The process of students co-generating improvements in their own and others' analogies, supported by the teacher, is thus identified as a powerful pedagogical process. A process that engages students in learning science, leading them to enhanced understandings of scientific phenomena and the development of skills in scientific reasoning. This research therefore extends the knowledge base considerably in both the theory and practice of using analogies in teaching science.

5.5 Further research

During this research analogical activities were used exclusively for concepts that students typically found challenging. This is primarily based on prior teaching experience that didactic methods were relatively ineffective for these concepts because they did not engender understanding, and thus a 'special' intervention was warranted. While this does not mean that less difficult concepts should not be taught using analogical methods, a teacher typically uses a range of teaching strategies which help to maintain students' interest and enthusiasm. In this teaching experiment, involving 24 applications of the intervention over a period of four years, three different analogical activities were used. Students constructed *physical models* to show relational understandings about the application of a scientific principle to a household electrical appliance (Vignette 4). *Role plays* were developed to promote group interaction and a consensus of understanding about 'invisible' scientific phenomena. For example; when considering how proton precession is harnessed to produce images of the body in MRI; how the Doppler effect is used to determine rates and directions of blood flow; and how light reflects inside a mirror to produce multiple images of a candle flame (Vignettes 1, 2 & 3). *A narrative written analogy* was developed to explain a scientific situation in familiar terms. Students explained why light of only certain frequencies causes electrons to be ejected from metal surfaces. (The photoelectric effect) (Vignette 5).

The choice of which type of analogical activity to use was not based on theoretical perspectives or determined by an investigation of prior research. While underpinned by a constructivist philosophy, choices were solely intuitive based on thinking about what might appeal to the students at the time. While this is perhaps valid in the context of a teacher planning individual lessons for his classes, in a broader pedagogical and theoretical sense, further research is needed to ascertain; factors that determine when to use the co-generation of analogies; and which factors determine the type of analogical activity to use.

During this teaching experiment, most interventions were designed to occur during a double lesson (100) minutes. This was primarily because analogical activities can be time consuming, and within the context described, there was not time for prolonged episodes of analogical development. This did not, however, preclude extending the activities if additional time was required for refining analogies. During the episodes, however, there was no formal attempt to ascertain within the lessons how long students took to 'get' the concepts. Further research may identify when further refinement of an analogy becomes superfluous and whether generalisable patterns can be developed as guideline for timing.

Some students could remember their analogies many months after the intervention while others admitted to forgetting about their analogies. Perhaps those who forgot had abandoned them because they had instantiated (Zook, 1991) the science and therefore understood it. While this concept is in congruence with the constructivist learning philosophy behind using the intervention as a tool for learning, ascertaining if, and when, students discard analogies after they have developed appropriate understandings about scientific phenomena would add further to what is known.

During the teaching experiment students shared and discussed their ideas. This allowed them to consider the science from a number of representational viewpoints. The role of multiple analogical representations in learning science requires further exploration;

especially in light of the benefits of a multi-representational approach to teaching science recently espoused by Tytler, Prain & Vaughan (2009).

Answers to these questions and others that would arise in their investigation will further add to our understanding about the use of analogy and ways in which teachers can maximise students' engagement, understanding and success in learning science.

5.6 Conclusion

The co-generation of analogies for science phenomena contributes positively to students learning in science. This conclusion is supported by the research findings, which identify that the majority of students in several episodes of the teaching experiment were able, with support, to develop and use their own analogies to foster and display appropriate deep understandings about complex science concepts.

Observations made during the teaching experiment substantiate the "double edged sword" (Glynn, 1991, p. 227) warning about the use of analogies in teaching. Even when teachers use analogies that are based on sound knowledge of the phenomenon, the analogies are open to misinterpretation and inappropriate mapping, leading to the establishment and/or entrenchment of misconceptions. Analogies that are generated by the students, stemming from flawed understanding can and do result in bizarre ideas which, if left unchecked, are likely to become a hindrance rather than an aid to the development of understanding. The double edged nature of the students' analogy development, however, provides positive opportunities for learning because students make explicit and clarify their misconceptions, thus rendering them accessible for change. The recognition and correction of the misconceptions so identified, is a co-generative role of the students' peers and/or of the teacher, in supporting the development and use of the students' own analogies; and in developing scientific understandings of the targeted concepts. By contrast, teacher led analogies may be less potent in opening up students misconceptions for modification and may more likely contribute to the development of alternative frameworks. Hence, students are more likely to construct extensive connections with an imperfect analogy they generate and contribute to, than from a teacher provided and perfectly mapped analogy. This builds on the notion that "even useful analogies are often imperfect" (Holyoak & Thagard

1995, p. 202). While Heyward, (2002) suggested that attempting to find “a holy grail [analogy] to explain phenomena” (p. 239) is flawed, this research suggests the holy grail is the correct scientific understandings, not the analogy. Imperfect as students’ analogies are, they are tools that, used appropriately, can interest and actively engage students in science. The process of co-developing analogies, facilitates teacher involvement and awareness of student misconceptions. The discourse associated with the correction of the imperfections of students’ analogies, helps to address the misconceptions and leads to deep and therefore lasting understanding of the targeted science.

The teaching experiment thus provides data that supports the guided use of student generated analogies as a pedagogical tool in science education.

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Appendix 1 Consent Form

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UTS CRICOS Provider Code 00099F

University of Technology, Sydney

Consent Form For Student

I ______________________ agree to participate in the research project entitled "Student generated analogies and their influence on the development of science understanding" HREC No 2004-068A being conducted by Mr Stephen Fogwill of Wyndham College for his Doctor of Philosophy Degree through the University of Technology, Sydney.

I understand that the purpose of this study is to consider how students learn when they construct models, analogies and role-plays.

I understand that my participation in this research will involve the following:

- completion of survey questionnaires,
- being videotaped while participating in class work,
- participating in a focus group that will be interviewed and that the interview(s) will be taped and transcribed.
- collection of copies of my written work

I am aware that this will require some time beyond normal lesson time and that these times will be negotiated so that my inconvenience will be minimised.

I am aware that I can contact Stephen Fogwill or Dr. Peter Aubusson if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason. I am convinced that my participation or withdrawal from that participation will have no adverse affect on my working relationship with the researcher or my academic progress.

I (the student) have attended an information session during which the researcher (Stephen Fogwill) has explained the project in detail and agree that he has answered my questions fully and clearly.

I understand that if I am willing to participate in the research, I may agree or not agree to the following aspects, and that the ones I agree to, must be initialled by both me (the student) and one of my parents / guardians.

I agree that:

	Student	*Parent*
• videotapes showing my involvement in activities may be used in conference presentations	☐	☐
• photos may be published in journal articles and	☐	☐
• research data gathered from this project may be published in a form that does not identify me in any way.	☐	☐

Please initial

We understand that all data (videotapes, photos, audiotapes and transcripts) will be securely stored in locked files and destroyed five years after completion of the research.

______________________ ____/ ___/ ____
Signed by student

______________________ ____/ ___/ ____
Signed by Parent / Guardian

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer, Ms Louise Abrams (ph: 02 - 9514 9615, Louise.Abrams@uts.edu.au), and quote the UTS HREC reference number HREC2004-068A. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Offices: City campus, 235 Jones St, Broadway NSW; Kuring-gai campus, Eton Road, Lindfield, Sydney NSW

Appendix 2a Science Activity Questionnaire

Science Activity Questionnaire

1. ***Briefly describe the purpose of the activity.***

____

____

____

2. ***To what extent were you participating in the activity***

Write a number from 1 to 5
(**1** = **almost no participation** and **5** = **very actively involved**)

Optional comment: ______________________________

____

3. ***To what extent do you think the activity helped you understand the science you were learning***

Write a number from 1 to 5
(**1** = **almost no help** and **5** = **helped a great dea**l)

Optional comment: ______________________________

____

4. ***Do you think the activity encouraged you and members of your group to stay focussed on what you were learning***

Write a number from 1 to 5
(**1** = **not at all** and **5** = **encouraged a great deal**)

Optional comment: ______________________________

____

5. ***To what extent was the activity enjoyable***

Write a number from 1 to 5
(**1** = **not at all enjoyable** and **5** = **very enjoyable**)

Optional comment: ______________________________

6. ***To what extent were members of your group using relevant science words while doing this activity***

Write a number from 1 to 5
(**1** = **not at all** and **5** = **all throughout the activity**)

Optional comment: ______________________________

____

7. ***To what extent were members of your group working cooperatively during the activity***

Write a number from 1 to 5
(**1** = **not at all** and **5** = **everyone worked very well together**)

Optional comment: ______________________________

____

8. ***To what extent were you happy about your final product***

Write a number from 1 to 5
(**1** = **not at all** and **5** = **very happy**)

Optional comment: ______________________________

____

9. Please write a brief comment about the usefulness of this activity in helping you learn the science you were studying in class.

____

____

____

____

____

____

____

Appendix 2b Science Activity Questionnaire (rev.)

Science Activity Questionnaire

1. Briefly describe the purpose of the activity.

2. To what extent were you participating in the activity? (tick one box only)

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment:

3. To what extent do you think the activity helped you understand the science you were learning?

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment:

4. To what extent were you and members of your group engaged in what you were learning?

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment:

5. To what extent was the activity enjoyable?

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment:

6. To what extent were members of your group using relevant science words while doing this activity?

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment: ______________________________

____

7. To what extent were members of your group working well together during the activity?

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment: ______________________________

____

8. To what extent were you happy about your final product? (______________________)

Describe your product

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment: ______________________________

____

9. To what extent were the members of your group talking about the science?

Very Low extent	Low extent	Moderate extent	High extent	Very high extent

Optional comment: ______________________________

____

10. Please write a brief comment about the usefulness of this activity in helping you learn the science you were studying in class.

____

____

____

____

____

Appendix 3 Interview Questions

Interview Questions

Could you please describe the purpose of the activity?
To what extent were you participating in the activity?
Do you think the activity helped you understand the science you were learning? If so, how? If not, why do you think it didn't?
In what ways, if any, did the activity encouraged you and members of your group to stay engaged with what you were learning?
Was the activity enjoyable? If it was, what do you think made it so?
To what extent were members of your group using relevant science words while doing this activity? (Did the activity help you to correctly use / learn / understand any relevant science words?)
During the activity, were members of your group working well together? How could you tell?
Were you happy about your final product? Why?
Please comment about the usefulness of this activity in helping you learn the science you were studying in class. (That is, do you think this activity helped you to learn? – If so how? and if not, why not?)

Video focus group question

To find out what was learnt and how, while watching the video, I would like you to make comments about things such as:

- What you were doing
- What the group was doing
- How the group was working
- Things that made you think about the science involved
- Things that you tried that seemed to work (make sense)
- Things that you tried and decided not to use (keep)
- How you were feeling
- What you thought about your final product

I might stop the video from time to time and ask you a specific question such as those mentioned above or others such as:
At this point in the video, what science was being discussed by the group?
Did this person understand what this other person was trying to explain (do or show)? How do you know?

Appendix 4 Codes

Codes

Codes have been used to identify data and assist with the Audit trail (Lincoln and Guba, 1985, p. 301)

A typical code is as follows:

FN-080606-12PhA – Photo electric effect

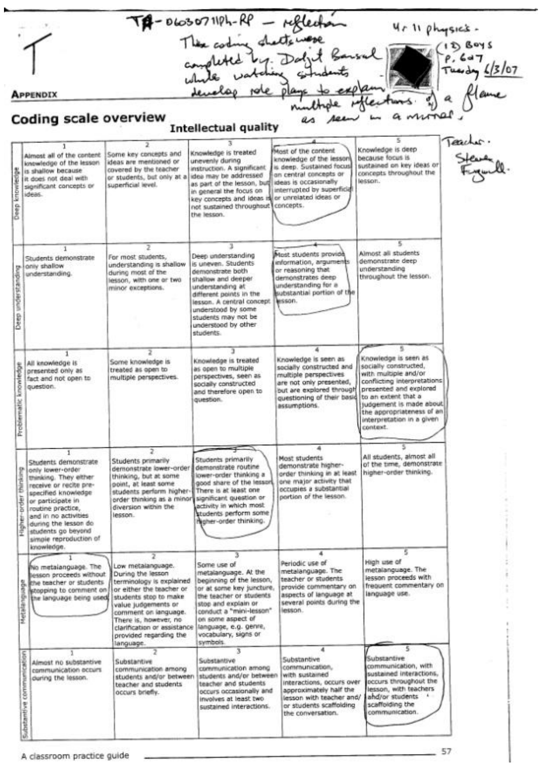
This code identifies field notes (FN) for an activity on 8th June 2006 (080606) during which Year 12 Physics (12Ph) students were developing their own written analogy (A) for the photo electric effect.

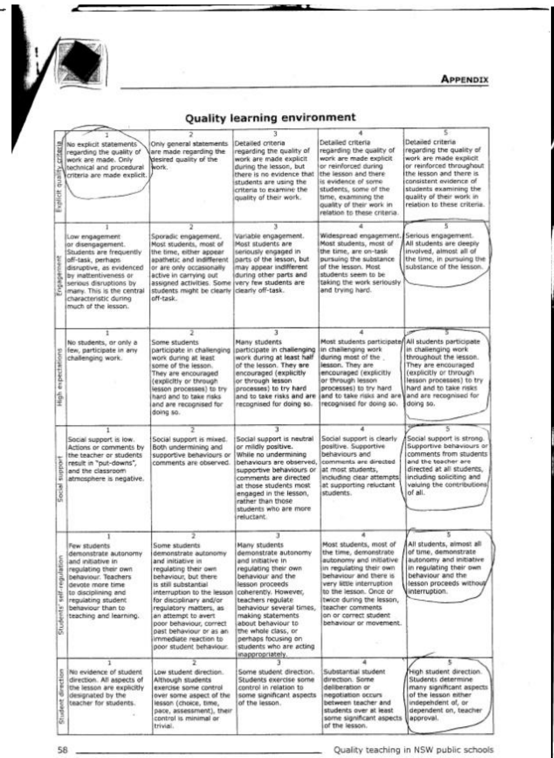
The table below identifies the codes used to identify data collected during this research.

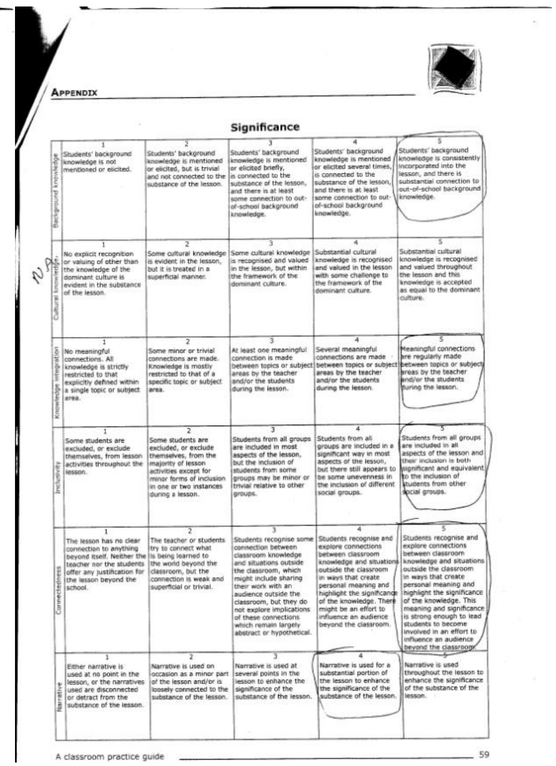
Description	Detail	Code
Data	Student Survey	SS
	Teacher Survey	TS
	Student Interview	SI
	Teacher Interview	TI
	Student Artefact	SA
	Teacher Artefact	TA
	Audio Tape/Transcript	AT / A
	Video	V
	Field Notes	FN
Activity	Role Play	RP
	Model building	M
	Analogy writing	A
	Test	T
Class	Chemistry	Ch
	Physics	Ph
	Senior Science	SS
Year Group	11	11
	12	12
Student identifier	Initials or number	EK or S1
Date	DD/MM/YY	080606

Appendix 5 Lesson coding sheet

Coding sheets used during teacher observation of a role play episode about reflection (see Vignette 2)







Appendix 6 Student question sheet (reflection)

Wyndham College Preliminary Physics – 8.2 The World Communicates

A person who just happened to be a Physics student prepared a wonderful meal for a special friend. The dinner table just happened to be positioned against a mirror. To make the occasion memorable a single tall candle was placed on the table quite close to the mirror. Towards the end of the dinner the friend expressed concern that they could see multiple images of the flame in the mirror and wondered if they had consumed something during the meal that might be affecting their eye sight.

The physics student explained that the candle had been placed deliberately near the mirror to achieve the “special effect” and that there was nothing to worry about.

Write a scientific explanation of the special effect. Include a labeled diagram in your response.

Explain how the physics involved in the candle image is significant to the development of the structure of optical fibres.
(For additional space, use the back of this sheet)

SF5.06
(SA-18.05.06-RP-11Ph)

Appendix 7 Photoelectric effect explained

The Photoelectric Effect – The text and figures below, taken from the 2nd Edition of a standard HSC Physics text - Physics 2 (Andriessen, Pentland, Gaut, McKay & Tacon , 2003, pp. 200-201) are provided to assist the reader.

Explanation of the photoelectric effect

Albert Einstein (1879-1955) successfully explained the photoelectric effect. He used Planck's theory in which the particles of light, or photons, carried energy that could be transferred to matter, and proposed the following assumptions.

1. Light exists as photons, each with an energy represented as $E = hf$.
2. Light intensity depends on the number of photons (the more photons, the greater the intensity of the light).
3. Photons with the highest energy correspond to light of the highest frequency.
4. To produce the photoelectric effect, where an electron is freed from the surface of a metal, the energy contained in the light photons must be equal to, or greater than, the energy required to overcome the forces holding the electron to the surface. The energy required to release the electron from the surface is called the work function.
5. If the energy of the photon is greater than the work function, the additional energy of the photon, above the work function energy level, will provide the kinetic energy of the photoelectrons.

When different metal surfaces are illuminated with monochromatic light, electrons are ejected from the metal surface. These electrons are called photoelectrons. Different metals hold electrons with different forces. Providing the photons of light at that frequency have sufficient energy to overcome the binding energy holding the electrons in the surface, the electrons will be emitted. If a graph of the photoelectron's kinetic energy versus its frequency used is plotted, the gradient of each line (representing a different metal surface) is the same (see figure 11.18). The point at which the lines intersect the frequency axis is a measure of the threshold frequency for each metal surface. If the monochromatic light is below this threshold frequency, no photoelectrons will be emitted from the metal surface. *(The experimental set up for making the measurements is shown in Fig. 11.15)*

The expression developed by Einstein to explain the observations of the photoelectric effect, combined the photon energy as described by Planck's equation, hf, the work function W, and the kinetic energy of the emitted electrons:

$E=hf= W+E_k$.

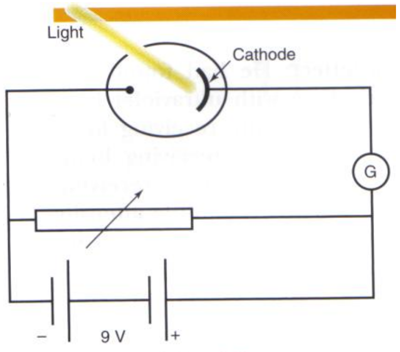


Figure 11.15 The voltage applied accross the variable resistor opposes the motion of the photoelectrons. The electrons that reach the opposite electrode create a small current, measured by the galvanometer. The value of the voltage at which the current drops to zero is known as the stopping voltage.

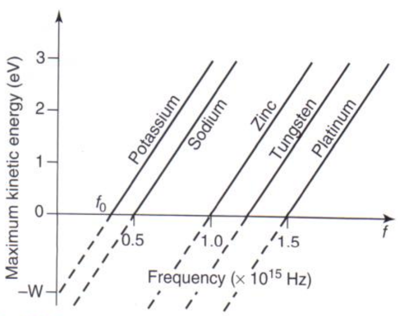


Figure 11.18 The graph shows the energy with which the photoelectrons are emitted and the threshold frequency for five different metals. Note that the gradient of all the lines is equal to Planck's constant.

Appendix 8 DET ethics approval requirements

Excerpt from DET "Guidelines for Approving Applications from External Agencies to Conduct Research in NSW Government Schools" June 2001, Amended March 2003

2.2 *All other external research projects*

Approval for all other external research projects - eg research theses associated with Bachelors (Honours) degrees, Masters (Honours) degrees and Doctorates - must be sought from State Office through the State Education Research Approval Process (SERAP).

Research should usually attempt to extend, rather than duplicate, existing knowledge. Applicants are to provide evidence that they are aware of existing knowledge and research in the area, and are required to demonstrate how the proposed project will add to the store of knowledge and understanding. Where a study is designed to replicate earlier work, it is necessary to provide grounds to justify such replication.

Applications submitted to State Office should be in accordance with the *Criteria for Approving Applications* (Section 3) and include the *Required Documentation* listed in Section 4. Before completing the application, applicants should read the criteria carefully. Note that, in signing *Form A*, researchers indicate that they are familiar with the criteria and agree to abide by them. All of the documentation requested must be provided: including Forms *A*, *B* ,*C* and *D*. Proposals cannot be assessed unless adequate detail is provided.

Proposals emanating from a university, which are required by university protocols to be approved by its research ethics committee, must be approved by that committee before final approval will be granted by the Department. To speed up the approval process, the Department is happy to consider the proposal at the same time as the university ethics committee is making its own assessment. The Department's final approval will be withheld, however, until notification of the approval of the university's human research ethics committee is supplied to the Department.

Key Terms

The following is provided to give explanation of several key words (see Page xiv) and other terms used in this thesis.

Analogy is a comparison between two entities, made in order to help describe/explain one of the entities. One of these entities is familiar and is called the base. The other, which is being described/explained, is called the target. The process of comparing attributes and relations is called mapping. Analogue and base are synonyms for the familiar entity in an analogy.

The features and of the target and base are called attributes. Interconnections between the attributes are called relations. In complex comparisons there are a number of attributes and relations. Collectively these are called domains. So a base domain is the collection of attributes and relations of the base. The target domain is the collection attributes and relations for the target.

An authentic class is a normal school class. Lessons are conducted as part of the regular school curriculum.

Co-construction/co-generation/co-development all refer to the student/student and student/teacher interactions that occurs as ideas are thought of and refined. The original ideas of individuals are enhanced through the supportive interaction of others.

Cookbook practical lessons are lessons in which all instructions are provided. Students need only to follow these instructions to achieve a desired result. Little if any creative thought is needed.

Conceptions are ideas or understandings that a person has. Inaccurate / incorrect / unscientific conceptions can be describes as misconceptions. When conceptions are different to accepted/traditional ideas but not wrong, they are called alternative conceptions. Alternative conceptions often occur when every day understandings are different to scientific understandings and hence the distinction between alternative and misconceptions can be contextual. Sometimes however, alternative conceptions are more correct than commonly accepted ones (see p. 29). Pre-conception are those conceptions that student bring with them into lessons.

Engagement has a range of definitions, however in the context of this research, the intellectual engagement (see p. 13) involved students in the active pursuit of scientific understandings about concepts in their courses.

The teaching experiment involved the application of an intervention. Each application was called an episode. Episodes were typically a 100 minute lesson. Some episodes carried into a second lesson. Descriptive accounts of what happened during the episodes have been presented in vignettes (see Chapter 4).

The FAR guide (Focus, Action, Reflection) (Treagust, 1993) is a three phase process which informs the use of analogies with students.

There many ways in which students can represent their understanding. While this experiment focussed on three types of analogical representations (physical models, role plays and written analogies) several others occurred. The role play activities in this teaching experiment typically involved students acting as features and demonstrating relations about the science concepts they were representing.

Teacher/research that involves a teaching experiment in which an intervention (teaching strategy) is evaluated and reported on, is typical of scholarly teaching (see also p. 53).

The intervention in this teaching experiment was focussed on students developing understanding about particular concepts. It was expected that if students had developed understanding, they would be able to correctly remember and explain the concepts a long time after the learning had occurred.