Science and Mathematics Education Centre

Evaluation of a Model for Teaching Analogies in Secondary Science

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ABSTRACT

Analogies have long been tools of discovery in mathematics and science, and are often used in the classroom as explanatory devices to help students understand difficult science concepts. However, research has shown that for many students, analogies engender misconceptions rather than scientists' science. It is believed that misconceptions arise when students reconstruct their knowledge within the context of their prior conceptions, and that misconceptions arise whenever the student has a different conception of the analog to the teacher or the student applies the analogy beyond its limits.

The literature is richly endowed with descriptions of how it is thought that analogies generate meaning and contain a range of suggestions for improving classroom pedagogy when analogies are used. Five teaching models have been identified which claim to improve analogical instruction, and one of these, the teaching-with-analogies (TWA) model (Glynn, 1989) has been modified at the Science and Mathematics Education Centre of Curtin University for use in secondary science classrooms. To date, no empirical studies have been performed to determine the efficacy of this modified TWA model.

This study set out to evaluate the modified TWA model in a qualitative interpretive manner by observing teachers, who had been in-serviced about the model, using analogies in their lessons. Data were generated from the verbatim transcripts of each teacher's in-class performance, each teacher's post-lesson interview and interviews with a number of the students who received the analogical instruction. The emergent data were interpreted from a constructivist perspective with attention being given to credibility, dependability and confirmability.

The data derived from one teacher teaching four analogies to Year 8 and 10 science students were reported in this thesis. Three of these analogies were taught using the modified TWA model and these analogies were, light waves are like water waves, conduction of heat in a solid is like the domino effect and the refraction of light as it passes from air into perspex is like a pair of wheels rolling from a

smooth surface onto a rough surface. The fourth analogy in which the size of a mole was illustrated using three brief analogies was reported only briefly because the teacher failed to use the modified TWA model during this lesson.

The study's findings demonstrated that student understanding of difficult science concepts did appear to be enhanced by the use of the modified TWA model when analogies were included in the lesson. For analogies to be effective, it is believed that two teacher activities are essential: firstly, ensuring that the students understand the analog in the same way as the teacher and secondly, that the unshared attributes of the analogy are highlighted during the lesson. It is also asserted that an exemplary teacher, teaching-in-field, can integrate the modified TWA model into her teaching if she is provided with peer support over at least three to four uses of the model during normal lessons. It appears that maintenance of the TWA model within a teacher's pedagogy requires a supportive colleague to provide critical feedback and encouragement.

This study raised some important questions that should be addressed in future research on the use of the modified TWA model. Can the modified TWA model produce conceptual change where alternative student conceptions are firmly entrenched? Can the modified TWA model be incorporated into the pedagogy of most teachers? Is there a more appropriate model for teaching-with-analogies?

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Chapter 1

INTRODUCTION

BACKGROUND TO THE STUDY

Since the beginning of recorded history, analogies have been used as concept building tools for children and for adults. Metaphors, similes, analogies and parables plus mental and physical models are common devices in spoken, acted and written communication. Metaphors and analogies are woven into children's stories, for example, with people represented by animals. Both fiction and nonfiction authors use analogy as a descriptive tool, and they are especially ubiquitous in religious writings, for instance, in Bible parables.

Each of the above literary devices are collectively considered to be analogies (Duit, 1991) because of their potential to compare one object or situation to another, and in the process, transfer either details or relational information, or both. Analogies are used and have been used because they have the power to evoke rich, almost instantaneous, mental pictures that serve to challenge the hearer to transfer knowledge from the familiar domain to the unfamiliar.

Analogies also can be tools of discovery. Johannes Kepler developed his concepts of planetary motion from the workings of a clock (Bronowski, 1973) and Huygens used water wave motion to understand light phenomena (Duit, 1991). Oppenheimer (1955) emphasised the value of analogies in the development of modern particle physics and showed how the similarity between nuclear and electrical forces predicted and led to the discovery of mesons. Perhaps the best described use of analogies in scientific discovery is Maxwell's mathematical description of Faraday's electric lines of force (Gee, 1978).

What works for the investigative scientist may be of value to other learners. For example, Cosgrove (1991) describes an exciting episode in which Year 8 boys discovered a valid model for an electric current using their own analogies. The question raised at this point asks whether the average student can economically and repeatedly employ these same reasoning skills. Indeed, to emulate the analogical reasoning of scientists and philosophers may be too much to ask of unsophisticated thinkers.

When describing analogies in this study, the familiar domain will, in accord with the majority of writers, be called the analog and the unfamiliar domain will be termed the target. Alternatively, Curtis and Reigeluth (1984) describe these domains as source and vehicle respectively, while Gentner (1980) uses base and target. The terminology may vary, but the common theme is the transfer of understanding because of commonality of structure and/or organisation between analogous domains. The process of linking valid attributes from one domain to the other is, in true analogical spirit, called mapping.

Although analogies are commonplace in human communication, there is a significant body of research that suggests that they are not as effective in the classroom as might be expected. Uncritical use of analogies may generate misconceptions (Champagne, Gunstone & Klopfer, 1985), and this is especially so when unshared attributes are treated as valid (Cosgrove & Osborne, 1985; Curtis & Reigeluth, 1984), or where the learners were unfamiliar with the analogy (Gentner & Gentner, 1983; Nagel, 1961). In addition, Johnstone and Al-Naeme (1991) suspect that analogies can be a source of confusing classroom noise, though they offer no empirical evidence to support this view. The effectiveness of analogical instruction though can be improved by training students in analogical reasoning (Friedel, Gabel & Samuels, 1990; Gentner, 1980; Klauer, 1989).

STUDY RATIONALE

The concensus amongst most investigators is that analogies enhance student learning through a constructivist pathway. Constructivism is the process in which learners compare new information with old within the context of their current conceptual framework and so reconstruct their knowledge. Every person has his or her own view of the world, having developed explanations for the phenomena round about him or her. Learners, therefore, possess these preconceptions or alternative frameworks (Driver & Easley, 1978; Dupin & Johsua, 1989) or children's science (Osborne, 1980) into which they attempt to integrate new ideas. Three decades ago, Ausubel (1968) pointed out that these "preconceptions (are) amazingly tenacious and resilient to extinction". Indeed, research since that time has shown that student's own concepts are so strongly held that in some instances, as seen from the teacher's perspective, they will be preserved in the face of obvious and contradictory evidence (Johsua & Dupin, 1987; Tasker & Osborne, 1985). Many students will accept the teacher's science for the duration of the topic being studied, but will revert to their intuitive views following instruction (Osborne & Freyberg, 1985). In other instances, students will construct alternative schema to accommodate the lesson content without altering their preconceived views (Johsua & Dupin, 1987; Tasker & Osborne, 1985). Research has shown that learners' intuitive beliefs are very resistant to modification.

If these natural conceptions which Dupin and Johsua (1989, p. 118) call "epistemological obstacles" are to be successfully challenged, then a carefully planned pedagogy is called for. In attempting to redress this problem, a number of models for more valid and reliable use of analogies have been produced. Five such models are Zeitoun's (1984) General Model of Analogy Teaching (GMAT), Glynn's (1989) Teaching-With-Analogy (TWA) Model, Clement's (1987) Bridging-Analogies, Dupin and Johsua's (1989) analogy teaching model, and Cosgrove and Osborne's (1985) four phase conceptual change model, where at the crucial third step, "the challenge phase", they highlight the value of analogies.

While the use of an analogy to identify weaknesses in the student's understanding can be useful, the analogy itself must be used economically and in a valid and reliable way. An analogy enables valid concepts from a familiar domain to be used to challenge the student's cognition, with the result that the learner is stimulated to reconstruct his or her knowledge (Sutula & Krajcik, 1988).

Thus, the rationale for the evaluation of a systematic model for analogical instruction, which is the focus of this thesis, is to highlight the dangers inherent in the haphazard, uncritical use of analogies in the science classroom and to provide science teachers with an efficient model for improving their teaching. A secondary goal is to encourage students to systematically and critically examine analogies that they or others may use in explaining science concepts.

The Teaching-with-Analogies Model

Following careful scrutiny of the five previously listed models, Glynn's (1989) Teaching-with-Analogies (TWA) model emerged as the best suited for use in secondary science classrooms. Each model however, has its strengths. Clement's (1987) Bridging-Analogies is a particularly useful tool for breaking the process of instruction into steps that are conceptually achievable by weaker students. The most extensive of the models is Zeitoun's (1984) in which he addresses planning (analogy choice), in-class presentation and post-lesson evaluation. It was thus believed that Glynn's (1989) model, focussing as it does upon the teacher's in-class presentation of the analogy, would be the most straight forward to implement and evaluate.

The model used in this study was derived from Glynn's TWA model and can be summarised in six points which involve:

1. Introducing the target concept to be learned.
2. Cueing the students' memory of the analogous situation.
3. Identifying the relevant features of the analog.
4. Mapping the similarities between the analog and the target concept.
5. Drawing conclusions about the target concept.
6. Identifying the comparisons for which the analogy breaks down.

The single difference between the modified TWA model and Glynn's model is the reversal of steps five and six. Based on some trials with Glynn's model it was believed that student understanding would be best served by examining the shared and the unshared attributes side-by-side. Anecdotal experience suggested that teachers and students rapidly map analog-target similarities resulting in the simultaneous generation of both valid and invalid comparisons. If the conclusions were drawn before the unshared attributes were identified, then misconceptions would arise more often than when these invalid comparisons were identified before the conclusions were drawn.

AIM OF THE STUDY

The Teachers' Use of Analogies project at the Science and Mathematics Education Centre (SMEC) at Curtin University (Treagust, 1989) is examining the viability of using analogies in science teaching. To date there is little empirical evidence available (Curtis & Reigeluth, 1984; Treagust, Duit, Joslin & Lindauer, 1992) to indicate whether any of the models described above, can enhance teacher use and student understanding of scientific concepts where analogies are often used. Consequently, this study proposes to test the efficacy of the modified

Teaching-With-Analogies model described above in a number of secondary physical science classes spanning Years 8 to 10.

RESEARCH QUESTIONS

While the use of analogies as concept building devices in science instruction is quite common, there are gaps in our knowledge concerning their mode of action, for whom they are most effective and which types of analogy are the most useful. In this study only one or two issues are examined in detail and the relevant research questions are:

1. Can a competent teacher use the modified TWA model to systematically present analogies during science instruction?
2. When analogies are taught using the modified TWA model, are the resultant student conceptions compatible with scientists' science?

METHODOLOGY

Because analogies are devices of human communication, it is essential to ascertain the analogy's meaning for the teacher and the students. To find these meanings, this study employed classroom observations and audio-tape recordings in combination with teacher and student interviews. Each episode was transcribed verbatim and analysed to yield data for interpretive analysis. Consequently, the mode of study is that of a qualitative case study (Merriam, 1988) which also uses some quantitative data.

The emphasis in the thesis is upon producing interpretations that are trustworthy, credible, transferable and dependable (Guba & Lincoln, 1989). In other words, the aim is for an outcome that is plausible and viable, and which possesses face validity (Patton, 1990). These criteria are especially important when reporting on the modified TWA model's implementation by teachers with their classes (Research Question 1) and in describing students' conceptual understanding (Research Question 2).

SIGNIFICANCE OF THIS STUDY

The potential significance of this study lies in the validation of a model for analogical instruction. The modified TWA model has been proposed as a systematic method for teacher presentation of analogies and for enhancing student cognition whenever analogies are used to teach scientific concepts. The possible outcomes of this study may be:

1. Establishing that the modified TWA model is both valid and reliable for use in secondary science classrooms.
2. Indicating modifications to the modified TWA model that could render it credible and dependable.
3. Identifying the need for a more effective approach to teaching analogies in science.

If the modified TWA model is successful, then this study should provide guidance for further trialing of the model and ultimately, the model's implementation through pre-service and in-service teacher education. If the model needs modification, then this study will probably indicate the direction for future classroom trials. Provided that the study is rigorous, it should also add to our knowledge of the role of analogies in the classroom.

SUMMARY

To this point, it has been established that analogies are used in everyday speech, scientific discovery and in the classroom. While analogies are often used in some science classrooms, and the capacity for analogies to generate misconceptions has been well reported in the literature, there is little evidence of improvements in pedagogy for analogical instruction. Five approaches for analogical instruction have been identified in the literature with each identifying the need to present analogies in a systematic and disciplined manner so as to enhance student understanding while reducing misconceptions. One of these models, Glynn's (1989) Teaching-with-Analogies model, has been modified and it is this study's goal to evaluate the effectiveness of the modified TWA model with the aim of improving the quality of secondary science instruction.

GLOSSARY OF SOME RELEVANT TERMS USED IN THIS THESIS

This glossary is provided to describe the manner in which each of these terms are used in this theis. It is not, nor does it purport to be, a philosophical discussion of the grounds for each definition.

Advance organiser This is any story, example, problem or demonstration that focuses attention on the ideas that follow. An analogy acts as an advance organiser in text (or teacher explanation) whenever the analog is presented before the target concept. The student is cued to the analogous situation before the target is introduced. Advance organisers are useful for motivation (Curtis & Reigeluth, 1984).

Analog The concept that is familiar and is understood by the learner. It also may be called the source or the base. The analogy transfers knowledge from the analog to the target explaining the target concept in terms of the analog (Duit, 1991).

Constructivism A process of knowing in which the learner constructs his or her own conception of reality based upon the interplay of prior knowledge and present experiences. Thus, understanding is the personal construction of meaning (von Glasersfeld, 1987).

Empiricism "The use of empirical methods in any art of science ... the doctrine which regards experience as the only source of knowledge" and "a conclusion arrived at on empirical grounds" (Simpson & Weiner, 1989, vol. V, p. 189). **Empirical** is defined as a practice that is based on the results of observation and experiment, not on scientific theory. Epistemologically, empiricism is often used in a similar way to both objectivism and positivism.

Embedded activator An in-text (or in-lesson) story, example, problem or demonstration that focuses attention on the ideas being considered. In this instance, the analogy is placed partway through the instruction. The learner has had the opportunity to absorb the basic elements of the concept, thus the analogy acts as a lead-in to the understanding of more difficult ideas. An analogy at this point may simply act as a consolidating device or to add variety (Curtis & Reigeluth, 1984).

Epistemology Describes the process of knowing about knowing or knowledge. Literally, a discourse on knowledge (Simpson & Weiner, 1989, vol. V, p. 338).

Mapping Describes the identification of perceived similarities between the analog and the target. Mapping links can be either valid or invalid (Duit, 1991).

Misconception A concept that a student derives from instruction or study that is not in accord with scientists' science. In this thesis misconception is used to describe student understanding that arises through inappropriate interpretation of the shared attributes of an analogy or where credence is ascribed to the unshared attribute(s). The term alternative conception(s) is used in this thesis for those concepts the student holds prior to instruction (also called children's science) (Gilbert & Watts, 1983; Peterson, Treagust & Garnett, 1986).

Objectivism Expresses the belief that knowledge exists independently of the knower and that truth is absolute and waiting to be discovered (Simpson & Weiner, 1989, vol. X, p. 644). A tenet of objectivism is that the true scientist is unbiased and objective and thus unlocks knowledge by controlled experimentation.

Ontology "The science or study of being, that department of metaphysics that relates to the being or essence of things, or to being in the abstract" (Simpson & Weiner, 1989, vol. X, p. 824).

Paradigm "A basic set of beliefs, a set of assumptions we are willing to make, which serve as touchstones in guiding our activities" (Guba & Lincoln, 1989, p. 80).

Positivism The strong positive response, particularly in the physical sciences, emanating from the belief that all natural phenomena can be explained by laws and axioms. Guba and Lincoln (1989) call this "the desire of social scientists to be rational and systematic, in the spirit of Descartes ("I think, therefore I am") and of positivism generally" (p. 35).

Post-synthesiser A story, example, problem or demonstration that summarises the ideas already presented. A post synthesiser analogy appears at the end of the instruction on a topic. The analogy concludes the instruction and acts as a summarising device (Curtis & Reigeluth, 1984).

Proposition In Chapters 3 and 4 this term will be employed to describe a single idea that is transferred from the analog to the target when the analogy is used. These propositions will be discussed from the perspective of whether they are valid or invalid (Novak, 1984).

Target This is the unfamiliar concept(s) that the analogy is being used to describe or explain (Duit, 1991).

Chapter 2

LITERATURE REVIEW

CHAPTER OVERVIEW

The basic purpose of this study is to investigate analogies as instructional tools. It is therefore relevant to consider analogies from two viewpoints; that of the teacher who makes the decision to use an analogy, and from the students' perspective as they endeavour to understand new concepts in the light of past experiences. The way the student and the teacher understand a particular analogy can range from congruence to dissonance. Why, or how is it, that analogies can in one instance expand the learners' understanding and yet in another generate misunderstanding or develop a misconception? The literature is richly endowed with many and varied answers to this question.

The role of this literature review is to describe the current knowledge base relating to the use of analogies in learning science. It also aims to provide some guidance for the process of evaluating the Teaching-With-Analogies model (Glynn, 1989, Treagust, 1989). Thus, this overview is presented as an advance organiser for the six sections comprising this chapter.

The primary task is to define and describe analogies as they are used within this study. Because analogies, and metaphors in particular, mean different things to different people, the second section will focus upon constructivism and the generation of meaning. The examination of analogies and constructivism then directs the reader into a review of how analogies are used in instruction. It will become evident at this stage that analogies can generate both understanding and misconceptions. The fourth part addresses the question of how teachers can improve analogical instruction and this naturally leads into the fifth section which examines the five approaches for teaching with analogies. The literature review provides the theoretical base for the exercise that will attempt to evaluate the modified TWA model. Thus, at the conclusion of this chapter, it will be necessary to discuss methods of evaluation.

THE NATURE OF ANALOGY

Definition of an analogy

The original meaning for the word analogy was as a mathematical term describing the equivalence of two ratios or proportions. It also expressed similarity or declared that two or more parallel relations were equivalent (Simpson & Weiner, 1989). This mathematical basis is reflected in Curtis and Reigeluth's (1984) description when they state that an analogy is any instance in which we use a statement of similarity. For example, the statement that an elephant is large, implies that when we change the subject to ant, the clause becomes, is small. Using the mathematical format, this analogy can be represented as, elephant : large : : ant : small. Miller (1979, p. 218) uses an overtly mathematical form for describing analogical relationships. For example, $3 : 4 :: 9 : 12$, or more generally, $x : y :: nx : ny$.

In physics, the concept that water waves carry energy is well known, so if light also carries energy, then it is *likely* that light is also wavelike. The resultant relationship is an analogy (Gentner, 1980) and could be written as

transfers energy : water waves : : transfers energy : light waves.

As can be seen from this example, an analogy can occur just as often as a spoken or written statement as a mathematical statement of proportion. It is as figures of speech or statements of structural or functional similarity that most analogies are encountered.

> Analogies have probably existed since the early development of language. Their use today is extraordinarily popular and frequent. Hardly a day elapses without encountering one (either in print from Plato to Einstein to Agatha Christie) or in everyday spoken language. In fact, language and thinking themselves, may be thought of as records of analogous experiences. Every new experience is related to an analogous set of experiences that help us understand it. (Curtis & Reigeluth, 1984, p. 99)

Even though analogies are ubiquitous features of our lives, it should be remembered that their mathematical origins regulate their correct use. The power of an analogy resides in its ability to denote ratio, similarity and correspondence. To perform this task correctly and repeatedly, especially for unskilled minds, analogies need to be used in ways that are valid, and in situations that are appropriate.

These ideas may be summarised by referring to the *Oxford English dictionary* (Simpson & Weiner, 1989, Vol.I, p. 432) definition of the word 'analogy'

> *Logic.* a. Resemblance of relations or attributes forming a ground of reasoning. b. The process of reasoning from parallel cases; presumptive reasoning based upon the assumption that if things have some similar attributes, their other attributes will be similar.
> *Nat. Hist.* Resemblance of form or function between organs that are *essentially* different (in different species), as the analogy between the tail of a fish and that of the whale, the wing of a bat and that of a bird, the tendril of the pea and that of the vine.

At this juncture, then, it is worth extending the scope of our definition of analogy so that it includes all the forms of *likeness* that are used in learning environments. In both language and teaching, metaphors and similes perform like functions in the classroom in that they stimulate the recall of past knowledge. In a similar vein, mental models (as thought experiments), physical models (e.g., the heart or DNA molecule) and scale models (solar system model) are similarly used as analogies in science instruction (Osborne & Gilbert, 1980). Duit (1991) asserts that the concepts underlying both metaphors and analogies are similar though noncongruent because analogies speak of explicit or literal comparisons which are basically true; while metaphors make implicit or nonliteral comparisons which are not true. In this sense, metaphors have 'shock' value in communication. Because metaphors are *plainly* discordant, they are very effective in pointing the hearer's thinking to generically different ideas and episodes, so as to draw from those discordant instances patterns and processes that apply to the subject of study. The frequent use of metaphors (Nagel, 1961, p. 108) "testifies to a pervasive human talent for finding resemblances between new experiences and familiar facts, so that what is novel is in consequence mastered by subsuming it under established distinctions".

The range: metaphor-simile-analogy-model will be taken as a continuum from most general to the most specific for this study. The extension of the term, analogy, to cover a broad range of, 'it is like' comparisons, either stated or implied, is supported by Gentner (1983). This all inclusive approach is the only rational way to proceed in view of the diversity of analogies used by teachers. Nevertheless, the principal focus of this study is upon the modified TWA model and how teachers use analogies in their classrooms.

Characteristics of Analogies

It is now necessary to identify the cognitive characteristics of this expanded family of analogies. Nagel (1961) broadly divides analogies into two types: substantive and formal. By substantive he means the instance in which a familiar object, system or phenomenon is used as a model to explain a second situation. The familiar becomes a framework for the construction of a theory that elucidates and make predictions about the new instance. For example, the kinetic theory of gases was formulated through a knowledge of Newtonian physics and colliding elastic spheres such as billiard balls. The formal analogy is the description of a theory derived from abstract correspondences such as Maxwell saw between the mathematical description of gravitation and the equations for the conduction of heat. In each type, there must of necessity be an obvious similarity between the familiar case and the unknown for the initial link to be formed. Extending the mapping to learn something new requires imagination and critical reflection to ensure that the correct features and relations are realised without the inclusion of invalid matches.

Curtis and Reigeluth (1984) surveyed analogy use in 26 elementary, secondary and post-secondary science textbooks. In classifying analogies these authors made a distinction between the "condition" (p. 108), the mechanism (p. 103) and the depth (called "enriched ... extended" p. 111). Their stance was similar to Nagel's when they classified the analogy's subject matter under "condition" as either concrete, abstract, or mixed concrete/abstract. The concrete analogy corresponds well to Nagel's substantive form. This initial classification could alternately be divided into two different categories, the distinction here being whether the mechanics of the relationship were structural or functional. This reflects a different viewpoint where the nature of the mapping is used to classify the analogy. An example of a structural analogy was 'a cell is like a room' analogy because it has walls, floor and ceiling plus ways for things to move in and out. A functional analogy was to use a building's thermostat as an analog for homeostatic temperature control. Curtis and Reigeluth included the hybrid structural/functional analogy to cover those situations where both types of mapping exist concurrently.

The third criterion, depth, focuses on the detail included in the analogy. Analogies are either simple, enriched or extended. An analogy is simple if when it is stated, the relationship between the analog and the target is obvious without explanation, for example, an artery is like a flexible pipe. Enrichment occurs when the conditions under which the target is like the analog are precisely stated, such as how and when the analogy is valid. These conditions qualify the analogy. The authors' definition of an "extended" analogy is the situation where two or more enriched analogs combine to illustrate the target or when an enriched analog teaches about two or more targets. That is, there are multiple points of correspondence between analog and target and the conditions are stated. Figure 1 depicts these three types of analogy:

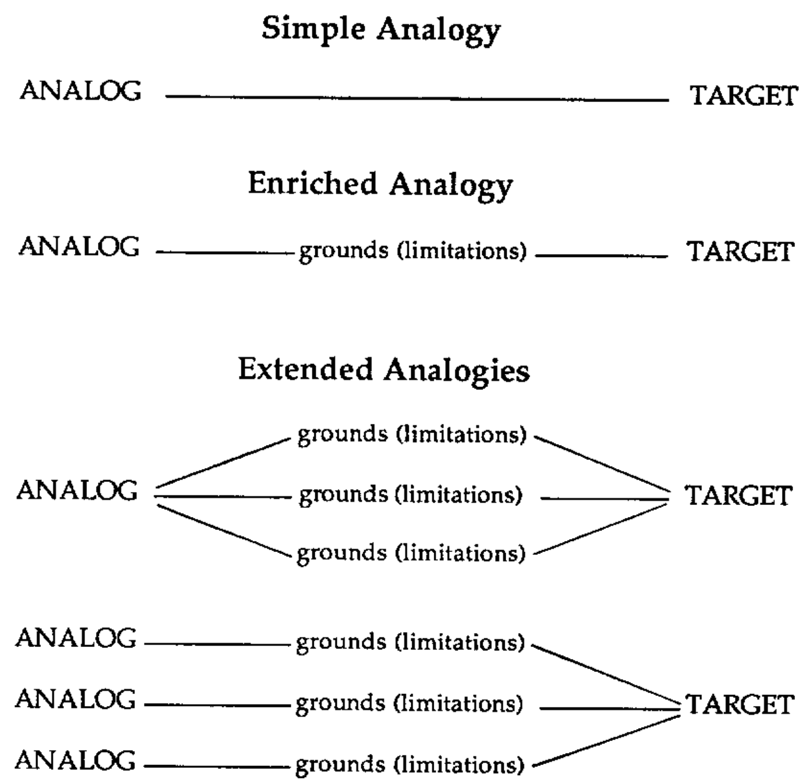

Figure 1: Simple analogy plus three levels of enrichment for textual analogies. (from Curtis & Reigeluth, 1984, p. 111).

CONSTRUCTIVISM AND THE GENERATION OF MEANING

Analogies and Learning

The foremost question in educational research asks, how do people learn? It would be inappropriate to investigate teaching with analogies without reviewing the learning theories that could underpin such a study. For 30 years until about 10 years ago, Piaget's staged view of learning predominated. "To Piaget, knowledge is the *transformation of experience* by the individual, not just the accumulation of pieces of information" (Farmer & Farrell, 1980, p. 49). Other useful learning theories are Gagné's hierarchies and Ausubel's meaningful learning theory.

Over the past 15 years, constructivism has revolutionised the study of learning by emphasising the individualistic way in which understanding is generated. However, constructivism does not negate these prior theories, rather it provides a basis for comparing each learning theory in a broader context and it highlights their limitations and builds upon their strengths. Analogies depend for their meaning on the learners' a priori understanding. Thus, constructivism currently provides the best explanation for the way an analogy generates meaning during analogical learning.

In this way the constructivist epistemology provides a sound platform for the study of teaching with analogies. Stake (1991) provides a personal flavour when observing that "it has become increasingly apparent to me that educators, as most people, work from experiential understandings, that their knowledge and all knowledge is a human construction." (p. 81).

Constructivist Rationale for Using Analogies

Objectivism emphasises the literal value of language and this is especially so in scientific communication. The objectivist notion that words and ideas have absolute meaning is evident in empirical statements where it is assumed that there is an inviolate one-to-one correspondence between reality and the knowledge of reality. From this perspective, Novak (1984) describes empiricism as being a major obstacle to the learning of science in schools. He believes that this right-wrong dichotomy shared by teachers and students, and reinforced by examinations, encourages the mere rote learning and regurgitation of facts without the student ever having to genuinely understand what has been studied. The constructivist paradigm takes a quite different position proposing that "cognition is the result of mental construction" (Ortony, 1979, p. 1). To use Driver's words,

> Central to this perspective is the historically important view that learning comes about through the learner's active involvement in knowledge construction. Within this broadly 'constructivist' perspective learners are thought of as building mental representations of the world around them that are used to interpret new situations and to guide action in them. These mental representations or conceptual schemes in turn are revised in the light of their fit with experience (Driver, 1989, p. 481-2).

Novak and Gowin's heuristic vision (Novak, 1984) similarly emphasises "the interplay of concepts, principles and theories with observation of events or objects" (p. 607) in learning for understanding. This viewpoint is pursued throughout this study of analogical reasoning.

Today, it is generally recognised that learners do not come to science instruction with a 'tabula rasa' but possess tenaciously held preconceptions concerning the phenomena with which they are familiar (Johsua & Dupin, 1987; Osborne & Freyberg, 1985). As the principal tool of education is language, and the teacher's goal is to establish valid grounds for the learner to explore scientists' science, the meaning of individual words and expressions is a vibrant cog in this overall process of developing cogent understanding. It must be asked, do analogies convey actual knowledge or are they simply a medium for the development of ideas?

Whenever an analogy is spoken or written, reference is being made to pictures and ideas in long term memory. The generative learning model (Osborne & Wittrock, 1983; Wittrock, 1985) describes the development of understanding during learning as being a vigorous interplay between prior knowledge and current experience. Osborne and Wittrock state

> that the brain is not a passive consumer of information. Instead it actively constructs its own interpretation of information, and draws inferences from them. ... The stored memories and information processing strategies of the brain interact with the sensory information received from the environment to actively select and attend to the information and to actively construct meaning. (p. 492)

This ebb and flow of facts and ideas in order to build a coherent mental representation of reality during constructivist learning is considered in detail by Driver (1989).

During learning, the child's preconceptions and misconceptions often act as a barrier to the reception of new, more valid propositions. Cosgrove and Osborne (1985) suggest a four stage model for working through such impasses, one element in the process being use of analogies. An appropriate analogy may serve to arouse relevant familiar concept(s) in long term memory. Thus, previously learned structural and organisational knowledge may interact constructively with the new challenging experience. When the learner holds invalid or flawed concepts, a well chosen, familiar analogy can act as an appropriate source of conceptual conflict for the student.

In the process of restructuring knowledge, the student must first become dissatisfied with his or her prior view. For this to occur, the student must be motivated to see a need to improve his or her understanding, and this is the role of conceptual conflict or dissonance. Only when the student is willing to relinquish the prior concept, can conceptual reconstruction commence. Building upon their earlier work (Posner, Strike, Hewson & Gertzog, 1982), Strike and Posner (1985) suggest that analogies and metaphors can initiate new ideas and understandings within the student's conceptual ecology. Strike and Posner recognised that not all new conceptions will even be considered, much less accepted. They list four criteria that ought to be met for conceptual change to occur.

1. There must be dissatisfaction with existing conceptions.
2. The new conception must be minimally understood.
3. The new conception must appear initially plausible. Any new conception that is adopted must at least appear to have the capacity to solve the problems generated by its predecessors, and to fit with other knowledge and experience.
4. A new conception should suggest the possibility of a fruitful research program. ... to open up new areas of inquiry (p. 216).

Similarly, in their review of conceptual change, Hewson and Thorley (1989) describe the Conceptual Change Model using the same four criteria. Their only difference is to refer to the second criterion as intelligibility.

In the context of the conceptual change model analogies should be particularly powerful in inducing conceptual change because they draw upon familiar knowledge with which the student is comfortable. The quality of the new concept is clearly related to the appropriateness, familiarity and the richness of the analogy as it is compared to the new ideas being considered.

While not discussing analogies, Novak (1990, p. 941) points out that "the challenge we face as science educators is primarily how to organise better instructional material and how to help students learn this material". As will be considered in more detail in the next section, this raises the question about whether or not teachers use analogies in a way that helps students construct meaning. As stated in Chapter 1, many researchers have observed that analogies are frequently poorly presented by teachers and are themselves likely to be responsible for the genesis of misconceptions.

Are Analogies a Source of Misconceptions?

Reference has already been made to the way people perceive the world about them. Few would challenge the notion that we all 'see' things in our own individualistic way. A work of art may enthral one person and repulse another. Thus, when an analogy is used to elucidate an unfamiliar subject, the recipient's perception of the analog must influence his or her conclusions about the target to some degree (Weller, 1970). This is in a sense, the dark side of constructivism and analogy use because it is not possible to predict exactly how another person will view the analogy.

A case is recounted (Champagne, Gunstone & Klopfer, 1985 referring to White & Gunstone, 1980) in which a science graduate used the water in pipes analogy to explain his conception of an electric current. He deduced that electrical resistance arose due to friction between the current in the wire and the insulation and concluded that if the insulation was broken, the current would leak out much like water leaks through a hole in a hose. He continued to say that much electrical engineering research was devoted to developing low friction insulation for wires. It appears that this student analogically derived these conclusions on his own and that they led to incorrect explanations of 'learned' phenomena.

When speaking of the widespread use of metaphors, Nagel (1961) observed that "little if any attention is generally paid to the limits within which such felt resemblances are valid" (p. 108). A similar caution is offered by Weller (1970) who noted that "the only safeguards against being entrapped is to be particularly cautious when one uses an analogy, to be aware of its limitations, and to be constantly looking for dissimilarities" (p. 116). Weller also recognised another hazard in analogy use that occurs when an analogy becomes so loved that the user becomes incapable of letting go. The result is belief in perceived similarities that go beyond the evidence and/or reason. Many models and their analogies have been used as powerful tools of scientific discovery and often the model has so diffused the theory it generated that the model is spoken of as the reality. Weller points out that those who use models and analogies to develop theories must make a conscious effort to keep the tools separate from the product. This will evidently be important when analogies are used pedagogically because the student might retain the analogy and ignore the understanding it generates, or at the least, confuse the two.

Gee (1978) came to similar conclusions when discussing Maxwell's use of analogies in mathematically describing Michael Faraday's electric fields. It is Gee's belief that drawing analogical arguments from models is inappropriate for general teaching. He warns of the dangers inherent in "erroneous inference by negative analogy or the reluctance to let go of some treasured and nurtured model" (p. 291). Gee's recommendation is that teachers should always make the student aware that an analogy or a model is but a representation of reality, not an end in itself.

With regard to modelling as an investigative process that often uses analogical reasoning, Giordan (1991) describes this style of thinking as constructivist. He calls this "process of the transformation of conceptions in which the chief protagonist is the learner and the learner alone" (p. 322) the *allosteric* model of learning. A model is described as a way of representing reality by an image that both describes its salient points and simplifies the situation. "Schematically, a model is an answer to a question" (p. 326). When giving actual instances of such a model, he uses what has been to date considered a simple analogy. For example, an electric current is modelled by the water in pipes or the bicycle chain analogy and the burning of wax in air is modelled using Lego bricks.

In comparison, Gee's approach is much more that of a purist. To quote his own words (1978)

> To use a model correctly demands that (a) we do not use the device to argue by analogy ... : (b) we should not claim that a model can explain (... reality - whatever that is): (c) we must be prepared to drop a model once a theory is realised; and (d) we ought to note the valuable parallel which exists between the growth of a scientific theory (in which a model may be a heuristic tool) and the intellectual growth of the learner (for which a model is a pedagogical tool). (p. 287)

Nevertheless, Gee recognises the analogy that Maxwell used as just that - "a partial similarity between the laws of one science and those of another which makes each of them illustrate the other" (p. 288). He also notes that an analogy may possess heuristic qualities for learning.

Thus, experimental observations and reflections upon analogy use sound the warning that indiscriminate or uncritical use of analogies can weaken understanding, or worse, construct misconceptions. It is not just the wrong use by the teacher that needs attention; a conscious effort is needed to examine the inferences being made by the students. As will be seen later, this is a particular strength of Glynn's (1989) model because it consciously addresses these issues.

Analogies Can Help Create Meaning

In defence of an analogical, constructivist pedagogy, Oliveira and Cachupuz (1992, p. 1) suggest that analogies and metaphors "may help bridge theory and practice" and assist students in making sense of the world in which they live. They assert that the new ideas that students encounter in chemistry are foreign to their conceptual framework. If these ideas are integrated by analogy into a familiar pattern that is easily received, understanding is enhanced. They describe analogical instruction as a constructivist learning approach because the analogy assumes "a creative function when it stimulates the solution of existing problems" by recourse to common-place ideas. This position is supported by Sutula and Krajcik (1988, p. 11) when they note that "cognitive psychologists agree that the use of analogies can influence meaningful learning by providing a link to previous learning". However, it is imperative, when making this nexus to prior knowledge, to recognise when the preconception is itself valid and to consciously eliminate unsustainable mappings which might support invalid preconceptions.

Understanding constructed by each individual reflects that person's unique perspectives and idiosyncrasies. If the constructed understanding is to be logical and socially congruent, while at the same time preserving the individual's character, in teaching it is important to identify the essential landmarks, fix those in place and allow the student to add his or her finishing touches. Analogies are appealing in this context because they have the ability to establish conceptual patterns (Gentner, 1988) as well as transmit specific items of data.

The use of analogies, in most of their forms, has the potential to enhance student understanding in a stimulating and economical way. The next section examines what the literature has to say about the ways in which analogies can be enhanced.

USE OF ANALOGIES IN INSTRUCTION

Analogy Use in the Classroom

The science and science education literature contain many analogies that are proffered as ways for presenting difficult topics in science. Some are elegant and appealing, others are common and well known, and others appear to be quite esoteric and are probably unfamiliar to normal students. As well, there are those analogies that are problematic (electric current is like water flowing in a pipe) in that they often generate alternative conceptions (Champagne et al., 1985) though they remain popular and are frequently used in science teaching. A representative sample of analogies is considered in this section.

Amongst the appealing simple comparison type analogies (Curtis & Reigeluth, 1984) is Biermann's (1988) example in which a cell making a protein molecule is likened to tradesmen building a house. Also in this category is the analogy in which the activation energy of a chemical reaction is compared to a hill (Hunter, Simpson & Stranks, 1976; Licata, 1988) or a high jump (Parry, Dietz, Tellefsen & Steiner, 1973). Other secondary science analogies are the disco-electron orbitals analogy (Battino, 1991); the polarised light-comb analogy (Murphy & Smoot, 1982); the supermarket-classification analogy (Australian Academy of Science, 1990) and the crowd-kinetic theory analogy (Coffman & Tanis, 1990).

There are very few analogies that are known to be truly effective. For example, the teaching of electric circuits is well reported as fraught with problems (Cosgrove, 1991; Dupin & Johsua, 1989; Glynn, 1989). A common analogy is to liken a direct current in a series circuit to the flow of water in pipes. Used in this sense, the analogy fails to model an electric circuit because domestic plumbing is not cyclic. This comparison generates misconceptions such as when a wire is cut, electricity will continue to leak out because that is what happens when a pipe is broken or a hose is cut. Often, students conclude that when a powerpoint without a plug in it is switched on, electricity will leak out into the air, or that resistance in a wire is a function of friction between the electricity and the insulation (Champagne, et al., 1985).

Glynn (1989) has modifed this water analogy by using the circulation of water in an aquarium and its pump plus filter as an analog of electric current. The analogy is compelling and is carefully developed to highlight invalid propositions and to derive maximum value from the shared attributes. Other investigators describe electric current as being like a continuous train on a circular track (Bullock, 1979; Johsua & Dupin, 1987).

Esoteric, unfamiliar analogies are those that are popular with their author but are hard to visualise and teach because the analog contains unfamiliar instances or ones that are conceptually too formal. Examples which appear to fit this category are "the ping-pong ball torture analogy for enzyme activity" (Helser, 1991) and "the shot gun-diffraction of light analogy" (Murphy & Smoot, 1982). Similarly, "a chess analogy - teaching the role of animals in ecosystems" (Kangas, 1990) requires expert knowledge of a board game that is unfamiliar to many students. While the analog-target matches are compelling, many students do not have the required background knowledge.

Who Actually Uses Analogies?

Many science teachers claim to regularly use analogies in their teaching and analogies are often encountered in student texts. Two studies focussed upon the use of analogies by writers and classroom teachers respectively (Thiele & Treagust, 1991; Treagust et al., (1992). In the classroom study, eight science teachers were observed for a total of 40 science lessons. No teacher was aware that the study was concerned with the use of analogies, thus, what was seen, was the teacher's normal classroom behaviour. Over this period, only six clear analogies were recorded during five separate lessons. Three of these analogies were simple comparisons and three were enriched, that is, the conditions were stated for which the analogy was valid.

Subsequent interviews with the teachers indicated that they were familiar with the problems of analogy use (unshared attributes) as well as the advantages. Interestingly, it was noticed that full advantage was not made of the analogies when they were used in class. "The study raises an important question as to whether or not the teachers in this study would improve their teaching of complex concepts if they used more analogies and used them more effectively" (Treagust, et al., 1992, p. 421). This last comment is the rationale for this study, namely, can teachers learn to make consistent, high quality use of analogies and so enhance student understanding of difficult science concepts?

In the textbook analysis (Thiele & Treagust, 1991), eight Australian chemistry textbooks were analysed for analogy use. Both the number and type of analogies varied considerably from book to book with the largest number being found in the topics dealing with atomic structure (e.g. electron distribution is like a rotating propeller) and energy (activation energy barrier is like a hill). Amongst the conclusions, it was noted that most of the authors did not state the limitations of the analogy they employed and that they overestimated the ability of students to map valid analog-target correspondences. While a substantial proportion of the analogies were of the simple comparison form, it was suggested that students would fare better with enriched analogies because these are qualified. This paper is of interest because many of the analogies to be used in this study are derived from textbooks.

A BETTER WAY TO USE ANALOGIES

Students Need Experience in Analogical Use

Recognition that teachers and students often fail to maximise the value of an analogy questions the value in training students in analogical reasoning. However, teaching students to use an analogy systematically has produced some encouraging results (Alexander, White, Haernsly, & Crimmins-Jeans, 1987). A controlled experiment with 36 average ability, fourth grade reading students, showed that those who received analogical training demonstrated enhanced capacity to complete verbal analogies of the form A:B::C:?

The quality of presentation of the analogy also affects comprehension of concepts in biology as demonstrated by the study of Bean, Searles, Singer and Cowan (1990), where students benefited conceptually from analogical instruction. In this instance, the assistance took the form of analogical study guides to augment lectures and text reading. When the analogy was enhanced by a visual representation of the analog, students' conceptual growth was increased. This visual advantage is described in two of the episodes reported for this study in Chapter 4.

In chemistry instruction, Friedel, Gabel and Samuel (1990) observed that students tended to use algorithms to solve problems rather than use the underlying chemical principles. The use of familiar, nonchemistry analogs as concept building tools were successful, especially where the students were trained in analogical mapping transfer. Too often, it is assumed that students can make valid and reliable links between the analog and the target, but evidence suggests that this is not automatic and that a systematic analysis of analogies will improve understanding and reduce misconceptions.

Physical models of reality are similar to verbal analogies in that students need help in recognising analogical similarities (Osborne & Gilbert, 1980). The concept forming power of models and analogies depends upon the student differentiating between the analogy and reality and in being able to integrate the ideas generated by the analogy into his or her mental framework. Based on research evidence to date, for both these functions, careful training and direction is likely to be needed.

Klauer (1989, p. 190) asserts that "special teaching for [analogical] transfer seems to be indispensable". His view is that the analogical transfer skill is a composite of general intelligence and expertise. Experts are more adept at analogical transfer simply because their skills have been honed by repeated practical experience. This does not come naturally, especially for novices. Sutula and Krajcik (1988) found differences in students' ability to solve mole problems when analogies were used; one group was left to map the analog-target correspondence for themselves, while a parallel group had the similarities provided by the teacher who added the expert skills lacked by the students. Thus, the identification and classification of analogical similarities and differences does need to be taught and this instruction should be repeated until each student is competent. This is a learning-to-learn issue that should be addressed by teachers who use analogies.

A further matter in this issue of who benefits most from analogy use is the question of student cognitive levels. While it has been shown that analogies enhance understanding by establishing links to previous knowledge, Sutula & Krajcik (1988) suggest that different strategies be employed with different students. For instance, with students possessing "high non-verbal cognitive ability, more positive results are found by allowing the students to infer their own connections of new knowledge to prior knowledge" (p. 11). Those students who show lower logical thinking skills derived greater relative advantage from analogies than do students with higher abilities. It is worth noting that these less able students needed teacher assistance to make the analogical connections. On the other hand, students operating at a high formal Piagetian level appear to sometimes be disadvantaged by analogy use because they often can construct a correct understanding of the target by direct means (Friedel, Gabel & Samuel, 1990; Gabel & Sherwood, 1980; Thiele & Treagust, 1991; Zeitoun, 1984). However, the delineation of analogical worth based on Piagetian levels is not clearcut (Gabel & Sherwood, 1980). Analogies can be valuable to both concrete and formal reasoners, but there are differences in cognitive value for each level.

TEACHING WITH ANALOGIES MODELS

It is evident that students need help if they are to correctly interpret analogies, and it is noted also that learning will be enhanced by teachers presenting analogies in a more systematic way. The presentation issue is thus one of clarity, efficiency and economy. The chief proponents of improved presentation are Brown and Clement (1989), Clement (1987), Dupin and Johsua (1989), Gentner (1988), Glynn (1989) and Zeitoun (1984). Glynn's Teaching-With-Analogies (TWA) Model will be considered last and in the greatest detail as it is the focus of this study.

Gentner's primary concern seemed to be with the need to establish some form of algorithm for use when analogies arise during instruction. Her interest was the need to identify some surface similarities to initiate comparison of a problem situation to one that is well understood. This would reveal the analog-target's "systematicity" which would be particularly useful for transferring patterns and ideas of arrangement and function from the familiar to the unfamiliar. However, the use of language such as "predicates" makes this work difficult to comprehend. Ideas that appear to be compelling are not easily conveyed and the mapping method is quite complex! Similarly, the "structure mapping rules" (p. 65) would probably be difficult for the average teacher to assimilate.

The "bridging analogy" (Brown & Clement, 1989, p. 242; Clement, 1987, p. 86) is more a set of analogical inter-relationships than a model for general pedagogical use. This concept of using an intermediate, more easily accepted analogy is a powerful way of bridging the gap between two distant domains that are analogical. While students may be incapable of connecting distant concepts, they may make the connection if this can be achieved through a number of smaller steps. This is what Clement means by a "bridging analogy". Instead of one large span, the bridge has many supports (mental resting points for the learners) along the way. The use of bridging analogies to represent instances of static equilibrant forces is illustrated in Figure 2.

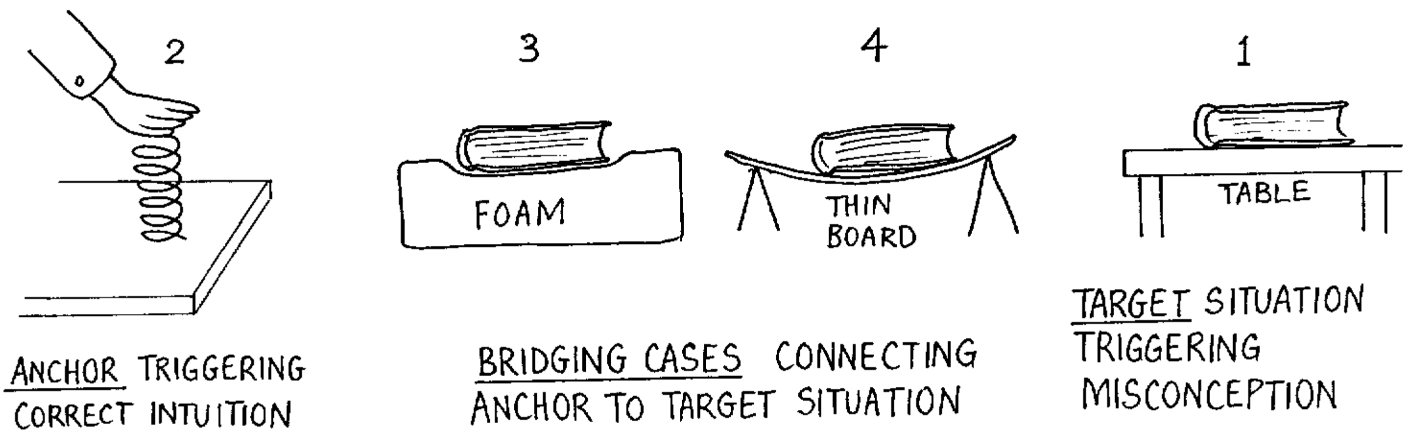

Figure 2: Bridging analogies to link anchor concept to target concept. (from Clement, 1987, p. 87)

In the illustration of a book placed on a table (Clement, 1987) "76% of a sample of 112 students indicated that a table does not push up on a book lying at rest on it. ... 96% of these students believe that a spring does push up on one's hand when the hand is pushing down on it." (p. 86). The hand on the spring is used as an "anchoring example that draws out an anchoring intuition" (p. 86). From this anchor, the student is then shown the book sitting on a board supported at each end. The book bends the board. This is the bridging analogy. It can then be reasoned that the table must exert an upward force equal to the book's downward force because the table does not bend. If the students are reluctant to accept the concept of forces in equilibrium for the book on the table, a second bridging step is included (book sitting on foam).

The analogical teaching model (Dupin & Johsua, 1989) contains five distinct steps. Initially, the analogy puts a new idea in a concrete, visualisable form, and the second stage performs a "descriptive function" (p. 210) by presenting the student with a plausible explanation comparing the new concept to old accepted ideas. Thirdly, the analog must be less complicated that the target in the problem being investigated and fourthly, the analog should simplify, not confuse. Finally, the time spent on the analog-target transfers must be economical. Dupin and Johsua centred their attention upon the continuous train analogy as a means for explaining the flow of electric current in a D.C. series circuit.

However, this model becomes more a set of criteria for analogy selection than as a presentation method. Nevertheless, such criteria have a place in teaching because each analogy should be assessed from these viewpoints before it is used in a class so as to ensure that it is relevant.

The "General Model of Analogical Teaching" or GMAT (Zeitoun, 1984) has also been proposed as a mechanism for logical presentation of analogies. This model contains nine stages briefly described as follows (p. 118):

(1) measure some of the students' characteristics related to analogical learning in general;
(2) assess the prior knowledge of the students about the topic;
(3) analyse the learning material of the topic;
(4) judge the appropriateness of the analogy to be used;
(5) determine the characteristics of the analogy to be used;
(6) select the strategy of teaching and the medium of presenting the analogy;
(7) present the analogy to the students;
(8) evaluate the outcomes of using the analogy in teaching;
(9) revise the stages of the model.

This model goes further than those preceding it in addressing some of the problems observed in analogy use. It does focus upon the students' prior knowledge (so too does Dupin and Johsua, but less so) and in this manner is strongly constructivist. It also asks the teacher to carefully consider the mode of presentation and has a review function at its conclusion.

What is notable about all these models is their lack of attention to the role of unshared attributes in generating misconception. The actual mapping process is also taken for granted in most cases, even though it is probable that students have difficulties in identifying the shared attributes.

Glynn (1989) developed his Teaching-with-Analogies (TWA) model as a six stage model which he described as follows:

> The Teaching-with-Analogies model is based on a survey of 43 science textbooks and an analysis of the analogies use in those textbooks. The most effective analogies from the standpoint of instructional design were identified. The authors of these analogies performed certain key operations that have been incorporated into a model which can serve as a guide for teachers and authors of science textbooks. The TWA model for using an

analogy to explain a science concept contains the following six operations:

1. Introduce Target
2. Cue Retrieval of Analog
3. Identify Relevant Features of Target and Analog
4. Map Similarities
5. Draw Conclusions about Target.
6. Indicate where Analogy Breaks Down. (Glynn, 1991, p. 230)

Glynn identified one writer, Hewitt (1987), author of *Conceptual Physics,* as an exemplary user of analogies in that each of the six operations were performed for the reader, but not necessarily in the above order.

Glynn (private communication, 1991, December 15) acknowledged that his analysis of analogy applicability was based upon Gagné's (1985) instructional procedures which are designed to activate and support internal learning processes. In brief, the instructional procedures consist of motivating students by drawing their attention to previously learned rules and concepts. Schemes for encoding these rules and concepts are suggested followed by examples, reinforcement and testing, all designed to assist the student in gaining a new capability.

The subjective application of Gagné's stages to textbook analogies resulted in "a recurring pattern of six 'functions' in analogies that science teachers ... considered to be effective. This pattern of functions common to the effective analogies was later represented as the six 'operations' of the TWA model" (Glynn, private communication, 1991, December 15).

The chief virtues of the TWA approach are its simplicity and logical sequence with the teaching process commencing with the concept under consideration. Where there is found to be a hiatus between the new concept and the students' past experiences, an analogy may well be appropriate. In introducing an analogy, Glynn emphasises the need for the analogy to be familiar and to not pose extra problems of understanding for the students. In a similar vein, "an analogy is considered 'bad' if it is difficult to identify and map the important features shared by the analog and the target" (Glynn, 1989, p. 18). Too often, analogical instruction ends with the valid analog-target mappings. Again Glynn comments, "analogies are double edged swords ... at some point every analogy breaks down" (p. 20). This is probably the greatest advance this model offers; it is unique in that it asks the inquirer to consider what doesn't hold true. Glynn illustrates the use of this model in a hypothetical discussion between a child and her teacher in which the water circulating in an aquarium-pump-filter system is used as an analogy for a D.C. electrical circuit.

EVALUATION OF ANALOGY USE

Need to Evaluate the Teaching-With-Analogies Model

Glynn's Teaching-With-Analogies model has been modified (items 5 and 6 reversed) at the Science and Mathematics Education Centre of Curtin University of Technology, Perth. This change is related to Glynn's model being derived from textbook analogies, whereas in the work at SMEC, the focus is upon teachers and the way they use analogies in class. Glynn's model recommends considering the unshared attributes after the analogy is summarised. While it is reasonable to expect a reader to continue reading and consider the analogy's limitations, in a classroom this may often not be the case. For this reason, the shared and unshared attributes are discussed side-by-side. The model has had explanatory notes appended (see Appendix 1 for details of the modified TWA model) and it is in this simplified form that the model is investigated in the following chapters of this thesis.

The *raison d'être* for this study is the evaluation of the modified TWA model. Evaluation is central to educational research and improvement. Evaluation is the act of ascribing value to an object, event or a statement. "People sometimes define the process of evaluating as discerning discrepancies between aim and actuality" (Stake, 1991, p. 70). As Stake points out, this is not always possible or desirable. "It may be useful in describing a program to point out congruence [between aims and outcomes] or lack of it, but that is for making the case understandable, not for indicating program merit" (p. 73).

To use Guba and Lincoln's (1989) words "evaluation produces data in which facts and values are inextricably linked. Valuing is an essential part of the evaluation process, providing the basis for attributed meaning" (p. 45). This assertion is stated from the constructivist platform. Opposite to this, the realist ontology presumes that objective data and meaning have absolute values. But meaning is constructed by the observer, hearer, reader and the interpreter. Thus, interpretive research, of which this study is an example, does not have absolute value, nor can it claim the label of truth.

In fact Guba and Lincoln commence *Fourth Generation Evaluation* with the following words:

> If this is to be a book about *evaluation*, it would seem reasonable to begin with a definition of what we shall mean by that term. But to propose a definition at this point, aside from being arbitrary and presumptive, would be counterproductive of the book's central themes. For we will argue that there is *no* "right" way to define *evaluation*, a way that, if it could be found, would forever put an end to argumentation about how evaluation is to proceed and what its purposes are. We take definitions of evaluation to be human mental constructions, whose correspondence to some "reality" *is not* and *cannot* be an issue (p. 21).

Merriam (1988) and Patton (1990) espouse a parallel view. They argue for the grounded, holistic case study that is true to life and which, by using thick description, allows the reader to enter into the events and to construct his or her own understanding of what occurred. Stake (1991) elegantly draws the threads of constructivism and interpretive research together. "But no aspects of knowledge are purely of the external world, devoid of human construction ... educational evaluators should not expect to make strong summary judgments of program quality" (pp. 82-83).

SUMMARY

The review of literature has shown that analogies are widely used concept building tools in learning. Using a constructivist pathway, analogies assist in articulating newly constructed theories; they suggest questions for the refinement and extension of theories and they provide opportunities for the application of theories to concrete physical problems by suggesting points of correspondence between theoretical elements and observable variables. Analogies also contribute to the achievement of inclusive systems of explanation by providing links between theories. Analogies help students understand the unknown in terms of familiar experiences and ideas and act as a motivating influence in studying unfamiliar concepts.

But not every aspect of analogy use is this positive. Abundant evidence has been tendered to show that in many learning environments, analogies have not realised their full potential. This happens in many cases because the analog-target mapping is at best haphazard. Likewise, the invalid analog-target mappings often are not considered or challenged, and this can leave students with some quite bizarre conclusions about the target. Fortunately, there are teaching approaches available that promise to enhance the advantages and help eliminate the disadvantages that have been identified.

None of the teaching approaches for analogy use appear to have been empirically evaluated to date. If the modified TWA model is as valid and reliable as is believed, then it should be evaluated and if successful, implemented as widely as possible. The evaluation should likewise harmonise with the currently accepted views of learning. For this reason, a constructivist methodology is appropriate for it should allow the reader to more fully understand the study, its subjects and the interpretations.

Chapter 3

RESEARCH METHODOLOGY

INTRODUCTION

The literature review shows that there is still much that is not well understood about the use of analogies in teaching. While there is the promise of enhanced student conceptual growth inherent in analogical instruction, doubts have been expressed by a number of researchers who have studied analogies as they appear in textbooks and as they are used in classrooms. This uneasiness was a source of the research questions which are stated as:

1. Can a competent teacher use the modified TWA model to systematically present analogies during science instruction?
2. When analogies are taught using the modified TWA model, are the resultant student conceptions compatible with scientists' science?

This chapter initially sets out to justify the choice of a qualitative, interpretive approach for the evaluation of the modified Teaching-with-Analogies (TWA) model and includes a full description of the modified TWA model itself. This is followed by a description of the study's sequence and methodology, the piloting of the study and how this investigation evolved from a broad based study into a case study of one exemplary teacher and two of her classes. The process for collecting, generating and analysing data is considered and the chapter closes with a discussion of validity, reliability, objectivity and triangulation as these concerns relate to this study.

THEORETICAL GROUNDS FOR THIS STUDY

Methodological Appropriateness

When embarking upon educational research, several methodological orientations are possible. Is the study to be quantitative, qualitative, or a mix of each? While the past decade has seen a reduction of the how much, how often, quantitative approach in favour of the qualitative, naturalistic typology, each method has its strengths and weaknesses. The challenge here, is to select the methodology that will provide the best information, and possibly, some answers to the research questions.

Commenting upon this dichotomy, Patton (1990) points out that it is not "necessary to be a qualitative methods purist." Qualitative data can be collected and used in conjunction with quantitative data" (p. 60). His thesis is that study sophistication rests upon matching the research methods to the research questions and the contextual frame of reference. Patton continues, saying that "Multiple methods and a variety of data types can contribute to methodological rigor" (p. 61). He describes the mixing of methods to satisfy a specific need, "a paradigm of choices." Flexibility also should be available in the methodology that is chosen.

Qualitative Research

Erickson (1986, p. 119) describes qualitative research as "ethnographic, qualitative, participant observational, case study, symbolic interactionist, phenomenological, constructivist or interpretive." Merriam (1988) employs a similar list of terms when she argues in favour of case studies. She comments (p. 16) that "discussions of case study are embedded in the growing body of literature on qualitative research and naturalistic inquiry." Guba and Lincoln (1981) chose the term 'naturalistic' to describe qualitative research and later (Guba & Lincoln, 1989) subsumed this into the constructivist paradigm. To summarise, naturalistic research, qualitative research and interpretive research are equivalent names for a single type of investigation (Spector & Glass, 1991).

"Interpretive participant observational research" (Erickson, 1986, p. 119-120) has its origins in anthropology and is that form of research that is particularly interested in asking the question "What is happening here?" (p. 121). Merriam's version (1988, p. 16) claims that "in a qualitative research [project] the paramount objective is to understand the *meaning* of an experience." Interpretive research should be as noninterventionist as possible, it is an approach in which the observer enters into the subject's activities, observes and *interprets* the data from a human perspective.

The major focus of the two research questions relating to teaching with analogies is in this direction. The questions investigate the congruence between what the teacher means and what the students understand when an analogy is used to illuminate a particular concept.

The qualitative research paradigm is essentially a social constructivist method because the emphasis is upon the meaning of words and actions as they apply to the actors themselves (Erickson, 1986; Gallagher, 1991). A spoken statement's meaning is judged by the hearer, it is that individual's intrinsic understanding of the statement that is true for that social context, at that time. In the words of Guba & Lincoln (1989),

> truth is defined as the best informed (amount and quality of information) and most sophisticated (power with which the information is understood and used) construction on which there is concensus (although there may be several constructions extant that simultaneously meet that criterion) (p. 84).

This statement is significant because it highlights the phenomenon that different people, hearing the same statement at the same time, will construct differing understandings from the same raw data.

The intrinsic beliefs and attitudes of individuals and groups cannot be easily determined by superficial or quantitative research. Erickson (1986) refers to Malinowski's ethnographic finding that "he was able to identify aspects of the [subject's] world view that they themselves were unable to articulate" (p. 123). The tool that revealed these innermost personal feelings was a sensitive interview technique. Positivists of Malinowski's day criticised such investigations calling them unscientific because they denied a rigid cause-and-effect relationship between the environment and human behaviour. Social behaviour was seen to be the effect of external factors controlling a person's behaviour in much the same way as Newton's laws determine the behaviour of moving particles. The constructivist epistemology reveals the weaknesses in such a perspective. Human beings are not mechanistic in the way they perceive reality. Individuals construct understanding by generating their own best fit of new information into their current world view.

The Study of Analogy Use Should be Qualitative

A qualitative research method seems to be indicated wherever analogies are used. Because an analogy draws upon the familiar and the commonplace, the analogy's meaning to the learner is of fundamental significance. This is because it is the meaning that the hearer constructs, that is valid for him or her in that instance. Neither the teacher nor the researcher can assume that his or her conception of the analogy's meaning is how the hearer receives and understands it. But it is the hearer's understanding of the analogy that generates the learner's concept of the target. When there are different conceptions of the analog present, there will be differences in the target concepts.

In many instances though, people find difficulty in enunciating their understanding and these non-articulated explanations have implications for this study. In a class of students drawn from diverse socio-economic environments, no meaning can be taken for granted because meaning is socially determined. It seems advisable that the teacher should review the students' understanding of the analog, before engaging in further instruction. Likewise, it is relevant to ask, what meaning is generated by analogical transfer to the target, and is it valid?

When an analogy is used as an expository tool, the student will probably experience difficulty in describing the mental image that the analogy evoked for him or her, and the extrapolation of his or her understanding that grew out of the analog-target mappings. Consequently, determination of the understanding that is constructed by a student when an analogy is used will probably be best revealed by a sensitively conducted interview.

Interviewing Teachers and Students

Two appropriate candidates for interview are the teacher and the students. It should be instructive to compare and contrast the teacher's conception of what happened during the lesson and how the students perceived the same set of words and actions. These perspectives of the teacher and students are in some ways diametrically opposed, or at the least, different. In a teacher controlled lesson, the teacher leads, the students follow; the teacher knows (scientists' science), but the students don't always have the teacher's knowledge. Moreover, the students may have different social, economic and ethnic backgrounds. It is within this mosaic that learning is attempted.

The nub of the question, as Erickson sees it, becomes (for the classroom) "what is happening here, specifically? What do these happenings mean to the people engaged in them?" (p. 124). This style of question defines what is needed to be known about analogy use in science classrooms. Such a question should guide the exploration of teacher and student perceptions of the analogy and how the analogy's impact will be evaluated.

At this juncture, a decision had to be made regarding the type of interviews to be used. Hook (1981) describes five different interview styles that are of value in educational settings. At the beginning of this study the post-lesson teacher interview was a "structured or standardised interview ... the interviewer follows a predetermined schedule where the questions, their sequence and their wording, are fixed" (p. 137). A sample teacher interview as it was used in this study is included as Appendix 2. For the post-lesson student interviews, the "focussed interview" (p. 138) was employed. Focussed interviews commence with a series of questions designed to produce a overview of the subject's ideas. Subsequent questions focus onto the salient items of interest and these become more and more specific as the interview proceeds. This approach is valuable because it can allow the researcher to ellucidate correct understandings, student extrapolations and misconceptions.

As experience was accumulated, both interview styles were modified by making them less formal so that items of interest could be pursued as they arose. For the latter portion of the study, the emphasis in the student interview was moved away from the analogy and onto the student's understanding of the concepts taught through the analogy. This was done because as the conceptual understanding that the student derived from the lesson was examined, the need to study each student's understanding at greater depth became evident. This approach promised to be useful as it demonstrated the status of the concepts held by the learner at that time. With reference to Hewson and Thorley's (1989) conceptual change model, the key interview questions that should demonstrate "the *status* of a person's conceptions" (p. 542) were questions relating to the conception's *intelligibility, plausibility* and *fruitfulness*. Another lead that was to be followed was to determine whether or not "the conception [was] a source of *dissatisfaction* to the learner."

When an attempt is made to study analogy use by teachers, and how it affects student comprehension and understanding, the above factors should be borne in mind. Such a study needs to be systematic and comprehensive. Similarly, it ought to consider issues of validity and reliability for all observations. The data that are drawn from the raw classroom observations and recordings (notes, audio and video records) should be derived objectively and be relevant in the study's frame of reference (Gay, 1980).

Generating Data From the Observations and Interviews

The observational and interview records did not of themselves constitute data per se (Erickson, 1986; Merriam, 1988). The process of transcription of audio tapes and the cleaning of field notes generated the data through a process of reflection, classification and evaluation of what happened, what was heard, what was said and how it was perceived. This was a process of distillation and was designed to yield some insights into what really does happen when a teacher uses an analogy.

On the matter of validity and reliability, because this study was naturalistic rather than controlled, each class event was multivariate. In order to generate reader confidence in the conclusions, an audit trail has been provided wherever possible. "Just as an auditor authenticates the accounts of a business, independent judges can authenticate the findings of a study by following the trail of the researcher" (Guba & Lincoln, 1981). It is hoped that the reader will be able to follow the events, data generation and reasoning, and so concur with the findings. Or, if issue is to be taken with the study's outcomes, at least the critic will understand how the reported assertions were derived. More is said about these issues later in this chapter.

THE TEACHING WITH ANALOGIES MODEL

The modified Teaching-With-Analogies (TWA) model that is central to this study was derived from the work of Shawn Glynn at the University of Georgia. Based upon some preliminary work with teachers involved in the teaching of analogies, the model employed at SMEC is a variant of Glynn's (1989, 1991) model in that steps five and six have been reversed. The following is a full description of the model as it was used during this study. While the model is organised into six steps, the sequence is not prescriptive. The value of the six steps is simply to provide a kind of check list that a teacher can use to ensure that each phase has been adequately covered when an analogy is presented to a class. There are likely to be situations where a particular analogy is better presented using a slightly different form and individual teachers will probably resequence the steps of the model to suit their style. From the vantage point of this study, it is important that all six steps are adequately covered since it is believed that the six steps are a minimum for sound analogical instruction. Finally, if successful, the model should be personalised by teachers so that they are comfortable with the model and can economically apply it to each analogy used.

The six steps of the modified TWA model are discussed in detail as follows:

1. Introduce the target concept to be learned
   This step can be anything from a brief introduction to a full explanation depending on how the analogy is to be utilised. If the analogy is to be used as an advance organiser, then the target concept would be introduced after the analogy. The analogy may also be used for reviewing the concept(s) in which case, the target concept is fully taught at this stage.
2. Cue the students' memory to the analogous situation
   This step involves the introduction of the analog and determines the student level of familiarity through questioning and/or discussion. If student understanding is low, the analog is modified or the process is aborted. The teacher should ensure that there is at least one obvious similarity for the students between the analog and the target.
3. Identify the features of the analog that are relevant
   This step involves explaining the analog to the students at a level that is appropriate to their understanding and which will accurately identify the features of the analog that will be used to build concepts in the next stage.
4. Map the similarities between the analog and the target concepts
   Item by item, the analog features are linked with the target concepts. There may be a one-to-one correspondence from analog to target, two or more analog features may converge on a single target concept or a single analog attribute may develop two or more target concepts.
5. Identify analog-target links where the analogy breaks down
   During the mapping exercise, the students may suggest inappropriate links. Other invalid transfers that the teacher may be aware of can now be combined with the students' alternative conceptions for discussion at this point. These conceptions should be discussed so that the student can distinguish the valid from the invalid. This step can be integrated into the discussion at any appropriate point.
6. Summarise, drawing conclusions about the target concept
   As in all teaching, a succinct summary of what has been learned about the target concept from the analogy should be stated to facilitate student learning.

The most significant feature of this model is probably stage five. Glynn's model is unique in highlighting this need to identify the invalid mapping links that students intuitively make. This activity may well dispel many of the student misconceptions that emerge during analogical transfer because analogies have no inbuilt guidelines that tell the hearer "no further please". This is a role the teacher can actively fulfil and so assist analogical instruction to achieve its full potential.

RESEARCH RIGOUR IN THIS STUDY

Rigour is equally as important in research conducted from a constructivist disposition as it is in studies of a positivist nature. Although constructivism accepts that it is the individual who constructs meaning from discourses or events, it nevertheless holds that the meaning must be compatible with the words and the actions. Where positivism concerns itself with validity, reliability and objectivity, within the constructivist paradigm these issues are replaced by credibility dependability and confirmability, respectively (Guba & Lincoln, 1989). In a similar manner to Guba and Lincoln, Patton (1990) describes validity in terms such as plausibility, authenticity and viability.

In the following pages, the traditional notions of validity, reliability and objectivity are contrasted with their more recent interpretive counterparts. The purpose of this discussion is to indicate to the reader that these issues of rigour have been kept in mind throughout this study and that many of the actions taken were implemented to make this study believable and to confer viability to the assertions and generalisations of Chapters 4 and 5.

Triangulation

Qualitative studies in particular have their credibility enhanced by the use of multiple measures. The 'triangulation' metaphor is drawn from navigation in which the certainty of an object's position is increased by stating its location relative to as many other known points as possible. Patton (1990, p. 464), lists four forms of triangulation. They are

1. Methods triangulation where different techniques for data collection such as quantitative and qualitative methods are used.
2. Triangulation of sources within a particular method. For example, observation vs interview; public vs private opinions; consistency of statements over time; different status, such as teacher vs student.
3. Analyst triangulation in which multiple observers and/or interpreters are employed. One example is the advocacy/adversary model in which the data are interpreted from opposing viewpoints.

4. Theory triangulation in which the study's foundation principles of action and interpretation differ.

It is assumed that looking at the same phenomenon from differing perspectives increases the certainty of one's interpretations. However, Mathison (1988) shows that this is often not the case, since differing perspectives may simply highlight the differences, not the similarities. People who are instantly recognised when their face is visible, may be unfamiliar when only their back is seen. Mathison continues ,

> In practice, triangulation as a strategy provides a rich and complex picture of some social phenomenon being studied, but rarely does it provide a clear path to a singular view of what is the case. I suggest that triangulation as a strategy provides evidence for the *researcher* to make sense of some social phenomenon, but that the triangulation *strategy* does not, in and of itself, do this (p. 15).

Mathison continues by pointing out that data from two or more angles can be convergent, inconsistent or contradictory. While there are major differences in each of these types of data, they may well be explicable within the study's context. In fact, examining the indeterminate and the divergent data may ultimately enhance the interpretations. A conundrum of this type is described in a curriculum study described by Grundy (1987). Triangulation involved project teachers, interested teachers and the observers. The first two groups saw the study events in quite different ways and effort had to be expended to reconcile these views. The end result appeared to be improved comprehension for both parties.

Credibility as Validity

Validity is concerned with the issue of actually measuring what we say we are measuring. Conventionally, validity comes in two forms - internal validity and external validity. These conventional validities are artefacts of positivism. "Internal validity is defined ... within the positivist paradigm as the extent to which variations in an outcome or dependent variable can be attributed to controlled variation in an independent variable" (Guba & Lincoln, 1989, p. 234). This position assumes that each and every situation can be stripped of all its variables but one, and that that variable can be experimentally manipulated to definitively demonstrate its contribution to change. Simply put, this is the determination of internal cause and effect.

Guba and Lincoln observe that "external validity can be defined positivistically as the 'approximate validity with which we infer that the presumed causal relationship can be generalised to and across alternate measures of the cause and effect, and across different types of persons, settings and times" (citing Cook & Campbell, 1979, p. 37). This means that internally valid findings can be *validly* extended to future circumstances.

Patton (1990) addresses the above issues in much the same way as Guba and Lincoln (1989). Patton's approach emphasises openness and integrity in both the conduct of the fieldwork and in reporting the results.

> The discipline and rigor of qualitative analysis depends upon presenting solid descriptive data, which is often called 'thick description' (Geertz, 1973; Denzin, 1989), in such a way that others reading the results can understand and draw their own interpretations (Patton, 1990, p. 375).

Merriam (1988) speaks in a similar vein when she advises leaving "an audit trail". In Patton's words, validity is replaced by "plausibility", "authenticity", "credibility" and "viability" (pp. 461-469). He asserts, that

> The ultimate test of the credibility of an evaluation report is the response of information users and readers to that report. This is a test of *face validity*. On the face of it, is the report believable? Are the data reasonable? Do the results connect to how people understand the world? (p. 469).

Guba and Lincoln arrived at a similar conclusion when they enunciated six steps for their criterion of "credibility" (1989, p. 237). They advise prolonged engagement to perform persistent observation coupled with peer debriefing (searching for alternative meanings), negative case analysis (analogous to statistical significance), progressive subjectivity (reflection upon developing constructions) and member checks in which the stakeholders (subjects) react to the findings. All of these phases combine to enhance credibility.

Dependability as Reliability

Within the positivist world, reliability is seen as a measure of repeatability or consistency. Reliability asks, would the same outcomes result if this experiment was replicated with the same or similar subjects in the same or in a similar context? From a constructivist stance, reliability in interpretive research is replaced by the notion of *dependability* (Guba & Lincoln, 1989). "Dependability ... is concerned with the stability of data over time" (p. 242). From the traditional viewpoint, alterations in methodology and hypotheses expose studies to the charge of being unreliable. But in studies that are characterised as interpretive, methodological changes and shifts in constructions are expected and will occur as such studies become increasingly sophisticated. "Far from being threats to dependability, such changes and shifts are hallmarks of a maturing - and successful - inquiry" (p. 242).

Having replaced traditional validity with credibility, Guba and Lincoln (1989) assert that "dependability parallels conventional ... reliability" (p. 242). Speaking in constructivist terms, they point out that "shifts in hypotheses, constructs and the like are thought to expose studies to unreliability. But methodological changes and shifts in constructions are expected products of an emergent design dedicated to increasingly sophisticated constructions" (p. 242). Their advice to challenges of unreliability is to make the process trackable by leaving an audit trail. Throughout this study there has been an overt desire to make the process and the interpretations trackable while at the same time trying to avoid over-reporting.

Confirmabilty as Objectivity

As Guba and Lincoln describe this criterion, it is the "positivist demand for neutrality and requires a demonstration that a given inquiry is free from bias, values and/or prejudice" (1989, p. 235). This is a clinical preoccupation, where it is assumed that all variables, bar one, have been controlled and that the outcomes reflect the effects of the experiment alone. The results are not a function of the intrinsic, human qualities of the investigator and/or the subject (or anyone else, for that matter).

The constructivist epistemology replaces objectivity with *confirmability* (Guba & Lincoln, 1989).

> Unlike the conventional paradigm, which roots its assurances of objectivity in *method* - that is, follow the process correctly and you will have findings that are divorced from the values, motives and biases, or political persuasions of the inquirer - the constructivist paradigm's assurances of integrity of the findings are rooted in the data themselves (p. 243).

Validity, Reliability and Objectivity in this Case Study

The previously stated criteria have their foundation assumptions grounded in positivism. "But the traditional criteria are unworkable for constructivist, responsive approaches on axiomatic grounds" (Guba & Lincoln, 1989, p. 235-6). They continue by saying that,

> internal validity, which is nothing more than an assessment of the degree of isomorphism between a study's findings and the real world, cannot have meaning as a criterion in a paradigm that rejects a realist ontology. If realities are instead assumed to exist only in mentally constructed form, what sense could it make to look for isomorphisms? (p. 235).

In this sense, conventional validities and reliabilities are inappropriate for this study. The two research question asked, can a competent teacher use the modified TWA model to systematically present analogies during science instruction and will such instruction produce student conceptions that are compatible with scientists' science? Student conceptual understanding is a construct of and by the student. It is a function of the student's mental environment and the classroom context in which the concept was formed, along with peer discussions which may or may not have followed. For this study the teacher's and the student's individual understandings were determined through interviews, therefore, the investigator, irrespective of his or her objective resolve, becomes an additional variable in this equation.

Moreover, the evaluation of the modified TWA model's effectiveness is likewise a mental construct. It is a synthesis derived from the mental constructs of the teacher, the students and the investigator. It would be a pretence to claim that such an outcome was devoid of personal values, biases and idiosyncrasies. Nevertheless, Guba and Lincoln (1989) emphasise the need for the assertions in interpretive research to be consistent with the context from which they were derived. They state that, "like objectivity, confirmability is concerned with assuring that data, interpretations, and outcomes of inquiries are rooted in contexts and persons apart from the evaluation and are not simply figments of the evaluator's imagination" (p. 243).

For this reason, the data reported in this thesis were thick description. The evidence for the use of the modified TWA model and for student conceptual understanding resides in those records of what was said and done, and what that means to the reader.

While it was impractical to comment upon credibility, dependability and confirmability in relation to every action taken during the study, the presence or absence of these qualities should become evident during the descriptions given in Chapter 4. It suffices to say that wherever possible, as many of these criteria as were appropriate at the time, were considered and applied to the work in the classroom, to data generation and to interpretation. With regard to triangulation, data were collected from as many vantage points as possible, bearing in mind the study's constraints. This too, is evident in Chapter 4. Simple quantitative data were collected in the form of the student worksheet.

It would not be honest to claim that these theoretical under-pinnings were always foremost in my mind. Amidst the rush, pressures, conflicts and disasters that are inevitable, there were times when specific ideals were forgotten. My only claim is to have endeavoured to have tried to make the most of each opportunity and to faithfully record each event. After all, the interpretations are no more than my personal construction of what I saw and heard.

STUDY SEQUENCE AND METHODOLOGY

The Study's Beginnings

In this study to investigate the implementation of a teaching model for analogical instruction, the first problem was the selection of subjects, both of teachers and students. The central concerns at this point were the dual issues of credibility and dependability. Credibility (or believability) asks whether the observations and data collection processes were sufficiently rigorous to confer believability upon the interpretations and allow the assertions to be transferable into generalisations. Dependability means what it says, can these subjects and places be relied upon to represent typical classrooms?

It is often difficult to satisfy the traditional criteria of validity and reliability in a qualitative study (Merriam, 1988). Erickson (1986) mentions validity and reliability, but has no more to say about how to achieve these qualities other than to emphasise the need to be as objective as possible in each observation or interview. Patton (1990) discusses this issue at length as it relates to qualitative research. Under the heading of purposeful sampling, he points out that "[t]he purpose of purposeful sampling is to select information-rich cases whose study will illuminate the questions under study" (p. 169). The constructivist concerns of credibility and dependability fit this study more easily than do validity and reliability because all that will be asserted is that what is reported did actually happen. This is a study of analogy use in specific situations at specific times without suggesting how the lesson would proceed with this teacher on another occasion, much less for different teachers and their classes.

The traditional constraints of validity and reliability would have meant that the subjects chosen (teachers and students) should be a random sample that was truly representative of the local educational environment. The particular research questions that are being investigated combined with the constructivist approach meant that subjects could be chosen simply upon the basis that they do use analogies in their teaching and they were willing to participate in the study. This is made clear at the outset and clearly identifies this approach as purposeful sampling.

The Study's Participants and the Analogies Studied

The in-class observations commenced in March 1992 and continued through until September 1992. Overall, 14 lessons (two of which were repeat lessons) were studied with six teachers. The instances of analogy use, in chronological order, were:

1. Year 8 Transition Science: the supermarket analogy (Australian Academy of Science, 1990) for biological classification was used by Teacher A with each of his Year 8 science classes; once with the modified TWA model, the other without the model.
2. Year 12 Human Biology: the escalator analogy was used to illustrate homeostasis. Teacher B taught this lesson without the modified TWA model.
3. Year 8 Transition Science: the circuit board analogy was used to teach the principle of inference in scientific investigations. Teacher A used the modified TWA model with both of his classes.
4. Year 10 Biological Change: the red and white paint analogy to represent incomplete dominance. Taught by Teacher C without the modified TWA model.
5. Year 11 Chemistry: moving students analogy for kinetic theory. This analogy was taught by Teacher D using the modified TWA model.
6. Year 10 Electronics: the continuous train analogy for a simple D.C. series circuit was used by Teacher E using the modified TWA model.
7. Year 10 Physics: light waves are like water waves. This analogy was employed by Teacher F using the modified TWA model.

8. Year 9 Energy in the Home: the continuous train analogy for a simple D.C. series circuit was used by Teacher C using the modified TWA model.
9. Year 8 Heat: conduction of heat is like the domino effect. This analogy was used by Teacher F using the modified TWA model.
10. Year 10 Biological Change: the encyclopedia analogy for homologous chromosomes was employed by Teacher B using the modified TWA model.
11. Year 10 Physics: the toy car analogy for the refraction of light was taught by Teacher F using the modified TWA model.
12. Year 10 Chemistry: three analogies for the mole concept were used by Teacher F using the modified TWA model.

In ten of the above instances, the teacher who was being studied provided the analogy from his or her repertoire. For the first and the second episodes respectively, the supermarket and the escalator analogies were provided by the researcher from the analogy bank at SMEC.

Data Collection

The observations in each instance included each of the following five activities. As many information sources as possible were employed in the interests of triangulation. The reason for using multiple perspectives was to wherever possible, identify biases and/or idiosyncrasies.

Handwritten observer notes. These were made throughout the lesson to augment the audio-tape record and to provide a basis for the post-lesson interview.

The portion of the lesson containing the analogy was audio-taped. Sufficient preceding and following dialogue was recorded to precisely describe the analogy and its context. All the teacher's and students' comments relating to the analogy were transcribed verbatim following the lesson. The lesson transcript was studied to identify the propositions presented to the students during the analogy's presentation. In this context, proposition means a statement of similarity or difference between the analog and the target which contributes to the students' conceptual understanding. Valid and invalid mappings that were stated or inferred during the lesson were treated as propositions for analysis purposes.

The teacher was interviewed. This was done using the Teacher Interview Protocol (Appendix 2) as soon after the lesson as practicable. One interview commenced in the following way:

> I. Thanks .... for giving me a few minutes of your time. That was an interesting idea you used in comparing light waves to water waves. I'm interested about why you chose to use an analogy at that point in your lesson. Can you tell me why you used an analogy there?
> ...
> I. Why did you choose <u>that</u> analogy to describe light waves?
> ...
> I. Was the analogy using water waves a spontaneous idea, or one you'd used before?
> ... and so on.

The interview plan was for a structured beginning that became focussed during the interview's latter stages. This strategy allowed the useful ideas to be probed as they emerged during the interview. The interview was transcribed verbatim. The teacher interview served two purposes, the first of which was to help the teacher reflect upon his or her use of the modified model in preparation for the next time that he or she would use the model. The second reason was to discuss and record the teacher's perception of the way the students received the analogy and the degree to which he or she felt they understood the lesson's concept(s).

A student worksheet. The worksheet was administered to each student in the class at the commencement of their next science lesson. A sample is included as Appendix 4. One version of the worksheet commenced as follows:

> During Friday's lesson an analogy was used to help describe light waves. The analogy was
>
> **"In some ways, light waves are like water waves."**
>
> I would like you to think about the ways that light waves might be like water waves. Please try to complete this simple matching exercise. The first column has the water wave feature and in the second column, the light wave characteristic that matches it. Try to complete the first two pairs and then see if there are any other pairs for the following pairs of spaces.
>
> Ideas that are correct matches
>
> | | **1. Water waves** | | **2. Light waves** |
> |---|---|---|---|
> | 1. | ____________________ | is like | light waves carry energy |

Ideas that are <u>not</u> correct matches

1. You can see water waves is like ____________________

The first two items in each category were simple completion activities with one half of the analog-target pair being provided. The students were asked to provide as many of the other analog-target pairs that they could recall. Finally they were asked in a single sentence to express their opinion of the interest and conceptual value of the analogy as it was used.

Student interview. The students were selected based upon the responses given on this worksheet. Students were selected if they had completed all or most of the matching exercise, irrespective of whether the responses were correct or not. This criterion was employed to lend credibility to the interviews. Those students who made perceptive remarks in the comment box at the bottom of the worksheet also recommended themselves as candidates for interview. This means of choosing may be criticised as distorting the data by choosing a sample that is not truly representative. The rationale for this choice was based upon the fact that the interview time was limited, thus, students were chosen who had the highest perceived likelihood of providing useful information. As noted, the criterion would not be who had recorded 'right' answers, but those who indicated that they would have something to tell. Each interview was tape recorded and transcribed verbatim.

Choice of Subjects - Teachers and Students

As already noted, this item is central to the issue of credibility and dependability. Several teachers had indicated a willingness to assist. Consequently, the criteria for working with a teacher and his or her class was based solely on two factors, firstly, did they use analogies on a regular basis in their teaching, and secondly, were they willing to cooperate.

In investigative research in schools, access to the school and to classes, combined with the researcher's credibility, does affect the study's credibility and dependability (Goetz & LeCompte, 1984). In each school where there were teachers who had offered to act as subjects, free access was provided by the principal. In most cases the researcher was known to the teacher and at one school the researcher was reasonably familiar to the students by virtue of his teaching part-time in that school. Only two of the students interviewed in that school had actually previously been taught by the researcher. From the perspective of access and familiarity, there were not any obvious constraints that threatened the study's credibility and dependability.

One of the two teachers who was studied on four occasions was less experienced than the other five teachers in the sense that he was teaching out-of-field and that he possessed a limited analogical repertoire. This teacher was retained in the project because the presence of a less experienced practitioner would have the advantage of keeping the study representative, and thus believable. To choose only teachers who were consummate performers in the classroom could bias the results because such teachers perform most tasks in an exemplary manner. There was a conscious desire to ascertain how teachers of all abilities fared with this model. It may well be that the modified model's greatest value will be to the novice teacher as it provides him or her with an extra skill.

The sample size for the study required that sufficient instances be studied to ensure that it was representative of that teacher's practice. If the investigation was credible, and representative of normal classroom practice, then believable generalisations may be drawn from the findings.

It was difficult to predict the number of instances to be studied, for, as Merriam (1988) and Patton (1990) indicate, with original, qualitative studies, such judgments are made as the study proceeds. It would have been ideal to study a broad range of teachers who use analogies on a regular basis. Unfortunately, in view of the time constraints, only four teachers were studied on more than one occasion and only two teachers were studied on four occasions. This situation arose because some of the teachers changed to topics where analogies were inappropriate or the researcher was unable to attend the classes at the times that were suitable.

Piloting the Study

At the outset, it was difficult to visualise the study's progress and direction. As already mentioned, Merriam (1988) emphasised the need to be directed by the activities of the subjects. She points out while discussing "what to observe" (p. 89), that

> Less structured observations can be compared to a television camera scanning the area. Where one begins looking depends on the research question, but where to focus or stop action cannot be determined ahead of time. The focus must be allowed to emerge and in fact may change the course of the study (p. 90).

Goetz and LeCompte (1984) offered similar advice. The interaction of the observer with the context and its events clarifies the questions or leads to their rephrasing. As there were no studies extant on the use of the modified TWA model, it was always expected that the study itself would determine its own final direction.

Rather than plan a specific pilot study, it was envisaged that the early observations would perform this role. Each episode of work with a teacher would contain observations of the classroom use of an analogy, interviews with the teacher and the students, plus a post-instruction worksheet to be filled in by each student. It was expected that transcription of the lesson and the interview audio-tapes combined with an analysis of the student instrument would provide a panoramic view of each episode. Critical reflection upon what was done and what was collected would provide positive and negative feedback. The plan was to use this information as the springboard for the next episode. It was anticipated that the study would evolve in such a way that there may not be a clear line of demarcation between the pilot phase and the final form of the study.

Three of the teachers were observed using analogies in a comparative manner. Study of these episodes in which the analogy was used without the modified TWA model produced results similar to those reported by Treagust et al. (1992). Observation of instances where the analogy was used naturally, followed by interviews, yielded consistent, but useful information. As Merriam (1988) recommends, this is the time to terminate that particular approach.

In-servicing the Teachers on the Modified TWA Model

Each teacher was introduced to the modified TWA model and given in-service training in its implementation. The in-servicing began with a discussion about the teacher's usual reasons for choosing an analogy and how he or she normally presented that analogy to their class. The modified TWA model was briefly described to the teacher with an emphasis given to Steps 2 and 5 in which the students' familiarity with the analog is probed and the unshared attributes are examined. The teacher was supplied with the two page description of the model so that he or she could study it privately. On the day of the planned observations, the teacher was asked if there were any problems with the model and if discussion followed, the model was briefly reviewed as needed.

Following each of the lessons in which the model was employed, a period of time was set aside for the teacher and the researcher to reflect upon the preceding episode and to plan the next implementation of the model. The purpose of this exercise was to promote the long term use of the model in terms of its repeatability and adaptability and it was hoped that this action would enhance the overall dependability of the study.

Observational Depth and the Thesis Report

As the teacher observations progressed, it became evident that it would take individual teachers longer to become proficient in the use of the model than was originally envisaged. Consequently, the goal was redefined to observing each teacher implement the model on four separate occasions, wherever possible. The data collection followed the same lines as described in the Data Collection section of this chapter

The observations derived from only one teacher were reported in this thesis because it was believed that the report would become unwieldy if both of the teachers who were studied on four occasions were discussed in detail. The analogical instruction lessons that are reported in Chapter 4 are: light is a special kind of wave motion because light is like water waves; the conduction of heat in a solid is like the domino effect; and the bending of light as it passes from air to perspex is like a toy car changing direction when it rolls from a smooth surface onto a rough surface. The teacher who used these three analogies taught a fourth lesson using a series of three short analogies to illustrate the mole concept. This fourth lesson is not discussed in detail in Chapter 4 because the teacher failed to use the modified TWA model during that lesson because she felt that the analogies were too short to warrant the model. Nevertheless, this lesson's omission of the model is discussed in the assertions and the generalisations in Chapters 4 and 5.

The reasons for choosing the teacher whose performance is discussed in Chapter 4 were that she was teaching in-field and her students were articulate during interviews whereas the second teacher was teaching out-of-field and his students were not as open during interview. The data from the other teachers observed during this study is being utilised in the *Teacher's Use of Analogies* Project at SMEC.

Change of Focus in the Student Interviews

During the early observations, the focus for the student interviews tended to be upon the analogy, the students' prior knowledge of the analog and their acceptance of the analogy. Later the decision was made to focus the student interview upon the conceptual outcomes of the analogical instruction. While it was always necessary to review the student understanding of the analog, it was hypothesised that the impact of the analogy could best be assessed by emphasising each student's post-analogical understanding.

This was done in the following way. Following the transcription of the classroom event, the student worksheet was prepared commencing with as precise a statement as possible of the analogy and its conclusion. The student was asked to complete two matching and completion exercises, one for shared attributes and the other for the unshared attributes. As described earlier, the student responses on these worksheets were used to select the candidates for interview. On each occasion, the student interview commenced with a statement like,

> I. Yesterday, Mrs ..... used an analogy when she said "Conduction of heat occurs because electrons and atoms vibrate and bump into the one next to them" What did you think of that idea?

The objective of this question was to help each student describe the lesson's basic concept as he or she understood it. Subsequent questions focussed upon the understanding of this concept, reasoning that, if the analogy generated understanding, then the analog should surface during discussion. Whenever the student made reference to the analog, this was probed to find what forms of mapping(s) were in the student's mind. Based on the observations of teachers earlier in the year, discussing the lesson's concepts was deemed to be more fruitful than talking about the analogy. This modification was concerned with revealing conceptual understanding, rather than just making statements of structural similarity between the analog and the target.

COLLECTING, GENERATING AND ANALYSING THE DATA

Data Collection

The investigative process contained seven activities that led to the generation of information about teacher action and student response during analogical instruction.

1. The modified TWA model was explained to the teacher and suitable lessons in which analogies would be used were identified
2. The lesson was observed in an objective manner.
3. The lesson was audio-taped and the relevant portion transcribed.
4. The post-lesson interview with the teacher was also audio-taped and transcribed.
5. At the commencement of the next science lesson, the students responded to a worksheet based on the analogy's propositions.
6. A representative sample of the students were interviewed and transcripts prepared.
7. The combination of *in situ* observations, verbatim transcripts of the lesson, teacher and student interviews and the analogical worksheets were analysed for evidence of the modified TWA model's use and of student conceptual understanding.

Data Generation

Following detailed observation of 14 science lessons, a mass of transcribed information was produced. Merriam (1988, p. 127) observes that "data analysis is the process of making sense out of one's data." The first task then, was to reduce the amount of information and give it some order. "In the process of analysis, data are consolidated, reduced, and, to some extent, interpreted" (p. 128). From Erickson's perspective (1986, p. 149) , he warns that "it should be clear from this discussion that the corpus of material collected in the field are not data themselves, but resources for data. ... All these are documentary materials from which data must be constructed through some formal means of analysis."

It is possible to glean from the the discussions found in the literature on interpretive research (Erickson, 1986; Goetz & LeCompte, 1984; Guba & Lincoln, 1981; Merriam, 1988; Patton, 1990; Taylor & Bogdan, 1984), some guidelines that are applicable to this study. The overall process for analysis of the records of instances of analogy use followed the pattern described below.

Lesson transcripts.

1. Each lesson transcript was carefully scrutinised to identify the analogy. The statements and incidents within this portion of the lesson were classified, wherever appropriate, into the six stages of the modified TWA model.
2. A rigorous search was made within the analogical portion of the lesson for clear statement(s) of the concept being taught.
3. All the mappings, both valid and invalid, were identified and where possible, the specific propositions that made up the concept were highlighted. This generated a list of valid propositions and a list of invalid propositions.
4. The summing up or concluding statement(s) of the concept, was identified.
5. Imprecise propositions and alternative conceptions mentioned during the lesson were highlighted.

Teacher interview transcripts.

6. The items noted at this point were the teacher's personal perception of the students' understanding of the concept. Steps missed, or steps that lacked depth were identified.

Student worksheets.

7. These were tallied to determine the nature and the frequency of the valid and invalid propositions.

Student interviews.

8. The students' versions of the concept(s) were analysed to identify valid and invalid propositions plus misconceptions.
9. Student explanations of the concept were highlighted, especially those portions that used the analogy to explain his or her understanding.
10. A search was made for student perceptions of positive and negative beliefs about the value of the analogy as a learning tool.

Synthesis of the Case Study Report

The raw data that emerges from the analysis of the transcripts and worksheets needed interpretation. Within each episode, patterns of agreement and disagreement between teacher and student interviews were sought, categorised, evaluated and synthesised into a coherent picture. Confirming data were compared and contrasted with disconfirming statements (real or apparent) in order to produce a balanced picture of student conceptual understanding. While this was a laborious and time consuming task, the rigour that was invested at this step determined the quality of the assertions and generalisations.

SUMMARY

The evaluation of analogical instruction that emerged was a qualitative study that was augmented by occasional quantitative data. The evaluation's subject base was finally narrowed down to the study of a single exemplary teacher with two of her classes. Four lessons were studied with this teacher and the detailed analysis of three of these episodes are reported in detail in Chapter 4.

The methodology was designed to provide information that would answer the two research questions. Investigative rigour was addressed through an endeavour to make the study *credible*, or plausible, transferable and dependable. Overall, the study was designed to possess face validity and to provide evidence of triangulation in data collection and generation. The next chapter examines the data in an endeavour to answer the two research questions.

Chapter 4

CASE STUDY REPORTS

The in-field studies spanned almost six months during which time fourteen lessons were observed. The information collection process was similar throughout with the pattern described in Chapter 3 being as follows:

1. Planning phase during which the modified TWA model for teaching analogies was explained to the teacher.
2. The entire lesson was observed and audio-taped. Notes were made explaining the environment and class organisation.
3. The teacher was interviewed as soon after the lesson as was practical. An example of the post-lesson teacher interviews may be found in Appendix 3.
4. At the beginning of the next science lesson the students were asked to complete a worksheet containing valid and invalid analog-target mappings.
5. Based on the worksheet responses, five or six students were interviewed.

All the interviews were audio-taped and all audio-tapes were transcribed verbatim. Whenever possible, the lesson tape was transcribed before tasks four and five were attempted so that the student worksheet and interviews could be focussed using an accurate account of the lesson and its conceptual content.

In total, the classroom presentation of 12 different analogies was examined with six science teachers. The classes ranged from Years 8 through 12 (13 to 17 years of age) and covered Physics, Chemistry, Biology and Transition Science (commencement of Year 8). Forty-eight students were interviewed and in excess of 150 pages of interview transcripts and notes were produced. In addition, over 250 student worksheets were administered and analysed.

In view of the mass of information collected, it became evident that it would be both difficult and inappropriate to comment upon every episode. Difficult, because there was marked diversity in subject and topic, teacher technique, and student level and ability. Inappropriate, because not every episode was complete, or because the teacher was teaching out-of-field. When teaching out-of-field, exemplary teachers often cease to be exemplary: "Willing and dedicated teachers can expect to experience considerable problems if they are required to teach in areas in which they have inadequate content knowledge" (Fraser & Tobin, 1989, pp. 6-7). This very problem was encountered with one of the study participants.

Thus, for this report, a decision was made to concentrate upon one teacher, teaching-in-field, and to discuss four of her classes as a case study. This exemplary teacher was called Mrs Kay for purposes of anonymity. Each lesson is described with reference to the original research questions:

1. Can a competent teacher use the modified TWA model to systematically present analogies during science instruction?
2. When analogies are taught using the modified TWA model, are the resultant student conceptions compatible with scientists' science?

In this chapter three lessons in which Mrs Kay used analogies to teach three difficult science concepts using the modified TWA model are discussed in detail. The fourth lesson which used three short analogies to teach the mole concept is discussed only briefly. Inasmuch as the use of a systematic model for teaching analogies was a departure from Mrs Kay's normal style, it must be remembered that this is an extra variable in the overall equation. What follows is a systematic description of the lesson's context, a verbatim record of the analogy within each of the three lesson's setting, the emergent data, and the subsequent interpretations.

The Subjects - Mrs Kay and the School

Mrs Kay is a skilful, experienced science teacher who is highly regarded in her school. Her areas of expertise are Chemistry and Physics. She is imaginative and was willing to cooperate with this study when asked. As I worked part-time in the same school and shared an office with Mrs Kay, it was possible to gain an insight into her methods and to discuss the study in a matter-of-fact manner.

The school itself is a large, independent, church college with a secondary enrolment of about 800 girls in Years 8 to 12. It is one of the elite fee paying schools in this city and as such is not representative of the overall educational scene. All science classes are taught in specialist science laboratories with ample equipment to mount whatever demonstrations are considered to be educationally necessary. The students though, are intellectually representative of a mainstream school and the classes studied were of mixed ability.

The four lessons that are reported in this chapter were observed during Terms 2 and 3 of 1992. The first episode dealing with light as a form of wave motion (Year 10) occurred during the last week of Term 2. The conduction of heat lesson (Year 8) in which the domino analogy was employed took place during week two of third term and this was followed in week three by the Year 10 lesson on the refraction of light. The lesson in which three brief analogies were used to teach the mole concept to Year 10 occurred in week five of third term.

EPISODE ONE
LIGHT IS A SPECIAL FORM OF WAVE MOTION

The first lesson to be observed with Mrs Kay was about light waves with a class of 27 Year 10 girls of mixed ability. The lesson is part of the Light topic and the objectives for this topic are listed in Appendix 6. The previous lessons had dealt with light as a form of energy, sources of light, and that light travels in straight lines (Objectives 2-6). The focus for this lesson was that light is a form of wave motion (Objective 1).

The lesson was observed and audio-taped, and descriptive notes were made throughout the lesson. Mrs Kay was interviewed following this lesson and this interview also audio-taped. At the beginning of the next lesson, the girls were given a worksheet on which they were asked to map as many of the valid and invalid attributes that they could remember. These responses were used to select suitable candidates for the student interviews. The lesson and all the interviews were transcribed, verbatim.

Verbatim Record of the Analogy as Used During the Lesson

The girls had just finished watching a videotaped demonstration of water waves. At one end of a large tank, a toy boat was pushed up and down, generating waves. These waves caused an identical toy boat, at the other end of the tank, to bob up and down in unison with the first boat.

In the following quotation, Mrs Kay's comments are prefaced by T and the student responses are identified by S. It was not possible to identify the individual students from the audio-tape. Throughout this chapter, quotations that are derived from the lesson transcript will be coded by a number in square brackets, e.g., [37].

The discussion commenced by talking about ocean waves.

T. That's right, the energy in the boat is transferred to the water. What is the water going to do with the energy? When the water vibrates, what is it actually doing?
S. Transfers the energy.
T. Yes, it's transferring the energy ... is everyone happy about that? The energy from the wind gets transferred to the water, water moves up and down, so which way does the energy travel? If the particles of water are actually individual particles, and they're going up and down, which way is the energy going?
That's right, the energy is going like this ...

This was followed by a revision of wave properties such as energy and amplitude, frequency and wavelength. The relevant units were also discussed.

T. Yesterday we were talking about water waves, but we're not going to learn about water waves in this topic, we're going to talk about light. Now yesterday we saw a film about water waves . Now what do you think, that light is waves as well? What do you know about light? What does light have in common with the water waves we saw yesterday?
S. (inaudible)
T. Yes, they both carry energy. Light and water waves both carry energy. That's one thing they both have in common, is there anything else?
S. Is it the way they bounce off whatever they hit?
T. Yes, that's right. We did see that, that's a good one Liz. Both of them bounce off whatever they hit. We know that light can be reflected and we saw that water waves can be reflected too.
They both transfer energy, they can both bounce off ... what else do they have in common, can you think of anything else? You've already told me this really, what would you say ...
S. (inaudible)
T. That's right, the medium is not permanently moved, so we can appreciate that light, like water waves, have these things in common. They both carry energy, the medium is not permanently displaced, and they can both be reflected. Now what else, what other characteristics would water waves have, they transferred energy from A to B, the waves consisted of what, what is a wave?
S. (inaudible)
T. Repeated vibrations. Well we've found out this for water waves, but we don't really know whether light waves consist of repeated vibrations or not. Do you think it likely that they do?
S. Well, they ... might ...
T. Well, light has got other characteristics in common with water waves, they carry energy from A to B, light is reflected like water waves, we don't know whether light is repeated vibrations but perhaps it's reasonable to predict that it might be. That's one of the things

we'll look into today. What is different about light and water waves? Obviously they are not entirely the same, they've got some things in common; is there anything that's different about them?

S. You can see water waves but you can't see light waves.

T. You can see water waves, you can see the water going up and down, but you can't see light waves. That's a good one.

S. You can turn the light off but you can't turn the ocean waves off.

T. I suppose if you had a big enough barrier, you could turn the ocean waves off. I suppose that's why they build the sea walls, isn't it? It is very hard to stop ocean waves though.

S. The medium ...

T. That's the point I was getting at, the medium. What is the medium for water waves? Obviously it has to be water particles. What about light, does light have a medium or not?

S. Mmm ... Air?

T. It can travel through air, yes, can light travel through anything else?

S. Water ...

T. Yes it does, it can travel through water. What else?

S. Glass.

S. It can't go through solid stuff.

T. It can go through solids. Glass is a solid. What can't light go through?

S. Wood and metals.

T. It can't go through metals ... it can't go through a solid that we call ... what is the word?

S. Ions ...

T. No. You're good chemistry students. It can go through ionic solids in fact. The word's opaque. O.K. Now does light have to have a medium or not?

S. No.

T. Why do you say no?

S. (inaudible)

T. It can go through a vacuum. Where does light go through a vacuum for us on Earth?

S. When you have a bell in a jar and there is no air ...

T. Yes, you did a test last year with a bell in a bell jar. When we had sucked all the air out of the jar we couldn't hear the bell but we could still see it, so light would travel where sound wouldn't. That's good proof of it. Sound needs a medium doesn't it. Now where does most of our light come from?

S. The Sun.

T. The Sun, that's right. What is there mostly between us and the Sun?

S. Space.

T. What is space?

S. Air in a vacuum.

T. Not air in a vacuum. For about 100 km around the Earth, there is air. As you go up it gets thinner and thinner and beyond that there are millions and millions of km which is just space, so most light from the Sun ...

S. What's in space?

T. Nothing. Nothing at all, there is the odd meteor, but mostly it is just space and only in the last 100 km we get the atmosphere. There are stars and obviously they're not space, but when you think how big the universe is, they are few and far between. Mostly it's space. Right then, we said that light has got some properties of water waves [100] but it is not exactly the same. What was different about it? Which do you think would travel more quickly, light or water waves?

S. Light.

T. Light gets to us very, very quickly. O.K. so light is a special sort of wave motion. [105]

Analysis and Data Generation

First of all, the lesson notes and the transcript were reviewed to search for evidence of implementation of the six steps in the modified TWA model, namely, introduction of the concept, cuing the students' memories to the analogous situation, identification of an obvious similarity between the analog and the target, mapping the shared attributes followed by identification of the unshared attributes concluding with a summary of the analogy. The resulting breakdown of the lesson is as follows:

1. *Introducing the Target Concept to be Learned (Lines 1-17)*

During the previous lesson, the class had watched a videotaped demonstration of water waves. As this portion of the tape directly preceded the section on the electromagnetic spectrum, the water waves example was re-shown, and this is the basis of the discussion in lines 1-10. Mrs Kay then reviewed wave forms, frequency, amplitude and wavelength. With these definitions clearly in the students' minds, she introduced the analogy.

2. *Cueing Students' Memory to the Analogous Situation (Lines 17-20)*

Mrs Kay introduced the analogy by referring to a videotape the class viewed during the previous lesson.

> Yesterday we saw a film about water waves ... do you think that light is waves as well? ... What does light have in common with the water waves ...?

This link between water waves and light was suggested with the purpose of intimating that there are ways in which light <u>is like</u> water waves.

The literature has emphasised the need for the analog to be familiar. During each post-lesson student interview, each pair of students referred to this property and was emphatic in asserting that it was their comfort with the analog that facilitated their understanding during the lesson. For example, they said that

> S. ... you go down to the beach, you know what they look like ... like you can see [waves] going up and down ... The waves crashing on the beach, you know that that energy is movement. ... you know what the comparison is like, you understand the comparison, you can relate to what she is trying to compare." [Ninka & Liz]

> I. Did you have any trouble knowing what was being talked about?
> S. No, because water waves are down at the beach ...
> I. So the familiarity aspect is important?
> S. Yes, you know it's waves that's being talked about. [Sue & Chris]

3. *Identifying the Features of the Analog that are Relevant (Lines 20-29)*

The analogy was not stated explicitly. The comparison emerged as the common features of water waves and light were identified. For example, during the lesson Mrs Kay stated:

> Yes they both carry energy. Light and water waves both carry energy. [21]
> Both of them bounce off whatever they hit. We know that light can be reflected and we saw that water waves can be reflected too. [24-26].

It appeared from Mrs Kay's confident assertion, and from the students' responses during the class and on the analogical worksheet (Table 1), that these ideas were almost unanimously believed. The student interviews that were analysed in the next section concur with this assertion.

4. *Mapping the Similarities Between the Analog and the Target Concepts (Lines 31-45).*

Mrs Kay's explanation of the analogy that "light is a special sort of wave motion" contained four propositional statements which constituted the shared attributes for this analogy and were, light and water waves both transfer energy, water waves and light can both be reflected, waves do not permanently move the medium and water waves and light consist of repeated vibrations. Each of these propositions was examined in its order of appearance.

On the worksheet, the first two propositions of both the shared and unshared attribute lists had one comment of the pair supplied. The following example is taken from the light waves worksheet:

Ideas that are correct matches

	1. Water waves	2. Light waves
1.	__________	light waves carry energy
2.	water waves can be reflected	__________
3.	__________	__________
4.	__________	__________

This was followed by a similar set of four spaces entitled "Ideas that are not correct matches". The complete worksheet is included in Appendix 4.

The students completed the semicomplete propositions about five times as often as those where they had to generate both sides of the statement. The frequency of the matchings is clearly an artefact of the worksheet's structure.

The student worksheets yielded each of the four propositions mentioned earlier plus variations and extrapolations. The shared attributes are presented along with the unshared attributes, and are listed in Table 1.

Because this lesson was taught during the second last period before the end of Term 1, there was only one period available in which to complete the worksheet and interview the girls. In order to increase the number of students interviewed, the girls were interviewed in pairs. Subsequently, six girls, in three pairs, were spoken to and the recorded interviews yielded over 10 pages of transcript. An example of the post-lesson student interviews is included as Appendix 5.

Table 1: Incidence of shared and unshared attributes in Year 10 class that studied "light is a special sort of wave motion" (n = 27)

SHARED ATTRIBUTES	
Water & light waves transfer energy	25
Water & light waves can be reflected	24
Water & light waves have repeated vibrations	5
Water & light waves have variable frequencies	4
Water & light waves have variable strengths	3
Water & light waves have amplitude	2
Water & light waves are continuous	2
Water & light waves can be refracted	1
Water & light waves can be stopped	1
UNSHARED ATTRIBUTES	
Water waves visible; light waves invisible	27
Light waves don't need a medium	26
Water waves slow; light waves fast	11
Each sort have quite different frequencies	3
Light waves can travel through a vacuum	2
Can feel water waves, can't feel light waves	2
Light can pass through transparent solids	1
Water waves break, light waves don't	1

Throughout the following commentaries, the student quotations (from the interviews) have no prefix but the teacher quotations (from the lesson transcript) are prefaced by T. and interviewer questions by I. Comments from other sources have their origins stated and each student is identified by name. The items (i), (ii), etc. refer to the valid or invalid propositions contained in each analog-target link, and were derived from the lesson transcript.

(i) Light and water waves both transfer energy. This propositional statement arose from Mrs Kay's statement that "Light and water waves both carry energy" [21]. This proposition was provided by 25 of the 27 students and was encountered in each student interview. Two student statements of this proposition were:

> ... water waves carry energy, ... light was energy, and if water waves carry energy, then light waves carry energy, and I could understand that. [Jodie & Sarah]

> .. like they do the same sort of thing, like they carry energy, and like they've got the same things in common. [Sue & Chris]

(ii) Water waves and light can both be reflected. The propositional statement concerning reflection was introduced when Mrs Kay noted that "both of them bounce off whatever they hit" [24-25].
The ability of both light and water waves to be reflected was readily accepted. On the worksheets, 24 out of 27 recognised this similarity as did students in the interviews, for example,

> ... they are a kind of waves that have characteristics that distinguish them, because water [waves] can bounce off one thing and light can bounce off something ...light waves can be reflected. [Jodie & Sarah]

Ninka and Liz discussed this comparison at some length, but had difficulty articulating a clear understanding of the likeness. Ninka expressed discomfort with this concept when she said, "I don't understand the reflected bit, that water waves can be reflected." There was no comment from Sue and Chris on this proposition.

(iii) Waves do not permanently move the medium. Mrs Kay reminded the students of this characteristic of water waves and light when she pointed out that "the medium is not permanently moved" [31]. This matching was not offered by any student on the worksheets but was mentioned by Jodie and Sarah in the interview:

> If an object was on it, it didn't move with the wave, it went up and down, but the wave will just go underneath it and it kept going, but the object will stay in the same place.

(iv) Water waves and light consist of repeated vibrations. During the lesson discourse, Mrs Kay stated that the "repeated vibrations" [38] of water waves are quite obvious and told the students that light is similarly a form of vibrational motion. Only one pair of students (Jodie & Sarah) mentioned this proposition during the interviews when they said, "they vibrate, they're vibrating." There was a paucity of comment upon this item.

During the interviews, several students extrapolated from what they saw and were told during the lesson and volunteered the following additional shared attributes.

(v) Water waves and light both have a frequency. Liz recognised a similarity between the observable frequency of water waves and the fact that a radio tuner also uses a frequency scale. She explained this during the interview by saying:

> Well you know that waves have a frequency, if you have radio waves, they have a frequency because it's marked on your little radio, so if the water waves have a frequency, and you can sort of see, and ... light waves have a frequency, I can understand that.

(vi) Water waves and light are continuous. Ninka explained that the light waves from the Sun are continuous in time as are ocean waves when she said during the interview:

> ... the Sun never dies and neither do the waves on the water never actually die, they never stop, you get what I mean, both of them never stop gives the similarity.

A similar comment came from Jodie and Sarah during their interview when they said that ".. light just goes straight ahead and water will go straight ahead too unless it was changed by something ..."

5. *Identifying Analog-Target Links Where the Analogy Breaks Down*

Mrs Kay highlighted four ways in which water waves are different to light and these unshared attributes were: you can see water waves but you can't see light waves, a light can be turned off but ocean waves are continuous, water waves need a medium but light does not and light waves travel much faster than water waves. The lesson transcript reveals that each of these unshared attributes was provided by the students in response to carefully framed questions. In their interview, Jodie and Sarah showed the value to their understanding of discussing the ways in which the analogy breaks down. They observed that:

> ... otherwise you would have thought they were pretty much the same thing ... and that water waves were virtually the same thing as light waves, but really, they do different things as well.

(i) "You can see water waves but you can't see light waves" [49]. During the interview, Ninka and Liz offered the following remark:

> Not all things, like you can't see light waves but you can see water waves. ... you can see [water waves] ... actually see something going up and down ...

Similarly, Jodie and Sarah said:

> .. you can see water waves, but you can't really see light waves, you can't see light moving around.

On the worksheet, every student provided a similar response.

(ii) "You can turn the light off but you can't turn the ocean waves off" [52]. No student mentioned this proposition.

(iii) "... the medium ... the medium for water waves, obviously it has to be water *... [light] can go through a vacuum"* [57-77]. Interview comments from the three pairs of students supported this statement.

> Water waves need a medium and light waves don't need a medium. [Jodie & Sarah]

> ... they don't have the medium ... whereas in water waves, the medium is water... [Ninka & Liz]

> ...water needs a medium and light tends to go by itself. [Sue & Chris]

On the worksheets, 26 out of the 27 students provided this unshared attribute.

(iv) Speed: "Which do you think would travel more quickly, light or water waves?" [101-103]. Two of the pairs of students commented on this difference:

> Light waves, they're quick ... fast. [Jodie & Sarah]

> ... you know light travels really fast, and water waves can't travel as fast as light ..." Restated later. [Ninka & Liz]

During the student interviews several students identified additional unshared attributes in a similar manner to the previous section dealing with shared attributes.

(v) Water waves can be felt but light waves cannot be felt. Jodie and Sarah had noticed that while you can feel water waves, you cannot feel light waves.

> You can feel water waves but you can't feel light waves ... you can put your hand up, but you can't feel the vibrations on your hand, but you can feel water vibrations ...

(vi) Size: Light wave vibrations are much smaller than water waves. Ninka and Liz showed that they understood that light waves are much

smaller than water waves when they said "Cause they're like, microscopic, ..."

(vii) Frequency: Water and light waves have different frequencies. This difference in frequency was mentioned by Sue and Chris during the interview in the comment: "they have different frequencies ..."

At this juncture, a misconception that emerged during the student interviews is worth mentioning. One student, Ninka, was confused about how far water waves and light waves could travel. She concluded that

> [light waves] could go on forever ... that's what I think ... water waves, they eventually end up stopped, I can't understand that light waves can just keep going and going.

6. Summarising Drawing Conclusions About the Target Concept

This was performed elegantly when in her closing comment, Mrs Kay concluded with, "O.K. so light is a special sort of wave motion." [104-105]

Interpretation: Evidence of Conceptual Understanding

In the context of this analogy, it must be asked, how has the use of the modified TWA model enhanced these student's understanding of the wavelike nature of light?

As was explained in Chapter 3, qualitative research of which these classroom case studies are an example, evolve as they proceed. Patton (1990) and Merriam (1988) recommend going into the field, collecting information and letting the resultant data direct the next episode. "A qualitative design unfolds as fieldwork unfolds. The design is partially emergent as the study occurs" (Patton, 1990). Guba and Lincoln (1985, p. 225) observe that "the design of a naturalistic inquiry ... *cannot* be given in advance, it must emerge, develop, unfold ...".

Application of the Modified TWA Model to this Analogy

Mrs Kay implemented the modified TWA model in a competent manner at this, her first attempt. Each of the six steps of the model was clearly evident in the lesson transcript and they were used in a linear sequence. The lesson transcript, in-class observations of student interest and the student responses during the student interviews all suggest that the analogy possessed both motivational and instructional value. The fact that each student interviewed accurately recalled the analogy in describing her understanding of the concept that light is a special kind of wave motion, supports the assertion that the modified TWA model did act as a suitable vehicle for the presentation of this analogy.

Evidence of Student Conceptual Understanding

So far, the evidence does appear to support a claim that the students' held acceptable scientific conceptions following analogical instruction because individual student statements show that the students found the similarities presented to them by the analogy intelligible and plausible. The analogy was obviously fruitful, because the students generated extra valid similarities over and above those suggested by Mrs Kay. In addition, students highlighted unshared attributes that were not discussed during the lesson. Dissatisfaction with the students' prior conceptions was not discussed. No student comments were encountered that indicated that there was dissatisfaction with the analogy that light is a kind of wave motion because it has many features in common with water waves.

These assertions can be augmented by Mrs Kay's reflections upon the lesson obtained from the post lesson interview.

> I was really quite happy with it, I was pleasantly surprised ... they came up with all the things I wanted to hear from them. ... They even gave the reflection which I didn't think they would give ... they did really seem to get quite a lot out of it and they got exactly the points I wanted them to get, so the water waves obviously is quite a good analogy.

We talked about the way the unshared attribute - "water waves need a medium and light does not" was explained using one student's recollection of the bell in an evacuated bell jar. Mrs Kay was confident that this proposition within the analogy helped the class understand the similarities and the differences.

> She remembered it and she is not a terribly bright student, so the fact that she remembered it probably meant that the others did as well ... Yes, I think they all remembered it, yes.

Mrs Kay then went on at length, saying, that she was very pleased with the way the analogy had brought this prior conception into the discussion. She believed that examining this unshared attribute had reinforced the students' ideas about light being a special form of wave motion. She found the model advantageous to student cognition, particularly as a result of the examination of the the unshared attributes.

> Yes ... I wouldn't have done [the unshared attributes], no, that was quite a good lead up to the next thing anyway.

In relation to possible misconceptions, she felt that step 5, in which the unshared attributes were discussed, was valuable because it made her and the students, examine the validity of each proposition.

> Yes, I was quite happy with that, and I spent a lot longer with that, and a lot longer discussing it [than] if I hadn't talked to you first ... that's good really. I think that they were quite interested in the discussion ...

The final comments demonstrate a high level of teacher satisfaction with the lesson and with the students' understanding of the concept.

> I think [the model] was really good. It was good because it made me think about it more. And I probably explained it more thoroughly than I would have done otherwise. And I got the impression that [the students] all seemed to know what was going on.

Based on the students' recollections of the concept and its attributes, there is evidence that they understood the overall concept quite well. When considering the valid and invalid attributes, they extrapolated to generate extra valid attributes indicates a sound understanding of the concept that "light is a special sort of wave motion". The following is a summing up statement by Jodie and Sarah which illustrates the students' understanding of this analogy.

> No, no, but now we know that water waves and light waves are pretty similar, but they do have their differences. If we were told that water waves did one thing, then maybe you'd think that light waves did the same thing, but we weren't sure ... if you didn't know water waves and light waves were similar, then you wouldn't say that light waves may do the same thing. ...
> No, no. Definitely that way ... it's better like that. It's kind of a little vague, but, it wouldn't be true if you said light waves are the same as water waves.

Another pair of students expressed their satisfaction with the analogy this way as evidenced by Liz's comment:

> Yea, yea, much better. Like if we couldn't relate them to water waves, it would be just so hard to understand, and Mrs Kay would have to be standing there for ages trying to explain, you know what I mean, it would take ages for some of us who are not smart to get it into our heads.

The final group of students, Sue and Chris, were also impressed with the analogy as shown by the following statement:

No, I found it interesting, definitely ... because she compared ... by saying one thing you can see and one we can't see is like the one we can see, yea ... and the differences as well.
Yea, it was helpful, it helped me think about and sort things out.
You see the waves going up there and you think light must go in sort of waves like that and you can see it ...

EPISODE TWO
CONDUCTION OF HEAT AND THE DOMINO EFFECT

The account that follows is a portion of a lesson with a mixed ability Year 8 class that was studying the topic Heat. The students had already been introduced to kinetic theory during their previous topic on Atomic Structure. The class observed was the third lesson on heat and was dealing with methods of heat transmission, in particular, conduction.

Verbatim Record of the Analogy as Used During the Lesson

T. If you remember girls, yesterday we were talking about heat ... and we said that heat is a form of ...

S. Energy.

T. Energy, that's right ... we also said that heat always travels in a particular direction ... what direction does heat always travel in?

S. Um, hot to cold.

T. From hot to cold. It's very hard to see heat ... that's right, heat always moves.
Now today I want to go a little bit further, and look at ways in which heat can travel. We decided that heat definitely does travel ... if you put your hand on the bench, it immediately starts to feel cold. Why is that?

S. There's heat leaving your body.

T. That's right, the heat is leaving your body. The heat is leaving your hand. Let's try an experiment. Touch the bench with your hands and then touch the taps, or a metal object. Which feels the colder?

S. The metal tap.

T. The metal one feels colder than the bench. Can anyone suggest why that might be?

S. (inaudible)

T. Use a thermometer, there's thermometers on the tray at the back so while we're talking about it, just get a thermometer from the box, get two thermometers and put one on the bench and the other one on the tap and we'll see if they actually are the same temperature or not, or just feel different.

S. (inaudible)

T. We'll just do that for a minute. There seems to be much ... ... what temperature does yours say?

S. This one says ... 19 degrees.

T. What does the other one say? I hope the two thermometers are the same.

S. 17 degrees.

T. Probably you've got two thermometers that are not exactly the same. They should really be the same. We said yesterday that everything in this room should be at room temperature apart from ... possibly the lights and anything that makes its own heat. They should be the same temperature yet the metal definitely feels colder. Why? That's what I want to talk about.

S. (inaudible)

T. It feels colder ...

S. Maybe it's that the bench has more area than the tap ...

T. I don't think it is area ...

S. (inaudible)

T. It's to do with the make-up of the substance, yes. Which one is your hand losing more heat to ... yes it's losing more heat to the tap. Some substances transfer heat better than others.
The metal tap, would you all agree with that, that the metal tap is transfering heat better because your fingers feel colder? Yesterday we said all matter is made of ... particles and we said that in a solid the particles are close together and in a liquid the particles are a bit more spread out and in a gas the particles are ... very spread out, that's right.

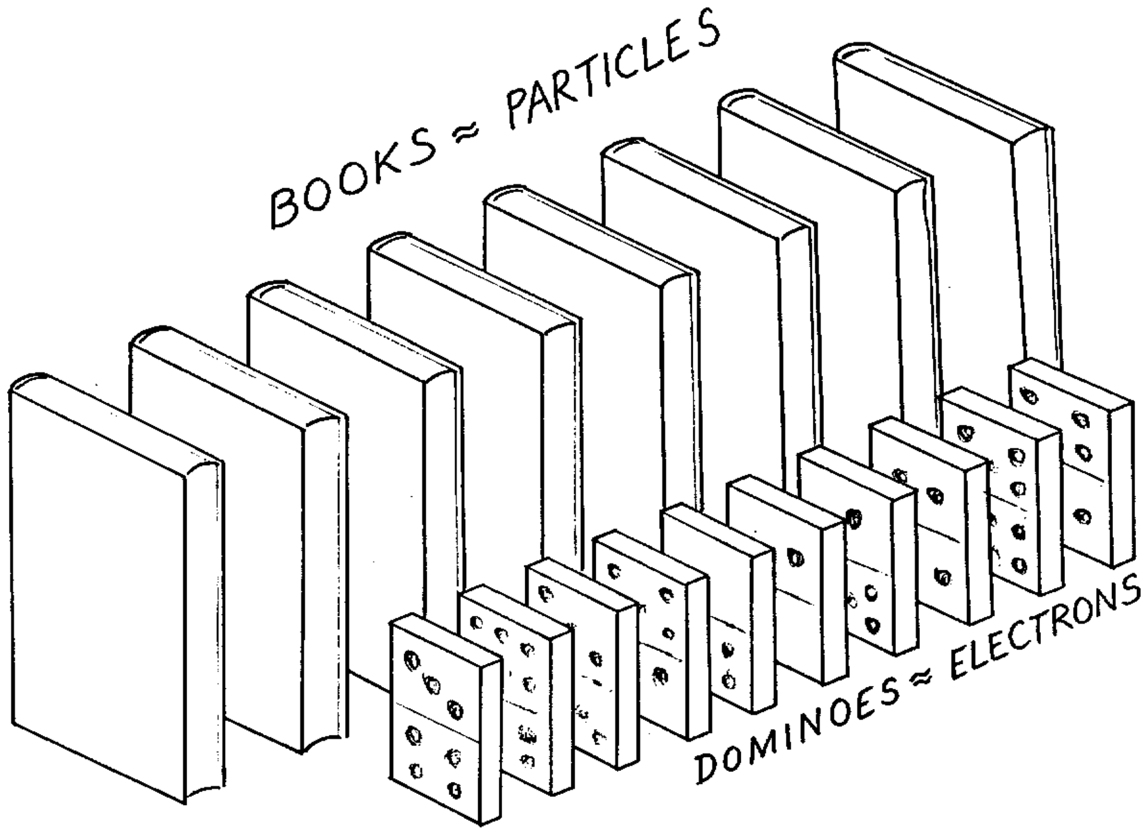

Figure 3: Books and dominoes to represent respectively, particles and mobile electrons in a solid.

T. Now we have a little example here [row of books and a row of dominoes - see Figure 3] and we'll look at the back row first. the dominoes are in front and we'll look at them later. I've got these books, they're meant to represent the particles in a solid which are quite close together. Now when we heat particles, what happens to them?

S. They move around.

T. That's right, they start to move and spread out ... and they also ... vibrate, was it? They vibrate. This is meant to represent a solid then, um, ... a solid, any solid. The particles of the solid here (books) ... now what happens if I heat one end of the solid? What am I doing to the solid?

S. (inaudible)

T. I'm making it vibrate more quickly. What is that going to do to this particle here?

S. It's going to bump the one next to it.

T. It's going to bump that one, which in turn will ...

S. Hit that one.

T. That's right, it will pass on ... let's see ... I'm heating this end of the solid and (pushes over first book) ... Oh, I didn't set it up right did I? I should have had it a tiny bit closer. Actually this would show something, not what I want, ... what might that be like? It didn't pass on the vibrations, what is it like, yes?

S. Maybe it was changing from ...

T. Well, I've got it probably a bit more like a liquid haven't I? We'll put them a little bit closer together and make it a bit more like a solid. so that should be like a solid now shouldn't it? So let's have another go .... (all fall over) that's like a solid ... all the particles are close enough together to pass on the vibrations. Now the way I had it before was more like a what? A little bit further apart ... that was more like a liquid wasn't it? Um, so that I can bump the particles (repeats books falling) but it doesn't necessarily pass it on. Now this way of transferring heat by particles passing on vibrations is called conduction. So conduction is made by the particles passing on vibrations. Now this happens best in solids, because in solids the particles are close together, like when I had the books together. In liquids or gases, each particle when it is bumped does not pass on the vibrations because the particles are a little bit too far away, so solids are the best conductors, now something else about this. Some solids are better conductors than other solids. Do you know which solids are the best conductors?

S. Copper

T. Copper is one,

S. Gold.

T. Gold, what else ..

S. Metals.

T. Yes, in general, metals .. you've given me the names of metals. Metals are the best conductors. Now the reason metals are the best conductors is because they have something called free electrons.

We talked about electrons in the structure of the atom didn't we. Do you know where the electrons are in the atom?

S. In the nucleus.

T. No ...

S. (inaudible)

T. They're around the nucleus aren't they. The electrons are around the nucleus. Now metals are rather different from other sorts of substances because the electrons are free to move, so there is space in metals where there are lots of electrons. Now that is what this thing is here [dominoes]. I haven't tried this before. What I'm trying to show you is why metals are especially good conductors. In metals we've got our big particle [book] so these are our atoms ... these books are our atoms here and these dominoes, the little ones, are meant to represent free electrons. Now when I heat one end of the metal, as well as the particles starting to vibrate, the free electrons also vibrate, so we've got double way of passing on the vibrations. Would someone like to come and do this for me ...

So we've got free electrons here and we've got big particles there, now in fact ... you do the dominoes and I'll do the books. We'll see which passes on vibrations the faster. Ready, set, go ... I haven't got the dominoes right [stopped half way] ... (giggles) .... do you get the idea?

That free electrons as well as big particles pass on the vibrations in metals so they're the best conductors. What would you expect would be the worst conductor ... which state of matter would you think?

S. Gases.

T. That's right, gases. Why are gases the worst conductor ...?

S. Because the particles are so far apart that they don't touch each other.

T. That's good. So far apart they can't touch each other when they vibrate. Gases are like having one book here and the next book might be right at the end of the bench ... so it does not matter how much I heat this gas particle, there is no way it is going to pass on the vibrations. So metals are the best, then solids, then liquids and gases are pretty poor. Let's just have a little look at the text book ...

The class was then asked to read the relevant pages in their textbook dealing with conduction

Analysis and Data Generation

First of all, the lesson notes and the transcript were reviewed to search for evidence of the six steps in the modified TWA model. The resulting breakdown of the lesson is as follows:

1. Introducing the Target Concept to be Learned (Lines 1-52)

Mrs Kay provided a logical introduction to conduction through reference to the previous lesson and by describing a commonplace phenomenon (which "feels the colder" [16], the tap or the bench) and by performing a simple experiment using two thermometers to measure the temperature of the tap and the bench. This phase closed with "would you all agree that the metal tap is transferring heat better"? [48].

2. Cueing Students' Memory to the Analogous Situation (Lines 53-56)

At this point, Mrs Kay proposed that,

> Now we have a little example here [row of books and a row of dominoes - see Figure 3] [53].

The visual impact of the line of identical books and the row of dominoes in front of the books quickly focussed the student's attention onto this analogy.

3. Identifying the Features of the Analog that are Relevant (Lines 56-59)

Mrs Kay then introduced the analogy by saying that, "a row of books and a row of dominoes is like particles in a solid". She followed with "these books, they're meant to represent the particles in a solid that are quite close together" [57-58]. It appears that Mrs Kay saw this comparison as being obvious and unambiguous. Her approach matches Gentner's criterion (1988, p. 76) that "access to memory is heavily influenced by surface similarity between base and target ... in judging soundness, it is systematic structural overlap that counts". In-class observations, the lesson transcript and the student interviews suggest that the students understood this likeness and found it attractive.

This was the time to check whether or not the students were familiar with the analog. By offering this comparison, Mrs Kay assumed that they were and she did not check their mental image of the model. During the post-lesson teacher interview, she indicated that the students' reaction at this stage encouraged her to go straight on: "I thought today the kids probably got the idea by seeing that without getting any more complex." Later, when unshared attributes were being discussed, she maintained her confidence that the class were happy with the initial proposition by stating "I still think they got the general idea", and "this lot did seem certain ... they did seem to be with it." As will be seen when the student interview responses to the specific propositions are discussed, it should be evident that, at this stage, the students were comfortable with this comparison.

4. Mapping the Similarities Between the Analog and the Target Concepts (Lines 60-135)

The book/particles dominoes/free electrons analogy contained seven propositions relating to the conduction of heat. These propositions are analysed in the order in which they occurred. The student worksheets also provided information which is summarised in Table 2.

Table 2: Incidence of shared and unshared attributes in Year 8 class that studied conduction of heat using the domino/book analogy (n = 22)

SHARED ATTRIBUTES	POSITIVE	NEGATIVE
Books in the line represent particles	21	1
Dominoes are like mobile electrons	22	
Books bumping is like particles bumping	2	
Books too far apart is like a liquid	1	
Only first book fell is like a gas	1	
Size: dominoes<books::electrons<particles	3	
Dominoes falling is like heat passing through	1	
Books falling is like heat passing through	2	
UNSHARED ATTRIBUTES		
Books are similar in size to particles	19	
Domino speed is similar to electron speed	14	3
Gas particles vibrate like solid particles	1	
Books & dominoes stop after hitting suggests particles & electrons stop after hitting	1	
Book speed is like particle vibration speed	1	

This student worksheet (Appendix 4), like the one used in the previous episode, had part of each of the first two pairs of propositions provided for both the valid and invalid mappings. In the following commentary, the same coding system is employed as was utilised in Episode 1. The items (i), (ii), etc, refer to the valid and invalid propositions contained in each analog-target link and were derived from the lesson transcript unless otherwise stated.

(i) "books ... represent the particles in a solid which are quite close together" [56]. The interviews revealed that the students recognised and readily accepted this initial premise. Refering to this initial link, the opening question in the interview asked each student "What do you think of that idea?" Each girl easily recalled the analogy expressing both interest and understanding at this level. Comments a little later in the interview revealed that each student understood that the books are supposed to be like atoms and that they were closely packed in solids. Lizzy's comment was typical: "the dominoes were the electrons and the books were the particles, the atoms."

When commenting about particles vibrating and disturbing the ones next to them, Sally and Lizzy stated that

> Mrs Kay made the point and I think the book does too, that the movement of the free electrons [dominoes] passes the heat better than the movement of the molecules. [Sally]

> When she showed us the books and the dominoes, how they fell onto each other, it was because the vibrating atoms bump into each other passing heat and energy, it was clear. [Lizzy]

Not one interview comment and only one worksheet statement was found that disconfirmed the "books are like particles" propositional statement.

(ii) "When we heat particles, [they] start to move and spread out ... vibrate more quickly" [57-66]. . In the interview with Peta, she explained the relationship between heat and motion in the following way: "it sort of gets heated up and moves a bit faster and it sort of it moves faster and then it is heated up."

While this was the only statement that mirrored the teacher's idea, the thread of the idea that getting hotter meant that the particles moved faster, ran through most of the interviews. However, the following comment by Sally suggests a misconception: "When they are heated, how they expand, they move when they're heated, they vibrate" Sally may have thought that the analogy was saying that the added heat <u>starts</u> the particle moving. Later when she was asked about insulators, she asserted that: "They don't move, the particles don't move so they can't conduct heat." This girl was the least talkative of all the interviewees and was the least sure of the four.

(iii) All particles move, when heat is added they move faster. Mrs Kay inferred this propositional statement when she said to the class, "I'm heating this end of the solid (pushes over first book)" [71-72] which hits the next, making it move, which is like transferring heat to the next particle. This idea that heat is analogous to motion was well represented throughout the interviews and the student worksheets. During the student interview with Tina, she made a very perceptive remark when asked to describe the analogy.

> S. It's, it sort of got me thinking that they sort of stop after they move. So they move and they hit something and transfer the heat and they just stop where they lose the heat, sort of just passes through.
> I. Like the book is lying there still, once it's done its job?

S. It's done its job and it stops.
I. Do you think that's how it really works?
S. No.
I. How do you think it really works then?
S. All the particles move around and they hit each other and they keep moving on so the heat transfers into other particles which keep moving and hitting the other ones and keep transferring the heat to everything.
I. So if you have this long piece of copper wire, and you heat this end, what happens?
S. It heats the next [particle] and the next one and the next one and it carries through.
I. What about the one that was moving that did the bumping, is it still going to be moving?
S. No. In a piece of copper wire it's not ...
I. So in a piece of copper wire, if you heat one up, it moves quickly, bumps something else, so it's not moving quickly?
S. No. It still is, but the example shows that it's not.
I. So you're saying to me - the example says it moves, then stops, but you know that it keeps moving?
S. Yes.

Tina recognised the flaw in the analogy that, if you take the analogy literally, the particle starts, hits, stops. However, she could disregard this misconception, but the research did not determine whether or not every other student was equally perceptive This observation makes a powerful case for examining the unshared attributes, and especially, from the students' cognitive viewpoint.

(iv) The particles are further apart in the liquid phase. This propositional statement emerged from the following comment made by Mrs Kay during the lesson. "A little bit further apart ... that was more like a liquid wasn't it?" [82-83]

This proposition emanated from the failure of the first attempt to apply the domino effect to the line of books. The fact that the books were too far apart was seized upon to analogically show why liquids are poor conductors. Sally understood this point really well when she said: "like in liquids they're too far apart, like they hardly bump into each other, so it's difficult to conduct."

Several students such as Lizzy, focussed upon gases which have even greater inter-particle distances: "in the solid they pass heat better than in a gas because in a solid the atoms are very close together, so not as much heat can be passed through in gases."

(v) One book hitting the next is like conduction. The statement by Mrs Kay that led to this propositional statement was, "all the particles are close enough to pass on the vibrations" [80-81], and "Now this way of transferring heat by particles passing on vibrations is called conduction." [84-86]

This mechanism is the central issue in this analogy for conduction. The interviews demonstrated that each student had absorbed this idea. In describing this mechanism, three of the four girls produced over one half of a page of transcript each. The fourth girl, Tina, provided ten full lines of information. The following four excerpts from the student interviews show how these students understood the domino-effect analogy for conduction of heat in a solid:

> When they vibrate they knock the next ones, and that vibrates too and it knocks the next one, and it vibrates as well, and in a solid [the atoms] pass heat better than in a gas ... [Lizzy]

> It makes the rest of [the atoms and electrons] move because one bumps into the other." [Sally]

> The particles, they vibrate and ... pass the energy on ... when it bumps into the other ones. [Peta]

> The first [particle] heated bumps the next one and then that one gets the heat, and the next gets it and so on. [Tina]

(vi) The books represent atoms and the dominoes represent free electrons. This propositional statement came from the following comments by Mrs Kay, "these books are our atoms here and these dominoes, these little ones, are meant to represent free electrons" [119-120]. This proposition that the dominoes represented the "free electrons in a metal" was also well received as evidenced by the following remarks.

> The dominoes were the electrons and the books were the particles, the atoms ... [Lizzy]

> Dominoes probably move faster because they're smaller ... there'd be more of them to the number of books ... electrons would move faster than the particles. [Tina]

(vii) Both electrons and atoms transfer heat energy. Mrs Kay had said that "free electrons also vibrate, so we've got a double way of passing on the vibrations" [122]. This propositional statement is important when discussing conduction in solids because it explains why some solids

(metals) are good conductors while others (wood, plastic) are not. The interviews again indicated that these two girls understood this idea.

> Substances with many free electrons convey heat more faster than those that don't have free electrons. [Tina]

> I. Why are metals good conductors?
> S. They have free electrons which move faster than particles but do sort of the same thing ... there's more things doing it. [Peta]

The comment from Tina in (vi) above also demonstrates that

> Free electrons, that's just in metals and they move all around the place because they're free. ... they're moving faster because they're smaller ... [Tina]

(viii) Because dominoes are smaller than books, free electrons are smaller than atoms. This propositional statement arose from seeing the model and the fact that Mrs Kay explicitly identified the books as being like atoms and the dominoes being like electrons throughout the lesson. Mrs Kay stated both before and after the lesson that this was her reason for choosing books and dominoes for the analog. The relative size of atoms and electrons was not discussed in the lesson and this idea was encountered on only three of the student worksheets. Several students mentioned this point during the interviews.

> I thought that the electrons had to be smaller since, because all atoms have electrons inside them ... so I thought they must be smaller, I thought the dominoes were a good idea. [Lizzy]

> ... moving faster because they're smaller than the particles. [Peta]

But Tina interpreted the relative size of books and dominoes and suggested that there is less difference between electrons and atoms than there is between dominoes and books. This is evident from the following interview statement: "... a bit nearer in size maybe?"

As in Episode 1, a student identified an extra shared attribute not mentioned by Mrs Kay.

(ix) The speed of the particles. The line of dominoes fell over faster than the line of books showing that electrons transfer heat faster than particles. This similarity was recognised by Lizzy as evidenced by the following interview comment:

> Dominoes will fall over a long time before the books. It is showing that a substance with many free electrons convey heat more faster than those that don't have free electrons. ... The dominoes fell faster than the books ... electrons move faster than the atoms.

5. Identify Analog-Target Links Where the Analogy Breaks Down

No invalid analog-target links were mentioned during the lesson, though unshared attributes were discussed at length during the post-lesson interview with Mrs Kay when she stated that

> Yes, I could have talked about the unshared attributes a bit more. I probably should have said that the particles are obviously a lot smaller ... we have talked about that before ... about the structure of the atom. ... I think they ... know they're smaller, but probably I should have said, ... obviously the particles aren't this size. I know I didn't do the unshared attributes. But to me it seemed a quick little thing [the analogy], that it wasn't really worth it.

Nevertheless, the students identified three instances in which the analogy breaks down These unshared attributes were:

(i) The particles stop moving after they hit the particle next to them. When the book or domino fell over it ceased moving, thus particles and electrons stop once they have transferred energy to other particles. This difference was volunteered by two students during the interviews.

> I. Once the book had fallen over it was still. Do you think that matches?
>
> S. No, I think they keep on vibrating, and just keep on moving. ... It was just showing what it actually did, how they passed on heat, not what they did after they passed on the heat." [Lizzy]
>
> S. I thought they'd still keep vibrating, because after they bump into the other ones ... they'd be all round the place ... [Peta]

Tina's comments on this item is described fully in the discussion of propositional statement (iii) which says that "all particles move, when heat is added they move faster".

(ii) Size difference between books and electrons was inappropriate. This difference was given by Tina when she said that: "you need bigger books because the particles are much bigger than the electrons."

(iii) Free electrons are far superior to particles for transferring heat, The real difference is far greater than the model indicates. This generated

a misconception for Sally because she was led, when discussing insulators, to say: "well solids don't have particles and like plastic, is not as good a conductor ..."

6. Summarise, Drawing Conclusions About the Target Concept (Lines 141-142)

The conduction concept was rounded off by Mrs Kay saying: "So metals are the best, then solids, then liquids and gases are pretty poor."

Interpretation of the Data

Application of the Modified TWA Model to this Analogy

Mrs Kay had already successfully used the modified TWA model in her Year 10 class (Light - waves). This Year 8 lesson occurred some four weeks later. It is clear that her efforts to map the shared attributes was not always precise, and she completely forgot the unshared features. In discussing this after the lesson, she commented about the model's six steps, "I had written it down, but I hadn't really looked at it last night which I probably should have. ... I should have looked at it, ... I could have talked about the unshared attributes a bit more." Mrs Kay's general reflections revealed that when time is precious, it is likely that steps in the modified TWA model will be forgotten, "I've had a rather busy time lately ...". Unless the model is well understood, and firmly imprinted in the mind, important steps are prone to be forgotten.

As discussed earlier when studying the student comments, the three steps of the model that appear to be most important to student cognition were student familiarity with the analog, the shared attributes and the unshared attributes. Student familiarity with the analog combined with the shared attributes provides the foundation upon which the student constructs his or her understanding. The unshared attributes on the other hand, if believed by the student to be valid, may generate misconceptions.

At this stage of this investigation, Mrs Kay appeared to be confident in the use of the modified TWA model. However, she still needed practice in the use of the model, coupled with critical feedback, if she was to convert it into an effective implement in her pedagogical repertoire.

Evidence for Student Conceptual Understanding

Again, as for Episode 1, the best evidence of student understanding should be Mrs Kay's and the students' interview comments. First of all, Mrs Kay's personal reflections are considered.

> You will probably find that most of these will have got the idea from seeing it, don't you? It's probably not a terribly difficult concept really ... and I think that from seeing that, most would get the idea. ... This lot did seem certain ... they're quite a bright little class really, they did seem to be with it ... .
> I thought today the kids probably got the idea by seeing [the analogy]. I think it was a quite good idea anyway.

Mrs Kay was cognisant of the student's thinking because when one girl suggested improving the model by having many more dominoes than books, Mrs Kay responded positively to the suggestion.

> I said, did the electrons travel more quickly or not and she said, 'well you'd really need more [dominoes] to really say wouldn't you?' Which was good ....

Confidence was engendered in Mrs Kay's opinion of the lesson's success because she was quite critical of several aspects of her preparation and presentation: "yes, ... yes, ... but I should have looked at it more closely." The lesson transcript and the student interviews were provided for Mrs Kay to read, and she maintained her assertion that the analogy had produced conceptual understanding.

From the students' viewpoint, each of the girls interviewed expressed satisfaction with the analogy and its presentation. Two students, Lizzy and Tina, extrapolated from the analogy when they provided both an extra shared and unshared attribute. As well as these additional attributes, other students made statements showing their subjective impressions such as:

> S. I was interested how [heat] got from one end to the other.
> I thought it was really good. I don't think there were really any other ways you could have shown it ...
> I. Did it help you understand?
> Yes it did. [Lizzy]

> I thought it was a good way to explain what happened ... it was a good description. [Sally]

> S. The dominoes didn't really vibrate, they just fell over, and I was, well, I got the idea ...
> I. Do you think the analogy helped you understand?

> Not really, because I sort of understood it when she said it before. [Peta]

Of interest though, is the fact that for the very next idea that Peta described, she used an analogy!

> We did a sort of experiment with marbles when they were put into a little round thing ... how they bump into one another when we were doing phase changes ... they bumped into one another ... you could see them moving.

While the analogy may not have been essential to Peta's understanding, it proved to be a valuable medium through which she could articulate her understanding. Peta demonstrated the fullest understanding of the four students and commented on the analogy overall by saying:

> It shows you that the particles transfer the heat from the hot one at the beginning and it transfers it to the next one which is colder and so it moves along like that. ... Yes, it makes it clearer to understand that [particles and electrons] carries and transfers heat.

It is worth reflecting upon Tina's interview comments that were reported under Step 4, item (iii). The status of her conceptual understanding (Hewson & Thorley, 1989) from the perspectives of *intelligibility, plausibility, fruitfulness and satisfaction* were evident in Tina's previous comments and in the ones that follow. Concept intelligibility was evident by the way Tina explained conduction.

> I. How do you think it really works, then?
> S. All the particles move around and they hit each other and they keep moving on so the heat transfers into other particles which keep moving and hitting the other ones and keep transferring the heat to everything.

The concept was also rendered plausible because Tina was able to discount the disconfirming message produced by a literal belief in the analogy.

> S. It's, it sort of got me thinking that they sort of stop after they move.. So they move and they hit something and transfer the heat and they just stop where they lose the heat, sort of just passes through.
> I. Like the book is lying there still, once it's done its job?
> S. It's done its job and it stops.
> I. Do you think that's how it really works?
> S. No.

This dialogue indicates dissatisfaction with the analogy's apparent message and satisfaction with the underlying concept. It appears that she saw value in the mechanism of the analog while simultaneously recognising the analog's limitation. The analogy's shortcomings, though, did not prevent Tina using the basic mechanism to explain heat transfer.

I. So if you have a long piece of copper wire and you heat this end, what happens?
S. It heats the next [particle] and the next one and the next one and it carries through.
I. What about the one that did the bumping, is it still going to be moving?
S. No. In a piece of copper wire it's not ...
I. So in a piece of copper wire, if you heat one up, it moves more quickly, bumps something else, so it's not moving quickly?
S. No. It still is, but the example shows that it's not.
I. So you're saying to me, the example says it moves, then stops, but you know that it keeps moving?
S. Yes.

Tina's concept proved to be fruitful in this instance because it allowed her to differentiate between valid and invalid propositions and to solve the copper wire problem in a facile way.

EPISODE THREE

REFRACTION OF LIGHT IS LIKE A TOY CAR

This third episode in the case study of analogical instruction using the modified TWA model centres upon another lesson with the Year 10 class studying Light. The objective for this lesson was number 24 (Appendix 6), being, "Draw ray diagrams to show what happens when light enters glass along a normal or obliquely to a normal." The same protocol was followed as for the observations and interviews during the two previous episodes. All interviews were transcribed verbatim.

Verbatim Record of the Analogy as Used During the Lesson

T. It's changed direction hasn't it? If I hadn't had the block there, the ray would have presumably kept on going like that ... that's the original ray ... without the block there it would have gone like that. The fact that the block has bent it ... so the light ray has bent as it's gone through the block, hasn't it? Would you agree with that? What do you notice about the ray that comes out ... I'll hold it up ... Do you notice anything about the ray that comes out ... the ray that went into the block ... that's ...
S. They're both parallel.
T. Parallel. That's right ... that's the ray we started with just there, that's the ray in the block and that's the one that comes out ... alright?

That's the ray and that's how it's bent in the block and that's how it comes out ... and that's how it would be if the block wasn't there ... So the ray of light has changed direction when going from one medium to another. Do you have any ideas why? Why it doesn't change direction when it enters at right angles ... just goes straight through ... and as soon as it is at an angle to the block, it changes direction and moves to one side. This is what we mean by refraction. Refraction means the bending of light as it goes from one medium to another. Can anyone explain why? Any ideas? Which do you think it might be easier for light to get through, do you think it might be easier for light to get through air or glass?

S. Air.

T. Air because air is less ...

S. Dense.

T. Air is less dense so it is probably easier for light to get through air than it is through glass. Let me show you a little analogy to illustrate this. This is what all the paint's for, now to represent the ray of light, I'm going to use this pair of wheels here coated in this nice fluoro paint [see Figure 4]. Now I'm going to do two demonstrations ...

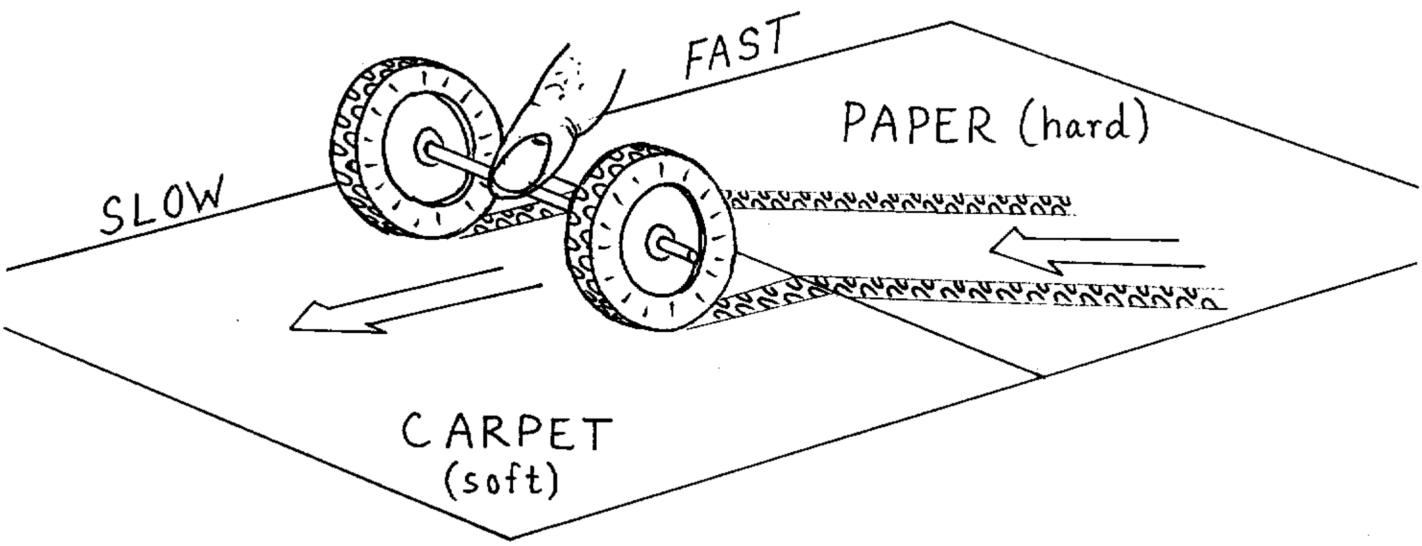

Figure 4: Pair of wheels rolling from paper onto carpet.

firstly ... I'll get one of you to push it so I don't cheat. Firstly, Jade, just do it ... this is meant to represent the ray of light. You might notice a difference, that's our ray of light, now our wheels going forward are meant to represent the ray. Now what's the difference between the ray of light, and ... there's two of them.

S. Well it's wider.

T. There's two of them so it's wider isn't it ... ...

S. It's larger.

T. Obviously, it's larger ... this is really like the two edges of the ray of light as it starts off ... it's wider and it's deliberately wider because it's a little bit hard to see the reason for its bending when it's as narrow as this (points to ray from light box). When it's wider, it's a little bit easier to see the reason for ... . Now Jade, I'd like you to just push that wheel straight keeping to that end, just push it straight from the paper to the carpet. Now that is like the ray of light going through the block along the normal. Just push it straight ... you can sort of just get it like that and just ... .

S. On the paper or the carpet?

T. On both. Push down on it reasonably hard, it's important that we push down hard ... you push down hard ... yes, go onto the carpet, so push it straight onto the carpet pushing hard. Keep going. Is it hard to push on the carpet? I think you might be pushing it slightly to one side ... did it feel harder to push on the carpet?

S. Mmm ...

T. Yes, alright, that is a little bit like the ray of light going straight on through ... I don't know whether Jade has bent it by pushing harder ... that's like the ray that goes straight through. What I want you to do now is have it entering the new medium at an angle. Let's have it at a fairly exaggerated angle ... who'd like to push this one? Jane or you Jen ... alright, just push it as best you can ...

S. This way?

T. Yes, don't ... push it but press down reasonably hard ... we want to get a bit of friction with the carpet ... pull, O.K. keep pulling ... ... alright, what's happened as it's gone onto the carpet? Just keep going to the edge, it'll wipe off the bench if we're lucky ... Good Jen ... that's terrific! (laughter) I don't know whether the bench cleaner will think it's terrific. Alright, what's happened to the car when it's at an angle?

S. It bent.

T. It's bent hasn't it. Would you agree? If I put a straight edge there, you can see that it's bent like that ...

S. Mrs Kay, isn't that because the wheel will move quicker on the ...

T. Yes. Exactly, yes, ... that's right Gemma. I was going to say, why? You all agree it has bent and that light did more or less the same thing didn't it when we passed our light through our block at an angle ... light also bent. Now Gemma was going to give me a reason... weren't you Gemma. Why does it bend when it approaches like that?

S. When the wheel is on a smooth surface it is going faster ...

T. It's to do with speed. That's exactly the point I wanted to make ... it's speed. When we move it here, which wheel is going to slow down first?

S. The one on the carpet.

T. That's right, the one going onto the carpet. It's going to slow down first because there's more friction on the rough surface. Now if you can think of this ray of light as being not quite as thin as it looks, but being wider, do you think, if it was magnified, one edge of the light ray would hit the block before the other side?

S. Yes, yes.

T. In exactly the same way with light, one edge of the light ray slowed down slightly before the other, so this wheel that hits the carpet first, is slowing down first, so that's covering less distance for a time, and obviously, once this one hits the carpet as well, they then become parallel again ... so it bends because the wheels and the light ray travel more slowly in a more dense medium, or in this case, on a rougher medium. So which way is the light bent? I'm going to get you to do this in a minute and draw it for yourselves ... which way is the light bent? If we put in a line here which we call a normal, let me draw ... there and there ... which way is the light bent? Is it bent towards the normal, that's the line there ... ?

S. It goes toward it.

T. It's bent towards the normal, isn't it. Just look at the light rays and tell me if that does the same thing? Does my light ray ... does the light ray also bend towards the normal?

S. Mmm.

T. To make it really fair for you, I should have it the same way round, shouldn't I ... like that. Does the light ray do the same thing? Does it bend in exactly the same way?

S. Yea.

T. You can't quite tell? That's ... if I take the block away, that's the one going in and that's the one coming out and that's how it was in between. Is it bent in the same sort of way? Would you say? That's the track of the car, except I've drawn the path coming out. Same sort of way? Alright, so it's got to do with speed. Now why doesn't the car or light ray change direction when we have it at right angles? The first one that Jade pushed, why doesn't that change direction?

S. Because they both slow down at the same time.

T. They both slow down at the same time. So that would be moving slower, but it doesn't change direction. It's the same with a light ray, if the light ray goes through at right angles, it slows down but it doesn't change direction. Mrs P was saying I should make this point about car wheels changing direction when they go onto a different surface. Mrs P's daughter was driving a car on holiday when she got one wheel on the gravel, and when she got one wheel on the gravel, what happened to the wheel?

S. It slows down.

T. That slows down, so what happens to the car?

S. It goes off the road ... (chatter).

T. The car spins round and if one wheel slows down while the other's going fast, the car can spin. Now Mrs P's daughter got the car out of control and she wrote it off, but they were lucky because they all got out unhurt. But it does happen with cars, that if you get one wheel onto the gravel, they can skid, so ... you think you understand why light gets bent? If it's to do with speed in different mediums ... isn't it? Go back to your places and we'll have a little note about this. Although I used a car to show the light, it's got some things in common. What's different about the car and light?

S. There was only one ray of light.

T. The ray of light was a lot thinner really wasn't it, that's really why I used the car because it's thicker and it's easier to see if it's thicker. O.K. so the bending of light as it passes from one transparent medium to another ... what's the reason again? Why is light bent when it travels from one transparent medium to another? It's to do with speed. So we can say that light travels more slowly ... ... in a more dense medium. So if the light ray enters at right angles, what happens? The light ray enters a different medium at a right angle, what happens? It doesn't bend. Does it change speed?

S. Yes.

T. Yes. You all happy with that again? At right angles it slows down but doesn't bend. If it enters another denser medium ... if it enters at an angle, it changes direction. Can you finish that sentence off ... it changes direction because ... ...

S. What do you call it of light?

T. I think you can say, at one edge of the light ray. What about if you talk about one edge of the light before the other side ... if we look at our sketch of the little car with the smooth and the rough, with our little car, that edge would hit the rough first, and it would bend like that, wouldn't it? That part that hits the rough surface first, now if you talk about the edge of the light, that way, the side of the light ray that hits the edge of the dense medium first, you could say, this wheel in the case of the car, this wheel slows down first ... now in the case of the light ray we could say, one side of the light slows down first, couldn't we, and that is what has the turning effect. One edge of the light slowing down first, so if you want to do a little sketch of this ...

So now I want you to do this experiment ...

Analysis and Data Generation

The lesson notes and transcript were analysed for evidence of the six steps of the modified TWA model. The resultant breakdown is as follows:

1. *Introducing the Target Concept to be Learned (Lines 1-26)*

Refraction of light was introduced by showing the students that a ray of light changes direction when it passes from air into glass or perspex. The demonstration using a Hodson light box precipitated the question, why do light rays bend when they pass obliquely from one transparent medium into another?

2. Cuing Students' Memory to the Analogous Situation (Lines 26-34, 39-43, 118-132)

Because many of the students would not have had a direct experience of the analog, it was established by demonstration using the apparatus illustrated in Figure 2. Being simple and visual, the analog became familiar to the students as it would remind many of them of Lego cars, etc. (they were Lego wheels). This led Mrs Kay into the analogy:

> to represent the ray of light, I'm going to use this pair of wheels coated in this nice fluoro paint. Now I'm going to do two demonstrations ... our wheels going forward are meant to represent the ray [of light]. [29-32]

3. Identifying the Features of the Analog that are Relevant (Lines 43-118, 149-161)

This episode lacked the linear progression of steps 1-6 that was evident in the two previous episodes. Mrs Kay appeared to consider each step where it was most relevant. In this way, steps three and four merged together. The feature of the analog that was most important at this juncture was:

> [the wheels] are really sort of like the two edges of the ray of light as it starts off ... it's deliberately wider ... it's a little bit easier to see the reason [for bending] [39-43]

4. Mapping the Similarities Between the Analog and the Target Concepts (Lines 43-118 and 149-161)

Explaining refraction of light by comparing it to wheels that slow down as they roll from a smooth surface onto a rough surface, utilised six propositions. The six propositional statements that Mrs Kay told the class were the shared attributes of the analogy were, the two wheels represent the edges of a the light ray, a ray that strikes the perspex at 90^{o} is not bent, a ray which strikes the perspex at an angle is bent, the ray bends because it slows down, when the ray strikes the perspex at an angle, it bends towards the normal and the light slows down because the perspex is denser than air. Each of these propositions is stated as the heading of items (i)-(vi) following Table 3 and are analysed in their order of occurrence. The student worksheet (Appendix 4) provided data relating to both the shared and the unshared attributes which are shown in Table 3.

The worksheet possessed the same format as for the two previous episodes and the results are reported in the same manner as for Episodes 1 and 2. The data listed in Table 3 were derived from the students' responses on the worksheet to the questions which asked them to list the shared and the unshared attributes. The only modifications made to the student responses were to shorten long comments and to group similar responses. As the number of students interviewed in this episode was larger (nine) and because almost every instance of each student's statements cannot be fully reported, for this episode, the frequency of each proposition in the interviews is stated (e.g., 5 out of 9).

Table 3: Incidence of shared and unshared attributes in Year 10 class that studied refraction of light using the pair of wheels analogy (n = 29)

SHARED ATTRIBUTES	
Each wheel is like an edge of a ray of light	10
Each wheel is like a ray of light	19
The perspex/glass is like a piece of carpet	27
Air is represented by the paper	9
The way the light is bent is like the way the wheels turned	5
The paint is like the light's path	2
The carpet is like a denser medium	1
UNSHARED ATTRIBUTES	
Wheels being joined is like light being joined in a ray	24
Friction slows light is like perspex slows light	10
Friction slows wheels is like friction slows light	4
Friction slows light is like density slows light	4
Friction slows light is like air slowing light	4
Speed on carpet is like the speed on paper	2
Friction slows light is like light bending through a dense medium	1
Perspex is like the carpet	1
Medium light passes through is like the medium wheels pass over	1

(i) The two wheels represent the edges of a the light ray. This proposition arose from Mrs Kay's statement "[the wheels] are really sort of like the two edges of the ray of light" [39].

On the worksheets, only 10 students actually recalled this proposition in its correct form. Nineteen students responded saying that each wheel is like a ray of light. This response may be a simplification rather than a conceptual error, for all but one of the nine girls interviewed talked about the wheels being analogous to the edge of the ray. Comparing the worksheets to the interviews, four girls wrote that each wheel was like a ray of light but then talked about the wheels representing the edges or sides of the ray of light. One girl, Cath, both wrote and said that the wheels represented separate light rays. Other student comments were typified by the following three comments:

> .... one side of the light as shown in the wheel example ... like a car when one side slows down ... [Jane]
>
> .. one edge of the ray would hit [the perspex first ... one edge gets there first ... like the wheels do ... [Kay]
>
> Well slowing down one side of it so that one side's at a different speed to the other ... [Cath]

(ii) A ray that strikes the perspex at 90^o is not bent. This propositional statement was derived from Mrs Kay's comments,

> This is like the ray of light going through the block along the normal ... just push it straight. [45-46]
>
> Both slow down at the same time ... It's the same with a light ray, if the light ray goes through at right angles, it slows down but it doesn't change direction. [115-117]

Each girl explained during the interviews that the light ray that struck the new medium at right angles (parallel to the normal) continues on unbent. Most could explain this in terms of both sides of the ray slowing down simultaneously. The question that was asked was,

> I. Does a ray of light always change its direction when it passes from one transparent medium into another one?
>
> S. ... not if it enters it at right angles into the medium ... it doesn't change direction. ..." [Jane]
>
> S. ... no it doesn't if the light ray was on the normal because if they hit the medium at the same time, ... travelling perpendicular, then it wouldn't bend because they both slow down at the same time. [Kay]

S. If it's going parallel, then it will go, it doesn't really bend, it'll go straight through ... both rays of light are hitting at the same time and they're both moving at the same speed so it doesn't bend. [Cath]

(iii) A ray of light that strikes the perspex at an angle is bent. Mrs Kay had said ..."when it's at an angle ... it has bent and that light did more or less the same thing ... when we passed the light through our block at an angle" [73-74].

Similarly, as for proposition (ii), each student interviewed provided an appropriate response indicating that she knew that a ray striking the new medium at an angle would bend. Two of the nine stated that the ray bent away from the normal, though this was corrected later in the interview by one of these students.

.... if they hit at an angle, one side of [wheels and ray] hits first so one side slows down before the other causing it to bend. [Kay]

... you could see the paint moving like the light was moving. Like when it went through the perspex it moved, I mean it bent in a different direction, and like seeing the paint do it, I mean the wheels, and then seeing the light do it you could see how it worked, it was easier to understand. [Kay]

... the part of the ray that goes in first, that's going slower than the other half so it changes direction. [Cath]

(iv) The ray of light bends because it slows down. This propositional statement was based on the following comment Mrs Kay made during the lesson.

In exactly the same way with the light, one edge of the light ray slowed down before the other, so this wheel that hits the carpet first, is slowing down first, so that's covering less distance for a time ... so it bends because the wheels and the light ray travel more slowly in a dense medium, or in this case a rough medium. [87-92]

This proposition was identified in eight of the nine student interview transcripts. Three of these student statements which are representative of the overall sample are:

... when [light] enters a different medium, the one edge of the light ray, um, ... would touch the more dense medium first and slow down more quickly than the other, and so it changes direction ...the wheels ... when one side rolled on the carpet, it slowed down and the other wheel went faster, and it changed direction towards the normal. [Jane]

... well because one side of the light as shown in the wheel example, one side of the light slows down, so the other one is travelling at the same speed and is faster, so one side is still travelling as fast as, you know, when it hits the medium, it's like a car turning, when one side slows down and doesn't travel as fast, it kind of goes around in a circle, and so it bends until both sides of the ray, um, travel at the same speed ... because one side of the wheel, see this one, travels down, and the other one goes faster, so it obviously bends because they're travelling at different speeds. [Kay]

Because one edge or side of the light beam hits the different medium before the other, so it slows down and the other one keeps going so it sort of bends until the other one catches up and they're both travelling on the same medium. ... One wheel hits the carpet at, before the other wheel just like one edge of the light hits before the other edge of the light. [Jen]

(v) When the ray strikes the perspex at an angle, the ray bends towards the normal. The stimulus for this propositional statement was Mrs Kay's question and answer, "... which way is the light bent [passing into a more dense medium]? It's bent towards the normal isn't it." [94] As already indicated, eight out of nine stated that the ray is bent towards the normal when light passes from a less dense to a more dense medium. Representative comments from the student interviews were as follows:

I. From a less dense to more dense medium, which way will it bend?
S. Towards the normal. [Jan]

Less dense to more dense ... towards the normal. [Sue]

I. Form a less dense, like air, to a more dense medium like glass, which way will it bend?
S. Towards the normal. [Cath]

(vi) The light slows down because the perspex is denser than air. On this occasion, Mrs Kay had said, "... why light gets bent, it's to do with speed in different mediums isn't it?" [130].

This proposition that refraction was a consequence of changing the speed of the light was mentioned in each interview. Clearly, the demonstration of the wheels slowing down going from paper to carpet, coupled with the 'car wheels in the gravel' analogy, made this idea intelligible to most of the students as illustrated by three quotations from the student interviews.

... [the] wheel goes slower makes the whole car turn ... and it's the same with, like light. [Cath]

... when it goes into the block or whatever, ... the ray of light slows down ... [Sue]

> ... the light moved ... changes speed ... a denser medium, it is more difficult to travel through ... I don't understand why it slows down in glass, but I can see from the example why it slows down on carpet. [Jane]

The following shared attribute was identified by the students even though it was not stated by Mrs Kay.

(vii) When a ray of light passes from a more dense to a less dense medium, it is bent away from the normal. Each girl was asked this question because it involved extrapolating from the concept. It was believed that this would be a good indicator of whether or not the students understood refraction following the use of the analogy. They may also have guessed, by saying the opposite to the previous case. Ability to explain why would favour extrapolation rather than guessing. Three student made four separate comments demonstrating this concept:

> I. When light passes from a dense to a less dense medium, which way will it bend?
> S. It will bend away from the normal. [Jane]
>
> Away from, away from the normal. [Sue]
>
> Away from, the normal, because it is, um, the same idea, but the other one comes out from the denser medium first , so it goes faster before the other one catches up, and then it goes on parallel to the other side. [Kay]

And again from this student:

> Well it's the other side that gets there first because it's on an ... angle and it bends back or goes back on the parallel of the ray it started on, before it got into the dense area. [Kay]

Three girls were not asked this question, but all who were, gave an answer similar to those above. In four out of six cases the students adequately explained why the ray bends away from the normal using the same arguments as Kay.

5. *Identifying Analog-Target Links Where the Analogy Breaks Down*

Mrs Kay identified several differences between the wheels and light rays during the lesson. These unshared attributes were:

(i) The pair of wheels were considerably wider than the light ray. (Lines 35-43). The central comment that highlighted this unshared attribute was:

> Obviously it's larger ... this is really like the two edges of the ray of light as it starts off ... it's wider and it's deliberately wider ... when it's wider it's a little easier to see the reason for its bending. [39-41]

This issue was taken up in the student interviews and resulted in the following responses:

> I. The two wheels were much wider than the ray of light?
> S. No, I just think it exaggerated it and so made it clearer. [Jane]
>
> Um, it is just sort of enlarged, just thought of it as enlarging the ray of light, magnified. [Sue]
>
> No, no, I don't think that would really matter if I think the wheels were skinny and there were two wheels joined by an axle, it would still go the same. [Kay]
>
> It was more obvious, more extreme so you could sort of really see ... if I hadn't seen that wheel, I probably wouldn't have understood the beam of light because it's so narrow, it's hard to believe it's got little edges. [Jen]
>
> It was like similar, but you still had your doubts that your light would be different until she said this is like a version of the light ray. ... If she just got out the wheels and said this is a light ray, I would have questioned that. [Kay]
>
> I just saw it more clearly, I thought it was easier to understand because light's so small and you can't really see it, you know the wheels and the fluorescent paint, I thought that was pretty trendy and it just made it bigger and easier to understand. [Cath]

(ii) There were two wheels but there was only one ray (Lines 135-136). This unshared attribute was recognised by all the students. Three examples of their responses are:

> No, because I thought of the set of wheels as two rays of light. Like the two outside bits of a beam. Like you know how a beam is like a solid bit of light, I kind of thought of that as the two outside bits or like two rays, you see, and the rays go along parallel together. [Kay]
>
> I. The two wheels were joined together with an axle, are the light rays in a beam joined together like that?
> S. No they are individual, but they're very close together. [Kay]
>
> I. Are the light rays in a beam joined together [like the wheels]?
> S. ... I wouldn't say they were joined together, I'd more say they're all going in the same direction, do you know what I mean? They're not joined together by an axle so that they can diverge if they wanted to. [Cath]

Two unshared attributes not identified by Mrs Kay were mentioned by the students during the interviews.

(i) Friction slowing the wheels is like friction slowing the light. During the lesson, friction was given as the reason why the wheels slowed down. A minority of the students interviewed recognised this as an unshared attribute. It is apparent though, that many of the students transferred friction as an explanation for the slowing down of light in denser media. For many, this was probably a misconception. Four student comments that indicated that these students thought that there was friction between light and glass are as follows:

I. Do you think there's friction between the light and the glass?
S. Yes. [Kay]

I don't think there is friction between light and air ... I think there would be between light and glass. [Jane]

S. If the medium's different, because of friction, it's a denser medium, then it's friction.
I. There would be friction between light and glass then?
S. Yes, more. [Jan]

I. Is there any friction between light and glass?
S. I think so ... that's why the ray bends. [Sue]

(ii) The two wheels being joined is like light rays being joined. Of the 29 students who filled in the worksheet, 24 recognised this unshared attribute. This level of response may be a function of the fact that this was one of the two invalid mappings where half the statement was provided for the students. The response rate for this semi-complete proposition was far higher than for all but one other partial statement. That nearly all members of the class recognised this link as invalid is encouraging.

One misconception emerged during the student interviews. Sue revealed that she thought the ray bent towards the normal because this provided a shorter route through the perspex block. If the ray slowed down, it took a more direct (shorter) route. She was the only student who held this idea and she gave this response in answer to the question,

I. Can you link the slowing down with the reason why it bends?
S. Um, it is easier, to make the path [shorter] to get though the block. [Sue]

6. Summarising by Drawing Conclusions About the Target Concept (Lines 138-148)

The refraction concept was reviewed by Mrs Kay concluding with: "At all angles, [light] slows down ... if it enters another denser medium. If it enters at an angle, it changes direction." [146-148]

Interpretation: Evidence of Conceptual Understanding

Application of the Modified TWA Model to this Analogy

Throughout this third lesson, the modified TWA model was subsumed into the lesson with each stage being used when and wherever Mrs Kay felt it was instructionally necessary. The lesson commenced with Step 1 and concluded with Step 6, but Step 2 (cuing the students' memory to the analogy) occurred three times, Steps 3 and 4 occurred twice and Step 5 (the unshared features) was similarly treated on two occasions. The effect, both at the time of the lesson and in rereading the account, was to characterise this lesson as being systematic while preserving spontaneity.

This integration of the modified TWA model into the fabric of the lesson probably indicates mastery of the modified TWA model by this teacher. To say that she was delighted with the lesson's outcome is evident from her comments and the manner in which she expressed them. Mrs Kay summarised her evaluation of this analogy in the following way:

> I thought that was the best I've ever taught that ... refraction from the point of the students understanding it. They seemed to just say, Oh yea, no worries, at the end, and that's what I like about it. ... It's certainly something I'd certainly do again.

Evidence of Student Conceptual Understanding

Credence has been ascribed to the teacher's qualitative assessment of the lesson's effectiveness in respect to student cognition. Mrs Kay gave her assessment of the analogy's effect during the post-lesson interview. Her evaluation is expressed in the following comments:

> I was really pleased with [the analogy] actually, [refraction] was something I've always found hard to explain, and I don't know that the kids find it easy, but I thought, doing it that way, clarified it a lot. .... I felt at the end of the lesson they seemed to have a good

understanding of it. Something I noticed was that sheet that I gave them at the end of the lesson, I said does it bend towards or away from the normal, they had no problem with that today. ... They all seemed to say towards it, where normally they will say, what on earth do you mean ... they seemed to have a better understanding than usual, I felt. I was really happy with it.

The analysis of the student interviews in Step 4 supports this assertion. Not only did eight out of the nine students interviewed consistently predict that the light would bend towards the normal when passing from a less dense to a more dense medium, they also provided a cogent explanation for this phenomenon. Moreover, when they were asked to extrapolate in stating which way the ray would bend passing from a more dense to a less dense medium, the majority unhesitatingly stated "away from the normal" and again could explain why. In giving these explanations, the students moved freely between the wheels analog and the light target. At this stage it is asserted that the girls found the analogy useful as an explanatory tool and as a means of articulating their understanding.

During unrecorded conversation following the interview, Mrs Kay expressed her delight at the speed with which the students came up with correct answers to her questions following the demonstration. She was most impressed with the speed and the consistency with which they could predict the direction of bending. A look back at the lesson transcript shows that Gemma, at the point where the wheels changed direction, spontaneously exclaimed, "isn't that because the wheels will move faster on the [paper]? Mrs Kay: Yes. Exactly, yes ...".

From their viewpoint, the students believed that the analogy helped them understand. A sample of their comments are:

> The wheels, I thought it was a good idea, it really explained it well, I understood that. [Jan]
>
> I think it was helpful because you could actually see the tracks of paint from the wheels ... it was helpful to understand the light rays bending. But you just have to know what are different and that. [Kay]
>
> It wouldn't have been easy to understand if she had just put it on the board in a diagram, it just wouldn't have gone in, do you know what I mean ... by demonstrating it, it actually registers, but otherwise it probably wouldn't have. ... it was a good way of explaining ... [Cath]

EPISODE FOUR

THREE ANALOGIES FOR THE MOLE CONCEPT

A fourth lesson was observed, recorded and transcribed during which Mrs Kay used three analogies to illustrate the size of a mole (6.02×10^{23} particles) for her Year 10 class. This class contained only about half the students who received the two analogies relating to light because the Year 10 classes are reorganised for each topic. The three analogies that she used were, in order of occurrence, the dollar analogy, the oranges analogy and the rice analogy.

For the dollar analogy, Mrs Kay proposed that when the Earth was formed (approximately 4.5 billion years ago), a mole of dollars was created and if this money was given away at the rate of a million dollars a second, how long would the mole of dollars last. When the calculations are performed, it transpired that about 60% of the mole of dollars still remains today.

The oranges analogy uses a standard large orange about 10 cm in diameter. The question is, how large is a mole of oranges? In this case, the volume of the mole of oranges was very close to the volume of the Earth.

For the rice analogy, the students were asked to what depth would a mole of rice grains cover Australia. Ideas such as 1 cm, maybe even 1 metre emerged. When the calculation was performed, the students were amazed to find that Australia would be covered to a depth of 1 kilometre with rice.

Analysis and Data Generation

The transcript for this lesson has not been included because Mrs Kay did not use the modified TWA model at any point during the presentation of these three analogies. When this omission was discussed following the lesson, she gave a very similar reason to the one supplied for not examining the unshared attributes in Episode 2 of the domino effect for conduction of heat analogy. Referring to the mole analogies, Mrs Kay said "they were just quick little analogies ... I didn't think it was really necessary to use the model ... they were just quick little ideas for the girls to think about."

It is evident from these four instances with Mrs Kay, that whenever she felt that the analogy was being used as a passing illustration or quick revisionary tool, the modified TWA model was not needed but when the analogy was central to the teaching of the concept(s), it was. What is most striking about this omission of the modified TWA model for these mole analogies is that this lesson followed the third episode (by two weeks) which stood out as an exemplary display of the use of the model.

SUMMARY

Mrs Kay taught four difficult science concepts using analogies. The wave nature of light was derived from water wave characteristics, conduction of heat through a solid was likened to the domino effect, the slowing down of light and its refraction as it passes from air into glass or perspex was demonstrated using a pair of wheels rolling from a hard surface onto a soft surface and the size of a mole was demonstrated using dollars, oranges and rice grains. The analogy for the first three lessons was presented using the six steps of the modified TWA model. Mrs Kay received in-service information with respect to the model before analogical instruction commenced and before and following each lesson for each of the first three episodes. The post-lesson discussion provided an opportunity for her and the researcher to reflect upon the lesson just completed and to prepare for the next implementation of the modified TWA model.

By the third episode, Mrs Kay had developed a high level of proficiency with the modified TWA model and it was observed that the model had become subservient to her's and the students' needs. Interviews with a sample of the students from each class focussed upon each student's understanding of the concepts presented via the analogy. The student worksheet and interview data were combined with Mrs Kay's personal perceptions of the students' understanding of the concepts presented and it was concluded that the resultant student conceptions were compatible with scientists' science.

The variety and depth of the student interview comments lead one to suggest that conceptual growth may well have taken place during the three episodes that were reported in detail. The fruitfulness of the students' extrapolations and their curiosity suggests that some students were willing to reconstruct their prior conceptions. Nevertheless, without pre-lesson interview or survey data to define the individual student's conceptual status, such conclusions must be limited to saying that there was credible and dependable evidence for asserting that the resultant student conceptions were compatible with scientists' science.

The fourth episode provided disconfirming evidence as to the permanence of the modified TWA model in Mrs Kay's pedagogy. This hiatus suggested that integration of the model into Mrs Kay's pedagogical skill-base is probably incomplete and highlights the need for reflective feedback from a colleague. This evidence indicates that teacher decision making regarding the appropriateness of using the modified TWA model with particular analogies in specific teaching situations warrants further investigation.

Chapter 5

GENERALISATIONS and CONCLUSIONS

INTRODUCTION

The purpose of this chapter is to draw together the threads of the rationale, the theoretical groundings for analogy use and the investigative process along with the case study data and the interpretations that were derived from that data. The overall goal is to generate credible and dependable generalisations for the use of analogies in science instruction. This will be extended to include recommendations for pre-service and in-service teacher education and also to suggest some directions for future research.

GENERALISATIONS

In Chapter 4, the data that were derived from each episode were analysed in a qualitative interpretive manner so that "the paramount objective is to understand the *meaning* of an experience" (Merriam, 1988, p. 16). The meanings of the statements that are made and the actions that occur during analogical instruction now need to be simplified into general assertions that are credible, dependable and confirmable (Guba & Lincoln, 1989). Consequently, the purpose of this chapter is to generate assertions that provide some answers to the research questions, suggest ways for improving classroom instruction when analogies are used and to point the way for future research

The two research questions form the basis for the construction of generalisations from the data and interpretations that were presented in Chapter 4. Each of the questions will be considered on its own.

Research Question Number 1

> Can a competent teacher use the modified TWA model to systematically present analogies during science instruction?

Two assertions relating to this research question are made in the two sections that immediately follow these comments.

1. *An experienced teacher can implement the modified TWA model.* Within her school, Mrs Kay is recognised as an experienced and innovative teacher. In brief, Mrs Kay was introduced to the modified TWA model through a discussion about the model's virtues and she was provided with the two page description of the model (Appendix 1) for her to study in private. All four episodes commenced with Mrs Kay choosing an analogy and setting the time for its use in class. For the first three episodes, on the day of the lesson, the modified TWA model was reviewed, the lesson was taught and recorded and followed immediately by a post-lesson interview with Mrs Kay. During the interview, her use of the model was discussed based on the in-lesson notes, suggestions were made for the next episode and plans made for the next implementation of the model. The fourth lesson was not preceded by a review of the modified TWA model, but a post-lesson interview was conducted as before. This may explain why Mrs Kay failed to use the model on this occasion.

In the first lesson (light is special kind of wave motion), the modified TWA model was used in a strictly linear sense (Steps 1-6 in that order). During the second lesson (conduction of heat is like the domino effect), Step 5 was omitted even thought this was the aspect of the model that Mrs Kay had found so valuable in the first episode. In response to the reflective feedback following that lesson, the third episode indicated that Mrs Kay had mastered the modified TWA model because, apart from Steps 1 and 6 at the beginning and the end of the lesson respectively, she used each of the Steps 2-5 several times and used it where each step was most appropriate. During lesson four in which three short analogies for the mole concept were used, the modified TWA model was not in evidence.

Based on the data reported in Chapter 4 over the first three lessons, it is asserted that in this instance, with this teacher, a systematic approach like the modified TWA model is a practical and achievable means to enhance teacher presentation of analogies during science instruction. Whether or not this finding is transferable to other teachers, times and places has yet to be determined.

2. *Integration of the modified TWA model into a teacher's repertoire requires practice and peer support.* The second assertion is that the implementation of the modified TWA model requires both practice and

peer support in the form of constructive feedback (Wallace & Louden, 1992). Mrs Kay did not appear to integrate the modified TWA model into her teaching style as rapidly as the researcher originally anticipated. Practice and constructive feedback coupled with reflection on practice was required before she, an experienced teacher, became proficient with the the modified TWA model. How this was done has been described in the Chapters 3 and 4..

At the conclusion of the first three episodes during which Mrs Kay used the modified TWA model, she appeared to be comfortable and fluent in its use and the students responded positively to the resultant analogical instruction. As reported in Chapter 4, there was a consistently high level of understanding encountered during the interviews. In the third episode, Mrs Kay felt that the students had understood refraction better than on any previous occasion that she had taught this concept. However, when Episode 4 is added to the analysis, it is apparent that the systematic approach embodied in the modified TWA model was possibly not yet a permanent part of Mrs Kay's pedagogical repertoire. An alternative conclusion is that she simply did not feel that the model was needed for short analogies of the type used to describe a mole. Mrs Kay did give a reason of this type when explaining her failure to examine the unshared attributes for the domino analogy.

It would, therefore, be reasonable to predict that the majority of practicing teachers would require extended practice combined with critical feedback before they could master the modified TWA model for presenting analogies in their teaching. Three applications of the model may well be a minimum number of attempts in order to achieve proficiency for the modified model or another appropriate model. Nevertheless, as Mrs Kay's experience demonstrated, three episodes provided insufficient practice for her to automatically use the modified TWA model as a framework for presenting analogies to her classes.

In addition, Episode 3 indicates that teachers will probably adapt the model to suit their personal teaching style.

Research Question Number 2

> When analogies are taught using the modified TWA model, are the resultant student conceptions compatible with scientists' science?

Based upon the in-class information and the data derived from the teacher's and students' post-lesson interviews, a single assertion is made.

When analogies are presented systematically, the resultant student conceptions are compatible with scientists' science. The student responses collected from the worksheets and the subsequent interviews provided extensive documentation of student understanding of the concepts involved. Using the constructivist criteria of credibility and dependability, it is probable that the modified TWA model did, through some mechanism, enhance student conceptual understanding of these difficult science concepts.

There is a need for caution in this assertion because the degree of conceptual understanding that would have resulted without the model or without the analogy is quite unknown. From the data presented, we can merely say that there was a high level of student reflective understanding achieved during these three lessons.

The most compelling evidence for the assertion that the modified TWA model induced the desired product of student conceptual understanding towards scientists' science are Mrs Kay's personal assessments of each lesson. She repeatedly stated that these students understood each concept better than on previous occasions in her teaching. She is recognised as an exemplary teacher, and based upon her experience, her evaluation should be considered to be credible. Based upon Mrs Kay's comments and evaluations, this study has raised many new questions and these will be discussed in a later section.

IMPLICATIONS FOR FUTURE RESEARCH

In the planning phase of this evaluation of the modified TWA model, the intention was to seek evidence for conceptual change during analogical instruction. Following the initial observations and perusal of the data and the literature (Hewson & Thorley, 1989; Strike & Posner, 1985), rationalisation of the study reduced this goal to a search for conceptual understanding during analogical instruction. As stated in Chapter 4 and in the above generalisations, it is believed that credible evidence for conceptual understanding was found. But what was the source of this growth, was it the analogy, the analogy plus the modified model or simply more thoughtful instruction on the teacher's part or a combination of all three? If the reason for increased student cognition was simply more thorough instruction, then the modified TWA model could be described as a catalyst for improvement.

As is often the case, this investigation has engendered as many questions as it has answered. Future research ought to explore some of the following possibilities:

1. Can analogies taught through the medium of the modified TWA model produce identifiable conceptual change in students' understanding of difficult science concepts?
2. Can the modified TWA model be modified so that it is easier for teachers to implement? In this regard, a simplified model is currently under consideration by the *Teacher's Use of Analogies* project at SMEC.
3. Do other models exist that can facilitate the presentation of analogies as well or better than the modified TWA model? Does this experience with one teacher and her students provide a basis for the synthesis of a better model overall?
4. Will this, or another appropriate model, work as well with spontaneous analogies as with pre-planned analogies?
5. Does the position and/or the type of analogy alter the modified TWA model's efficiency? That is, does the model work as well with relational analogies as with structural analogies (Gentner, 1988) and is the model equally useful with analogies that are used as *advance organisers*, *embedded activators* and *post-synthesisers* in the instructional sequence (Curtis & Reigeluth, 1984)?
6. Is analogical instruction using the modified TWA model equally effective for students of different ages and different abilities?

Future Research Project: Identification of Conceptual Change

The first of the above questions provides the rationale for the next study in the *Teacher's Use of Analogies* project at SMEC. That goal will be to identify credible conceptual change during analogical instruction.

At this point in time (October 1992), it is approximately three months since Mrs Kay's students saw the 'toy car is like a ray of light' analogy. Four researchers are visiting this class and every student is being interviewed to determine the status of each student's conception of refraction. Another Year 10 class, also taught refraction by Mrs Kay but without the analogy, is also being interviewed. It is anticipated that this investigation will expand our understanding of the role analogies play in the construction of concepts during learning.

A future study is envisaged that will require the identification of a student alternative concept that is highly intuitive and resistant to change. Misconceptions that could be suitable for such an investigation include, a table does not exert an upward force on a book resting upon it (Clement, 1987) and an electric current is consumed in a simple D.C. circuit (Dupin & Johsua, 1989).

Initially, the conceptual status of each member of a class of students will need to be identified. This could be achieved using a diagnostic instrument followed by focussed interviews. The students will then receive normal instruction containing an appropriate, embedded analogy using the modified TWA model and following the lesson their conceptual status will then be reassessed using a diagnostic instrument and interviews. It may prove necessary to repeat this exercise deleting either the analogy and/or the modified TWA model with further classes. Without doubt, there is a considerable scope for research in the domain of analogical instruction

IMPLICATIONS FOR TEACHING

Implementing the Modified TWA Model in Schools

The first implication for classroom practice that emerges from this study is to reinforce Glynn's (1989) warning that, "analogies are two-edged swords" (p. 20). The very real potential of an analogy to produce misconceptions has been considered in Chapter 4. However, analogies appear to possess considerable potential to enhance student conceptual growth when used in conjunction with a dependable model.

The evidence collected during the lessons, and from the post-lesson interviews, supports an assertion that the advantages of modified TWA based instruction outweigh the disadvantages. This is particularly so when the unshared attributes are critically analysed in class. Whenever a set of prompts is used by the teacher to remind him or her to consider the analogy's familiarity plus the valid and invalid mappings, this amounts to the use of a systematic teaching approach. To my knowledge the modified TWA model is the only model to date to be evaluated in a systematic manner.

Because many teachers use analogies in an ad hoc manner, it may be advantageous for student cognition to make the modified TWA model generally known. Of particular import is the need to evaluate student familiarity of the analog whenever an analogy is employed in class. Similarly, it is likely that instruction may be improved whenever time is taken to discuss the credibility of an analogy's analog-target mapping.

Advertising the modified TWA model and its benefits is necessary. A first approach is through journals and magazines, especially those that classroom teachers are likely to read. But, as our experience with Mrs Kay demonstrated, teachers need much more than just a list of things to do. It is intended that videotapes can be produced showing analogies being taught using the modified TWA model or a derivative of it, and supported by evidence of improved student cognition. This material could be further extended using workshops and/or local in-service activities.

The interaction between Mrs Kay and myself indicates that a collaborative pair will probably be an efficient way to bring about teacher improvement because of the privacy it offers to both members during critical feedback (Kilbourn, 1991). Integration of a technique such as the modified TWA model into a teacher's repertoire may best be achieved by firstly providing in-service experience for individual school groups followed by the establishment of interested pairs Nonjudgmental feedback proved to be the most effective method for Mrs Kay. The opportunity to have a comfortable environment in which to reflect upon one's performance is probably essential if the model is to become part of a teacher's repertoire.

It is Essential to Check Analog Familiarity When Using Analogies

The second step of the modified TWA model involved establishing that the analog was truly familiar to the students. In the three observed and reported episodes in this thesis, the analog was well grounded through either, a videotaped instance or an actual demonstration. Whenever there is vagueness or uncertainty in the minds of the students, the credibility (validity) of their analogical mappings should be queried. If the teacher's concept of the analog is markedly different to that of the students, alternative conceptions will probably follow.

Another teacher who participated in this study (Lesson 4, Teacher C, Chapter 3) related the following story during the post-lesson interview following her use of the mixing red and white paint analogy for incomplete dominance. Teacher C was describing an analogy she used on another occasion to illustrate the shape of an erythrocyte. She stated it as follows:

> Sometimes it confuses the students more if they don't see it the same way I do. Particularly if I pick something I think they understand and they don't, or I'm familiar with and they're not. Like the butter menthol for instance. I used to describe an erythrocyte as looking like a butter menthol. I used to say an erythrocyte looked like a butter menthol with it being circular with the indentation on both sides, because when I was at school that's what butter menthols looked like, but they don't look like that any more, which I didn't realise. They're now square so all these kids were led to believe that erythrocytes were square ... !

It is asserted that, whenever it can be established that the students visualise the analog in the same way that the teacher sees it, valid transfer of understanding may follow. When the students visualise the analog in a way that is different to that of the teacher, alternative conceptions will probably result.

The Unshared Attributes Should Always be Discussed

In the fifth step of the modified TWA model, which involved examining the analogy's validity, all the propositional statements that emerged from the analogy have been shown to be valuable in avoiding alternative conceptions. Mrs Kay was impressed with this process following her first use of the modified TWA model and she stated that she had never before thought to do this, even though she has been using analogies in teaching for about 20 years.

The student responses support the generalisation that this is an essential step whenever analogies are used in instruction. The value to student cognition inherent in examining the unshared attributes is reinforced by Peta's interview comments following the use of the 'conduction is like the domino effect' analogy. Peta described how the analogy, if taken literally, shows that particles start moving when they are heated and stop moving after they have passed some heat on to the next particle. She believed that the particles were in constant motion and said "no, it still is [moving], but the example shows that it's not." She understood that the analogy broke down at this point and volunteered this information during the interview. Two other students recognised this limitation when asked about it but the fourth student thought that the particles were stationary after conduction had taken place.

In each of the three episodes reported in detail in Chapter 4, it was evident that the students did want to know which features of the analog-target mappings are valid and which ones are not. That students do want to know the limitations of the analogy is evident in a statement from Episode 1: "otherwise you would have thought they were pretty much the same thing ... but really they do different things as well" [Jodie & Sarah].

A Collection of Appropriate Analogies

Another implication for practice is the need to reduce the use of inappropriate analogies. As considered in Chapter 2, the literature contains a bank of evidence as to the strengths and weaknesses of a large number of analogies. Thiele and Treagust (1991) and Venville and Thiele (1992) have analysed the analogies present in the Chemistry and Biology textbooks that are commonly used in Australia. A bank of science analogies is being compiled and is being adapted for teacher use at the Science and Mathematics Education Centre at Curtin University. These analogies, collected from many diverse sources, should prove to be a valuable resource for beginning and experienced teachers. It also is believed that greater student understanding will be achieved if these analogies are used systematically with a model such as the modified TWA model. This analogy bank needs to include the modified TWA model or another appropriate model, with its virtues and methodology presented in a user-friendly manner. Additionally, the assumed knowledge for each analogy will need to be clearly defined along with the possible valid and invalid attributes. Student understanding should be improved by highlighting to the potential users, the positives and negatives of the individual analogies.

IMPLICATIONS FOR PRE-SERVICE TEACHER EDUCATION

Much of what has been said in the previous section is applicable to teacher pre-service education. New teachers are particularly in need of instructional skills. A trialed model such as the modified TWA model and an item bank of appropriate analogies should be very attractive to pre-service teachers.

Moreover, pre-service is a favourable time and place to introduce a model for teaching with analogies without endangering a class full of students. A teaching with analogies component could be integrated into the science methods course. Each student could present a science concept using an analogy to their peers. This would provide a less stressful environment than a class of children, and it would have the added advantage of peer and lecturer feedback. An extension of this could be a subsequent opportunity for the student teacher to use the modified TWA model (or another model) during practicum with selected instances videotaped for critical analysis at a later date.

The value of the post-lesson analysis of analogical teaching has been demonstrated as an outcome of this study. Reflection on practice proved to be both stimulating and productive.

LIMITATIONS OF THIS STUDY

While every attempt was made throughout this study to be as rigorous as possible, there are limitations that must be born in mind when the assertions and recommendations contained in this chapter are considered. First of all, although six teachers and fourteen lessons were studied, only one teacher's performance over four lessons was analysed and reported in detail in this thesis. Secondly, the data derived from these four lessons was only interpreted from the perspective of conceptual understanding. A third limitation was a lack of quality control in the post-lesson worksheet. The students appeared to need more direction in the generation of the shared and unshared attributes, especially for Episode3.

With respect to these three limitations, the next task is to evaluate the modified TWA model with a group of teachers covering a range of abilities and experience to determine whether the findings of this study are indeed transferable to the wider population of science teachers. Likewise, as discussed under "Implications for Future Research", there is a need to evaluate the most appropriate model for teaching-with-analogies with respect to its capacity to produce conceptual change as proposed by Strike and Posner (1985).

CONCLUSION

In commencing this study, the following two questions were asked:

1. Can a competent teacher use the modified TWA model to systematically present analogies during science instruction?
2. When analogies are taught using the modified TWA model, are the resultant student conceptions compatible with scientists' science?

The study of the literature (Chapter 2), the qualitative methodology (Chapter 3), the data collection and interpretation (Chapter 4) and the generalisations (this chapter) described the evaluation of the modified TWA model.

In respect to the first research question, the study has shown that a competent teacher can implement the modified TWA model in a highly productive manner. This finding should be transferable to other teachers in the ways suggested under "Implications for Teaching" and "Implications for Pre-service Teacher Education".

The second research question was concerned with student cognition when the modified TWA model is used to teach a difficult science concept. An ample body of evidence has been collected from three teaching episodes which support the premise that student understanding is enhanced when analogies are used in a systematic manner. Selected student responses have been cited in Chapter 4 endowing this claim with plausibility.

It already has been acknowledged that this aspect of teaching science with analogies is vast and diffuse This study has done no more than show that a systematic model for teaching with analogies can be implemented by an exemplary teacher and that students do derive conceptual benefit from instruction using the modified TWA model. Nevertheless, the study has proved to be fruitful in respect to the two research questions. The study also has exposed new horizons and has begun to point the way for future studies of analogical learning. If all one learns is where to look and what to look for, then the exercise has been productive (Patton, 1990).

In commencing Chapter 1, reference was made to the ubiquitous nature of analogies in everyday speech, education and fiction. From antiquity, analogies have been employed to describe complex situations in a word, a sentence or in a story. The power of analogies and metaphors to evoke vivid images and solve problems is as useful today in the classroom as it was as a tool of discovery for Galileo, Maxwell and Kepler.

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Appendix 1

The modified Teaching-With-Analogies (TWA) model.

Teaching With Analogies

Definitions:

Analogy: a process of identifying similarities between different concepts (Glynn, 1989)

Analog: the familiar, student world concept

Target: the unfamiliar, science concept which is being explained or learned

The Advantages of Analogies in Teaching

1. Visualisation Process

An analog which the student is familiar with, or has seen, is valuable in helping students visualise abstract concepts.

2. Real World Linkage

Presentation of a concrete analog within the students' real world facilitates understanding of the abstract concept by pointing to the similarities between objects or events in the students' world and the phenomenon under discussion.

3. Motivational Function

As the teacher is drawing from the students' real world experience, a sense of intrinsic interest is generated. If students are able to achieve a higher level of conceptual understanding than usual, this also can result in motivational gain.

4. Encourages the Teacher to Consider the Students' Prior Knowledge

Students' prior knowledge can influence the way they will perceive the new concept and it can be advantageous to consider their perspectives before teaching.

The Constraints of Analogies

1. Analog Unfamiliarity

The student is often unfamiliar with the analog, especially as the analog usually comes from the teacher. This will only cause greater confusion and misunderstanding if it is used. Teachers should try to choose analogs which are familiar to their students or explain the analog to the students to help remediate this problem.

2. Stages of Cognitive Development

If students lack visual imagery, analogical reasoning, or correlation reasoning, then the use of analogies is believed to be limited. In addition, those students already functioning at a high level may have attained an adequate understanding of the target and the inclusion of an analogy might add unnecessary information loads that could also result in new misconceptions being formed by the students.

3. Incorrect Transfer of Attributes

The features of the target and analog that are not shared are often a cause of misunderstanding for the learners if they attempt to transfer them. When analogies are used during classroom instruction, discussion should take place to assist in defining the limitations of the analogy.

A Model for Teaching With Analogies

The following is a model (adapted from Glynn et al., 1989, p. 389) that a teacher could use when teaching with an analogy to improve the effectiveness of teaching and facilitate the correct application by the students. The six steps of the model are numbered from 1 to 6, however this is not a rigid pattern in which the steps must be implemented. Each step is important but the order in which they are used will depend on the individual teaching style, the particular concept and analogy being used and the lesson format the teacher wishes to follow.

1. Introduce the target concept to be learned

This can be anything from a brief introduction to a full explanation depending on how the analogy is to be utilised. If the analogy is to be used as an advance organiser, then the target concept would be introduced after the analogy. The analogy may be useful as revision. In this case, the target concept will be fully taught at this point.

2. Cue the students' memory of the analogous situation

Introduce the analog and identify how familiar the students are with it by questioning, for example.

3. Identify the relevant features of the analog

This involves explaining the analog, the detail of which depends on the students' familiarity, which should have been determined (see step 2), and identifying the relevant features.

4. Map out the similarities between the target concept and the analog

The relevant features of the target concept are outlined and clearly linked with the corresponding features of the analog.

5. Indicate where the analogy breaks down

During the use of the analogy, any misconception the students may be developing should be noted. The teacher should be aware of any other areas where the analog and target do not correspond. These should be pointed out to the students so that they are less likely to draw incorrect conclusions about the target from the analogy. This step can be incorporated at any appropriate point.

6. Draw conclusions about the target concept

As with any teaching strategy, the important aspects of the target concept should be summarised in a conclusion to facilitate learning.

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Appendix 2

Post-lesson Teacher Interview Protocol.
For use in interviewing a teacher who has used an analogy during the lesson.

INTERVIEW SCHEDULE: Teacher who has used an analogy

A. Thanks .... for giving me a few minutes of your time. That was an interesting idea you used to compare .... to ....

I'm interested about why you chose to use an analogy at that point in your lesson. Can you tell me something about why you used the analogy?

[Is the use of an analogy a premeditated strategy - that is, when there is an obvious 'block' in the students' understanding of a particular concept, do you deliberately reach for an analogy? Or do you use analogies when they appeal to you rather than when student needs demand them or are analogies a 'spice' you just add to the lesson every so often to make it interesting?]

T. xxxxxxxxxxxx

A. Why did you choose <u>that</u> analogy to explain ....?

[Was it simply the best you could think of at that time or did you plan to use it if the need arose? Had you though about the fit of this analogy to the conceptual problem facing the class or was it that you just like that analogy?]

T. xxxxxxxxxxxx

A. Was the analogy about .... a spontaneous idea or one you'd used before?

[Do you think about the appropriateness of an analogy before you use it or are they ad hoc. Have you considered the conceptual minefield inherent in poorly chosen analogies?]

T. xxxxxxxxxxxx

A. How did you feel the students reacted to this comparison? Do you think they felt comfortable with the analogy - what I mean is, do you think they had a good idea of how .... worked?

[Do teachers examine the relevance of their "wonderful" analogy to the students' world of experiences? E.g. beehive analogy for equilibrium]

A. When you decide to use an analogy and you start to tell the students about it, if they appear to be confused, do you stop or just continue and give them more details?

[Will the teacher drop the analogy when it is not sufficiently familiar to the students or does he 'struggle on through''?]

T. xxxxxxxxxxxx

A. Last period, you said that .... was like .... Before you used this analogy, did you weigh up the pluses and the minuses of this comparison?

[Is there a conscious attempt to evaluate an analogy before it is used? Do the potential benefits outweigh the possibilities for generating misconceptions?]

T. xxxxxxxxxxxxx

A. What were the positive links between .... and .... that you had in mind when you used this analogy?

T. xxxxxxxxxxxxx

A. Were there any false links that could have been produced in a student's mind by mentioning this analogy?

T. xxxxxxxxxxxxx

Depending upon how the teacher performed the next step, choose the relevant question.

A. Do you normally lead the class through the analogy pointing out the ideas that are true and the ideas that are false?

T. xxxxxxxxxxxxx

A. What about mentioning one or two parallels between the analogy and the target idea and getting the class to supply as many of the others as possible - I mean both the good and the bad features of the analogy?

T. xxxxxxxxxxxxx

OR

A. Do you always lead the class through a discussion of the positive and negative aspects of the analogy like you did last period?

T. xxxxxxxxxxxxx

OR

A. Do you often leave the class to work out the rest of the links between the analog and the target concept like you did last period?

T. xxxxxxxxxxxxx

A. Do you have any ideas about how we can get the best mileage out of these analogies and still protect the pupils from the misconceptions that are generated by the analogy's unshared attributes?

[Is the teacher aware that some of the class will have constructed a different meaning to his as a result of the unshared attributes being viewed as valid?]

T. xxxxxxxxxxxxx

A. Was this analogy then, in your mind, appropriate for the concept about .... that you wanted to get across to the class?

[Has the teacher rethought the appropriateness of this analogy in view of the balance between shared and unshared attribute s?]

A. Would you use that analogy again in that way for that concept? Would you want to change anything about it?

T. xxxxxxxxxxxxx

A. Is there anything you would like to add to this?

T. xxxxxxxxxxxxx

Appendix 3

An example of a post-lesson teacher interview.

Mrs Kay POST-LESSON INTERVIEW
Year 8 HEAT - Period 2, 23/07/92

I. Thanks very much .... for doing the dominoes analogy. I was just wondering when you went into it, could you recall the model for the use of the analogy?

T. I had a quick look at it before I came down and I'd had a quick look at it because I had written it down but I hadn't really looked at it last night which I probably should have. I should have talked about the shared attributes which I didn't really do ... did I ... I should have talked about shared and unshared attributes.

I. I noticed you didn't mention anything about the unshared, I think the shared ones came out

T. Came through ... yes ... what should I have said about the unshared attributes ...

I. The ones I jotted down ... probably the fact that the particles we're dealing with are not the same size, the number, and possibly the speed with which they move ..

T. Yes ... yes .. the speed ...

I. So you find that the model is something you'd need to use a number of times before you became familiar with it?

T. Probably, yes ... yes ... but I should have looked at it more closely .. I've had a rather busy time lately ... yea, I probably could have talked about the unshared attributes a bit more.

I. I'm interested because so often you can't plan a perfect lesson.

T. Mmm.

I. You came from chemistry here

T. That's right ... it would have been nice to have set it up properly but there is a class in here before ... before school and I thought I might set it up then but there was a class here then so ... I was in another room so .. it makes it very difficult really to actually set it up ... you're setting it up as the girls arrive so ...

I. Coming back to the six points, would you feel you'd need to become much more familiar with them?

T. Probably ... yes

I. So they become an automatic thing?

T. Yes. I suppose, yes, you don't do it often enough ...

I. We're talking about this as a model that ultimately, teachers can use. Do you think the model is a bit complex?

T. Possibly, I thought today the kids probably got the idea by seeing that without getting any more complex? I thought we ... you know, we've talked about ... well ... I probably should have said the particles are obviously a lot smaller ... we have talked about that before ... talked about the structure of the atom, and the structure of matter. I think they're probably, you know, know they're smaller but probably I should have said, you know, obviously the particles aren't this size. But I still think they probably got the general idea from that, don't you?

I. Mm ... yea ... there is a bit of debate around that with simple analogies where, an analogy is short and sharp, whether it is valid to just leave it as it is and with more detailed analogy to go into the shared and unshared ...

T. I think that was probably my instinct today, that it was a short sharp analogy ... I wasn't too worried.

I. There is maybe no minefield there, not like with the light ... they came up with six unshared attributes which showed that they obviously had things that they were concerned about ..

T. Yes ... but with this one ... you will probably find that most of these will have got the idea from seeing it, don't you? It's probably not a terribly difficult concept really ... and I think that from seeing that most would get the idea. ... I don't know, it's my feeling ... probably the size I could have said that atoms are not as big as ...

I. It would be curious to see whether their apparent understanding was ... because they seemed to be with you.

T. Yes ... the year 10s did didn't they that lesson ... ask them questions today and you never know what they might have thought ... This lot did seem certain ... they're quite a bright little class really ... they did seem to be with it but, as i said I thought the year 10s, I thought it had gone down real well with the year 10s but the next day they were saying ...

I. But when they filled in that work sheet,

T. They weren't too bad?

I. The majority ... I gave them four shared attribute spaces and four unshared and half the class filled in most of the space .. and when i interviewed them They were very clear ... so I didn't give you the feedback on that only because it was right at the end of the term and I transcribed it over the holidays ... but I'll let you have a look at the transcripts, you might be very surprised how much actually stuck with the girls I actually talked too. I was very pleasantly surprised.

T. Oh, that's good ...

I. No, I know I didn't do the unshared attributes, but to me it seemed a quick little thing, that it wasn't really worth it? This little improvisation with the dominoes, how did you come to that, I'm curious about that.

T. I thought I'd better make it a little more interesting if all these people are coming to watch me (laughter).
I thought, you know, it isn't all that interesting, but when the idea came and you said you'd bring some dominoes, Richard had dominoes anyway, so I said, right give me the dominoes so I'd do both at once, that's how it came ... you get these ideas .. it was a spur of the moment idea .. that is why it wasn't really worked out properly. I think it was a quite good idea anyway.

I. It was too

T. Have you seen that before?

I. No, I've never seen it

T. You've learnt something

I. Yes. One of the students did mention the difference in number ..

T. She did, that ... it got that point across

I. Did I miss that one?

T. I said did the electrons travel more quickly or not and she said well you'd really need to have more of them to really say wouldn't you? Which was good ...

I. You mentioned the space ... they were spaced well and one of the students said and if you had the right number?

T. That's right ...

I. There is actually a huge number ..

T. Huge number

I. Well that would probably be in your unshared attribute list

T. We sort of mentioned that ... or one of the girls mentioned it.

I. That would probably be the place to go to the unshared attributes ...

T. Yes ... we'd need a lot of dominoes, very close together ... an awful lot of them and they would go quickly while the books were going slowly ... it is one that is probably worth thinking out, you know because ...

I. Well we can write this up and attribute it to you.

T. Well it wasn't a bad one at all.

Appendix 4

Examples of the worksheets that the students filled in at the commencement of the following lesson.

Year 10 Light Name: _____________

This is not a test.

During Friday's science lesson an analogy was used to help describe light waves. The analogy was

"In some ways, light waves are like water waves"

I would like you to think about the ways that light waves might be like water waves. Please try to complete this simple matching exercise. The first column has the water wave feature and in the second column the light wave characteristic that matches it. Try to complete the first two pairs and then see if there are any other pairs for the following pairs of spaces.

Ideas that are correct matches

	1. Water waves	**2. Light waves**
1.	______________	light waves carry energy
2.	water waves can be reflected	______________
3.	______________	______________
4.	______________	______________

Ideas that are not correct matches

1.	You can see water waves	______________
2.	______________	Light waves do not need a medium
3.	______________	______________
4.	______________	______________

Is there anything else you would like to tell me about this analogy and the way it was used?

____

____

____

Year 8 Heat Name: ____________

This is not a test.

During Tuesday's science lesson an analogy was used to help describe light waves. The analogy was

"Conduction of heat occurs because electrons and atoms vibrate and bump into the one next to them."

I would like you to think about the ways that the conduction of heat is like a line of books or dominoes falling over and hitting the one next to it.. Please try to complete this simple matching exercise. The first column has the book/domino feature and in the second column the heat characteristic that matches it. Try to complete the first two pairs and then see if there are any other pairs for the following pairs of spaces.

Ideas that are correct matches

	Books or dominoes		Conduction of heat
1.	Each book in the line	is like	____________
2.	____________	is like	the mobile electrons in a metal
3.	____________	is like	____________
4.	____________	is like	____________

Ideas that are not correct matches

1.	____________	are like	atoms and molecules in size.
2.	The speed of the dominoes	is like	____________
3.	____________	is like	____________
4.	____________	is like	____________

Is there anything else you would like to tell me about this analogy and the way it was used?

____

____

____

Year 10 Light Name: ____________

<u>This is not a test.</u>

During Friday's science lesson an <u>analogy</u> was used to help describe light waves. The analogy was

> **"Light is refracted (bent) when it travels from one transparent medium to another because it changes speed just like the wheels slowed down when they went from paper to carpet"**

I would like you to think about the ways that refraction of light is like a pair of wheels rolling from smooth paper onto rough carpet. Please try to complete this simple matching exercise. The first column has the pair of wheels feature and in the second column the refraction characteristic that matches it. Try to complete the first two pairs and then see if there are any other pairs for the following pairs of spaces.

Ideas that are correct matches

	Pair of wheels		**Refraction of light**
1.	each wheel in the pair	is like	____________________
2.	____________________	is like	the piece of carpet
3.	____________________	is like	____________________
4.	____________________	is like	____________________

Ideas that are <u>not</u> correct matches

1.	____________________	is like	rays of light being joined
2.	Friction slows the wheels	is like	____________________
3.	____________________	is like	____________________
4.	____________________	is like	____________________

Is there anything else you would like to tell me about this analogy and the way it was used?

____

____

____

Appendix 5

An example of a post-lesson student interview.

Mrs Kay's Class Year 10 LIGHT STUDENT INTERVIEWS
Wednesday Period 5 29/07/92

I. Thanks Jane for talking to me about yesterday's lesson. Mrs Kay said that light is refracted or bent when it travels from one transparent medium to another because it changes its speed. This was just like a pair of wheels rolling from smooth paper onto rough carpet. What did you think of that idea.

S. Well I thought that was a really good idea, you know, it was kind of like a really good example, how they were the same and how that when the carpet slowed down the wheel as perspex slowed down the light because of the medium it was travelling in, and how the medium was different.

I. You found that quite interesting?

S. yes.

I. Does a ray of light always change its direction when it passes from one

S. I think, I think if the density of the medium was different, then I think that the light would bend as it slows down through, because the dense medium makes the light harder to ... slows down the light as it is harder to get through the medium.

I. Alright, why does it actually bend then, you said it slows down, what actually causes the light to bend.

S. Well because one side of the light, as shown in the wheel example, one side of the light slows down so the other one is travelling at the same speed and is faster so one side is still travelling as fast as, you know, when it hits the medium, but um, the slower medium and so when one side - it's like a car spinning - when one side slows down the travels as fast, it kind of goes around in a circle, and so it bends until both um, both sides of the ray um travel at the same speed and then it starts going parallel again, because one side of the wheel, see this this one slows down and the other one goes faster, so, it obviously bends because they're travelling at different speeds.

I. Does it bend every circumstance where light goes from one medium to another and changes speed?

S. Well I think it would if ... if the density of the medium it is going through was denser, obviously, it will slow down because the light would find it harder to get through and so it slows down and ... no it doesn't if the light ray was on a normal because if they hit the medium at the same time, but if it was travelling coming towards the ... towards the other medium at an angle so the one ray would hit the medium first and then the other and so bends. It was travelling perpendicular, then it wouldn't bend.

I. What actually makes the ray of light slow down when it goes from air to glass?

S. Because, um, because i guess, if the medium was denser, then it would just be harder to get through like in the example where the wheel was travelling from paper which is a smooth surface to the carpet which is rough kind of more close together, kind of and so it would be hard to get through to from a smooth surface to ... or in the instance of light from a air to a denser substance or carpet, so it slows down.

I. Was there anything from the wheel analogy that suggested to you why the light actually slows down?

S. Um ...

I. The word friction was used ...

S. Yea, um friction, well in the wheels, friction slows it down because when one object hits another object and the other object is trying to move ... it's like when you try and move an object onto another object, there's a force because this object's not moving and the other one is moving so the force kind of, it's like snooker where you hit it with, and something slows it down after a while because of the friction of the moving object on the surface and it slows down - if it's rougher, then smooth then the friction will slow it down, but I don't think there was any friction in air , no, that's an assertion, but I don't think it slows down like friction slows down the wheel.

I. It's an interesting idea but you don't think friction is right?

S. Yea.

I. The two wheels were joined together. That's why they bent. Are the light rays in a beam joined together?

S. No. No.

I. You're quite happy about that?

S. Yep.

I. You can see how the analogy needs to have the wheels joined together?

S. Yea, yea, because if one wheel, there would obviously just be one, so it bends at the same time.

I. When light passes from a less dense to a more dense medium, which way will it bend?

S. Well, um, if it ... it would bend towards the normal, if it was travelling at an angle like this, um, it would bend, it would bend, see if the - it would bend towards the normal, because the bottom ray which hits the denser medium first would slow down and therefore the um, other ray, the other wheel would um, still go as fast as when they were travelling through the paper so it would go as fast and it would bend towards the normal and if it was going the other way, that would slow down first as well and it will always bend towards the normal.

I. Did the wheels help you on that idea.

S. Yea ... it showed me because it was pretty hard like you couldn't actually see um the two parts of the ... the two edges of the light because it was like one ray, there was two wheels joined together it was really easy to see.

I. When light passes from a dense to a less dense medium, which way will it bend?

S. Away from the normal because um it is the same idea but the other one comes out from the denser medium first so it goes faster before the other one catches up, and then it goes on parallel to the other side.

I. Did the fact that the two wheels were much wider than the ray of light affect your thinking?

S. No. No. I don't think that would really matter if I think the wheels were skinny and there were two wheels joined by an axle, it would still go the same.
I. Is there anything else about this example that you maybe found useful or confusing? Did you appreciate Mrs Kay using an example to show this idea?
S. Yea because it helped me understand it easier because with just one ray of light, it would be very hard to see why it bent, but when it was, um, with two wheels it was easier to see why it bent, you could easily imagine it easier - if you had everyday examples to kind of help you with it.
I. Well thank you very much Jane.

Appendix 6

Year 10 Light objectives.

LIGHT YEAR 10 1992

TEXT: MAKING SENSE OF SCIENCE - PHYSICS

1. Understand that light forms part of the electro-magnetic spectrum and that all electromagnetic waves travel at $3X\ 10^8 m/s$ in a vacuum (p.95,96).
2. Describe the importance of light carrying energy (p.97).
3. Describe the various sources of light (p.98).
4. Describe the terms luminous and non-luminous giving examples (p.99).
5. Explain how luminous and non-luminous objects are seen (p.99).
6. Understand that light travels in straight lines (p.100).
7. Describe the terms ray, beam, parallel, converging and diverging rays.
8. Describe the terms opaque, translucent and transparent and give examples (p.100).
9. Explain the formation of sharp-edged and fuzzy edged shadows: (p 101) and use the words umbra and penumbra in the correct context.
10. Apply the principles involved in the formation of shadows to shadows in astronomy (p 101, 102).
11. Understand how a pinhole camera forms an inverted real image and the effect of changing object distance or using many pinholes (p.103).
12. Recognise white light as a combination of light of all visible frequencies (p.120).
13. Describe how colour filters work and how light from them can be mixed (p 121).
14. Describe how coloured objects are seen by reflection (p 121) and the mixing of coloured pigments.
15. Explain why the sky is blue and sunsets are red (p 121-2).
16. State the laws of reflection (p.106).
17. Illustrate, by means of a ray diagram, how an image is formed by a plane mirror and describe the image in terms of position and type (p.105).
18. Describe some uses of reflection (p.106).
19. Draw a ray diagram to show what happens when rays parallel to the principal axis are reflected by concave and convex mirrors (p.107-8).
20. Define the terms principal focus, focal length, centre of curvature, radius of curvature, pole, real image, virtual image (p.107-8).
21. Construct ray diagrams to show the position, size and nature of the image formed by concave and convex mirrors. (p. 107-8)

22. Describe an easy method to find the focal length of a concave mirror (p.107).

23. Describe uses of concave and convex mirrors (p.108).

24. Draw ray diagrams to show what happens when light enters glass along a normal or obliquely to a normal (p.109).

25. Understand what causes light to bend when it enters a medium of differing density (p.109).

26. Recognise and explain examples of refraction of light.

27. Describe the dispersion of white light to form a spectrum (p 120).

28. Draw ray diagrams to show what happens when light enters a rectangular glass block, and a prism (p.110).

29. Describe total internal reflection (draw ray diagrams) and the conditions necessary for it to occur (p.111).

30. Describe how total internal reflection in prisms can be used in periscopes, vehicle reflectors.

31. Describe how optical fibres carry images (p.111) and the uses to which these fibres are put.