Science and Mathematics Education Centre

TEXTBOOK AUTHORS', TEACHERS' AND STUDENTS' USE OF ANALOGIES IN THE TEACHING AND LEARNING OF SENIOR HIGH SCHOOL CHEMISTRY

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ABSTRACT

This thesis reports a series of studies into textbook authors', teachers' and students' use of analogies to improve students' understanding of abstract chemistry concepts. The five research problems considered: (a) the nature and extent of analogy use in textbooks; (b) the views of textbook authors and editors concerning analogies; (c) how, when, and why analogies were used by experienced chemistry teachers; (d) the development of an instrument to determine chemistry students' understanding of analogies; and (e) how chemistry students use the analogies presented as part of their chemistry instruction.

Study One reports the findings of an investigation of ten chemistry textbooks used by Australian students for the nature and extent of analogy inclusion. The study found that, while used sparingly, analogies were employed more frequently in the beginning of textbooks and that the analogies used concrete analog domains to describe abstract target concepts. There was considerable use of pictorial-verbal analogies although simple analogies comprised a substantial proportion and stated limitations or warnings were infrequently employed.

Study Two involved interviews with the authors of eight of the above mentioned textbooks to determine authors' views on analogies and their use in textbooks and teaching. The study identified a relationship between how frequently analogies were used by the author and what he or she considered to be the characteristics of a good chemistry teacher. Each author had a good understanding of the nature of analogy and each sought a flexible environment for its use – most arguing that analogies are better used by teachers than printed in textbooks. They appeared to favour analogies embedded in text or placed in margins rather than as post-synthesisers or advance organisers.

Study Three reports an investigation into six chemistry teachers' use of analogies in Western Australia and England. This study found that the teachers drew upon their experiences and professional reading as sources of the analogies that tended to be spontaneously used when they felt their students had not understood an explanation. The analogies tended to map functional attributes of abstract target concepts with some teachers using the blackboard to illustrate pictorial analogies and some including statements of limitations.

Study Four describes the development of analogy maps – instruments used to determine the effectiveness with which students map given analogies. The iterative development process engaged classroom-based research methods to develop an instrument of value both for teaching and for school-related research. A rating system enables researchers to compare students' effectiveness at mapping analogies with variables such as analogy type.

Studies Five and Six describe how a combination of interviews and analogy map surveys were used to investigate how students used analogies in chemistry. The study found that students felt more confident with pictorial-verbal analogies although they were not necessarily able to map these analogies better than verbal (only) analogies. Also, student mapping confidence appeared not to depend upon the level of enrichment supplied and added enrichment did not necessarily aid mapping performance. Further, the analogy maps were useful as a means to identify alternative conceptions and there was little evidence that the analogy maps contributed to the formation of alternative conceptions in the learners.

The final chapter draws together and discusses the assertions made in all of the previous studies before considering the contribution of the thesis to theory building. The implications of the research are discussed and suggestions made for future research on analogies in chemistry education. The chapter concludes by outlining examples of how and where the findings of this research have begun to be disseminated.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

BACKGROUND TO THE STUDY

Overview

This chapter introduces a study into textbook authors', teachers' and students' use of analogies in the teaching and learning of senior high school chemistry. It begins by describing the framework within which this research is set and goes on to discuss the nature of analogy as a pedagogical tool. Following this introduction, the research problems are stated and a rationale provided for the study, clearly setting this thesis within the realm of international research that has been steadily developing since the middle of the 1980s.

The significance of this study is outlined in this chapter and then the research problems are broken down into a series of research questions that provide a framework for the structuring of this research into five phases. This thesis contains a series of studies, which, although being informed by each other, stand as research studies in their own right. Each of these smaller studies addresses one of the research problems and each is guided by the research questions developed from the research problems. The chapter concludes with a discussion of the limitations of the study and the research problems.

Introduction

Since the middle of the 1980s, considerable research has been conducted in science education seeking to address Shulman's missing paradigm of teachers' content knowledge (Shulman, 1986). Investigations of how teachers transform their subject matter knowledge into pedagogical content knowledge has allowed for a more careful analysis of effective teaching approaches and strategies. Shulman proposed that the emphasis of research in education should change towards addressing questions about "the *content* of the lessons taught, the questions asked, and the explanations offered. . . . the sources of the analogies, metaphors, examples, demonstrations, and rephrasings" (p. 8). The use of analogies as an aid to instruction is proving to be one of several specific foci within the broader aspects of pedagogical content knowledge that are currently being addressed in educational research.

In recent years, studies have shown that analogies can be useful in teaching abstract concepts such as those found in senior chemistry (Friedel, Gabel, & Samuel, 1990; Gabel & Sherwood, 1980). Much of this research involved empirical investigations focusing on performance changes in knowledge tests of written chemistry or science problems following analogically-inclusive instruction (see, for example, Brown & Clement, 1989; Harrison & Treagust, 1993; Webb, 1985). Several of the above studies, however, have reported difficulties encountered by students; difficulties related to the tenuous assumption that students have a high familiarity with the analog domain used and that they are able to effectively make the cognitive transference to the target domain.

In addition to those studies solely in the field of school science instruction, some broader science education studies have focussed on the frequency and nature of analogy examples found in textbook materials used by students (Curtis & Reigeluth, 1984; Glynn, Britton, Semrud-Clikeman, & Muth, 1989). While these studies have identified many different modes of operation of written analogies, little has been reported regarding the relative usefulness of the different analogy types in enhancing the teaching-learning process. Indeed, concern is held by chemical educators (Gabel, Sherwood, & Enochs, 1984) that many students approach learning and problem solving in chemistry by relying upon rote or algorithmic methods. These students, although lacking an understanding of the underlying concepts comprising chemistry, still attain a reasonable measure of success in conventional classroom tests and examinations and often are considered to have made satisfactory progress.

If chemistry students are to attain a more meaningful chemical education, then there is a need for a heightened conceptual understanding rather than an improvement of rote or algorithmic methods. Hence, teaching tools such as analogies, that may promote better understanding of chemical concepts, need to be refined and made available for use by chemical educators and chemistry textbook authors along with the skills and strategies for their efficient use.

Analogy Defined

Common reference to analogies is found in recent literature and textual materials. These references often are used interchangeably with other terms such as metaphors, similes, illustrations, models, and examples. Arber (1964) considered that the variety of use attributed to the term analogy has resulted in it becoming a "tempting word for each man [*sic*] to define in his own way" (p. 36). The word *analogy* has its roots from the Greek in the mathematical equality of relations and proportion. Clearly, analogy comprises two separate domains and the comparison and apparent likenesses between these domains. Analogous relationships in mathematics (Miller, 1979) can be expressed in the manner thus: A : B :: C : D . For example 4:16::3:_ where the relationship between A and B gives some indication to the solution of D, given C. In a literary setting, an analogous relationship may be expressed as follows:

Einstein : Relativity :: Darwin : ____.

Educational researchers writing on the topic of analogies have provided several definitions of analogy from various perspectives. Most focus upon the comparison of the similar attributes or features of these two domains. For example, Glynn et al. (1989) consider analogy as "a correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas" (p. 383).

Other authors consider also the accuracy of the transference process between the two domains by referring to analogy as "a mapping of knowledge from one domain (the base) into another (the target) which conveys that a system of relations that holds among the base objects also holds among the target objects" (Gentner, 1988, p. 64). Some other discussions value more the transference process without an analysis of the structures or processes per se. One example of this might be taken from Keane's (1987) work in which it is reported that "an analogy can be said to involve the understanding of an unfamiliar *target domain* in terms of a familiar *base domain*" (p.

67). For the purpose of this thesis, the definition above by Glynn et al. (1989) has been considered central to the construction of shared meaning of analogy. The analogy requires the selection of a student world *analog* (base or vehicle) to assist in the explanation of the content-specific *target* (or topic). The use of these specific terms varies among researchers. For the purpose of this thesis, the two italicised terms will be used exclusively.

Glynn et al. (1989) often have recognised that there must be some key identifiable concept linking the analog to the target. They refer to it as the super-ordinate concept and illustrate the relationship pictorially as in Figure 1-1.

Superordinate concept, principle, or formula

Analog Attributes		**Target** Attributes
1	. . . . .compared with.	1
2	. . . . .compared with.	2
3	. . . . .compared with.	3
n	. . . . .compared with.	n

Figure 1-1. The relationship between the analog and the target concept. (Adapted from Glynn et al., 1989, p. 384.) Note: The researcher has used the term "attributes" where Glynn et al. use "features".

An analog, used to assist in the development of a target, has associated with it many attributes, some of which are comparable to the target concept. In the process known as *mapping*, these analog attributes (features or characteristics) are actively compared or transferred to the target. It should be noted that there are many attributes of the analog that are not mappable to the target concept. This issue is discussed in more detail in Chapter 2 (Constraints of Analogy Use).

Research Problems

The purpose of this study was to investigate how textbook authors, teachers and students use analogies to improve understanding of abstract chemistry concepts. The study identifies the setting and types of analogies most used by textbook authors and teachers and examines ways of determining students' mapping ability of common textbook analogies. The findings of the study have been used to inform a series of in-service training sessions for teachers and teacher educators; a basic tenet of these workshops is that systematic incorporation of analogical material can improve students' conceptual understanding. This thesis is substantially different from most studies in the field, however, as it addresses the topic of analogy use by the teacher – and, to a lesser extent, the student also – in predominantly natural settings of classroom activity. It considers analogy use from a variety of perspectives including school textbooks and teachers' explanations, and it describes how learners may use analogies to aid their own conceptual understanding. The study provides recommendations for practicing teachers, teacher educators, and textbook authors concerning the appropriate and efficient use of analogically-inclusive instruction in chemical education, with particular emphasis at the senior secondary level.

The broad purpose of this study described above is summarised by the following five research problems:

1. What was the nature and extent of the use of analogies in textbooks used by senior secondary chemistry students in Australia?
2. What were the views of textbook authors and editors concerning analogies and their use in textbooks for secondary chemistry students?
3. How, when, and why were analogies used by experienced chemistry teachers in normal classroom instruction for secondary students?
4. How might an instrument be developed to determine chemistry students' understanding of analogies that they encounter during instruction?
5. How did chemistry students use the analogies presented to them in textual information and what types of analogies did students of different abilities find easiest to understand?

Rationale

Research into the use of analogies to improve students' performance in science has produced results that lack agreement; some studies have found significant gains in student performance, while others have found no significant changes (Friedel et al., 1990). Some research has shown that analogies preferentially aided students who function at the formal operational level while other studies have found that these students did not gain as much as those students who are functioning at the concrete level (see Gabel & Samuel, 1986, for a useful overview). There is a need for further work to determine the relationships that exist between learner characteristics and analogical learning ability (Curtis & Reigeluth, 1984).

Most of the studies that have been conducted in this field have made use of instruments involving pencil and paper tests to assess student recall (Curtis & Reigeluth, 1983) rather than attempting to measure whether the students were really engaging analogical transfer processes to understand concepts or solve problems. It is still to be properly determined whether concrete operational students are capable of taking a familiar situation and applying it to a new situation in chemistry – the operation required to effect analogical transfer. Alternatively, this limitation could arrive out of differing perspectives of the analog-target relationship. Teachers mentally process attribute information about the target and transfer it to a constructed analog during explanation. Students, however, receive the analog and must transfer its attributes to construct a new target concept; the reverse procedure. Brown and Clement (1989) suggest that it is often assumed, perhaps incorrectly, that students make, or are helped to make, the correct correspondences between the analog and the target.

Attempts to identify, analyse, classify, and quantify analogies presented to students in chemistry instruction have produced only limited evidence of the effective use of analogies in both spoken and written instruction (Curtis & Reigeluth, 1984; Leatherdale, 1974; Treagust, Duit, Joslin, & Lindauer, 1992). Reasons given for these findings have included the teachers' poor repertoire of effective analogies, an awareness that the disadvantages of using analogies might outweigh the advantages on occasions, and a lengthening of the time required for instruction when incorporating analogies in teaching (Simons, 1984; Treagust et al., 1992; Webb, 1985). Although the ways in which analogies are most successfully used in normal classroom instruction has yet to be thoroughly investigated, Treagust et al. (1992) argue that the teacher's perspective of how students learn and how they should be taught may preclude the frequent use of analogies because:

> [r]ather than taking into account students' preconceptions, for example, lessons are often introduced by definitions and illustrating examples, which might be termed the traditional way of teaching. In this style of teaching, there is little opportunity to involve the students in constructing their knowledge of a concept in terms of a familiar analogue. (p. 421)

Glynn et al. (1989) encourage research of a qualitative nature into teacher-student-textbook interactions involving analogies. The use of analogies in the normal classroom setting is expected to be dependent upon a range of factors such as teacher experience, attitude, and knowledge; teacher-student relationships and interactions; students' ability, population, and background; and the content or curriculum under study at a given time. As there is a lack of research indicating the effects of these, and other, factors it is necessary to begin with careful observation and interview methods that describe some of the effects of these factors on analogy usage.

Recent research in science education has produced various models for the use of analogies both in the classroom and in textbooks. These models include the Teaching-With-Analogies model (Glynn, 1989, 1991), designed for use by authors of textbooks and also transferable to the classroom setting for teachers, and the General Model of Analogy Teaching (Zeitoun, 1984) for verbal classroom instruction. Principally, these models involve steps to guide instructors through important phases of the analogy process. There still is need for further research, however, indicating the extent to which examples of analogies found in science textbooks align with these research models for analogy inclusion (Glynn, 1989). Studies have yet to address why textbook authors use or avoid certain analogies and not others and why analogies are used in the way they are. It would seem appropriate that dialogue take place to determine the views of these writers. In addition, there is a lack of research that adequately validates the above models from the perspective of student learning.

The literature reports various different types and settings of analogies that can be used in instruction. Curtis and Reigeluth (1984) examined 26 science textbooks and classified the 216 analogies identified according to different criteria that they assembled based on instructional design characteristics. In a later study, Curtis (1988) suggested that there was a need to determine the structure of analogies that function most effectively for science students (see also Shapiro, 1985).

In the field of chemical education, empirical studies (Friedel et al., 1990; Gabel & Sherwood, 1980, 1983) have shown that analogies are sometimes useful in instruction to improve chemistry problem solving skills. Despite some use of control procedures, however, many of these studies were hindered by the high proportion of students who were unable to satisfactorily understand the analog or to successfully effect the analogical transfer from the analog to the target domain. One way in which these inadequacies may be addressed is to use an interpretive observation and interview design rather than experimental design as students' background familiarity with the analogs are not likely to be constant across different content areas. Research is yet to address the question of whether there are suitable analogies applicable to chemistry that the majority of students can understand (Gabel & Sherwood, 1980) and when analogies are most helpful, or most confusing, to the learner (Curtis & Reigeluth, 1984; Glynn, 1989).

Significance

The research described in this thesis has significance in three areas, namely curriculum and textbook design, teachers' beliefs and behaviour, and science education research directions. While the research is part of the growing international interest in analogical reasoning relating to science education, it is one of the few pieces of qualitative research to date that principally describes how analogies are used by textbook authors, teachers, and students, rather than testing the outcomes of quantitative measures. While both types of studies are required, this type of research permits new directions to be opened in research in analogically-inclusive instruction and alternative representations. The wide field of observation that is reported in this study allows for a better understanding of the extraneous variables that have hindered the efforts of quantitative research conducted previously and acts as a guide which may allow future research to be more successful.

The study encourages textbook and curriculum writers to present chemistry materials in a manner that aids conceptual understanding rather than facilitating further reliance upon algorithmic processes. This study provides guidelines to textbook authors on how to structure and present analogies so that they can be better understood and used by chemistry students.

The influence of the study upon teaching practice could be considerable. Most teachers personally experience the apparently random success and failure of analogy when teaching. Hence, many have a high level of curiosity about analogy use and are interested in the development or maintenance of a working repertoire of analogies. With the findings of this research, teachers are challenged to examine more carefully aspects of the learner including: (a) conceptual ability, (b) prior chemistry knowledge and background experiences, (c) naive scientific conceptions brought to chemistry, and (d) students' familiarity with the analogs used by teachers. In addition, teachers have been provided with strategies that will assist them to educate their students in methods of analogical reasoning.

Several other outcomes of this research make useful contributions to science education research. Firstly, a framework has been prepared for the classification of analogies in both written and spoken instruction which may be used by future researchers to examine analogy usage across content areas other than chemistry. Publication of this framework as a research instrument also will assist the unification of the language related to analogies in science education over which there is considerable disagreement (see, for example, Thagard, 1992; Dagher, Thiele, Treagust, & Duit, 1993). Secondly, as analogy researchers in science education turn their attention to understanding better how students make sense of analogies and how knowledge construction occurs with analogically-inclusive instruction, the use of an instrument to probe students' analogy related conceptions is required. The development of an instrument fulfilling the aims of Research Problem 4 above could make a considerable contribution in this respect.

Phases of the Study and Research Questions Addressed

This study comprised five phases, each of which examined one of the five research problems which are restated below as study headings. Chapters 3 through 7 each describe a phase of the thesis study. Specific research questions relevant to each of the phases have been presented below:

Phase 1: An Examination of the Nature and Extent of the Use of Analogies in Chemistry Textbooks Currently Used by Secondary Students in Australia.

This phase of the thesis involved a refocussing of a previous study (Curtis & Reigeluth, 1984) in which 27 science textbooks, including four chemistry textbooks, were examined for analogy inclusion. In that study, identified analogies were compared and contrasted with respect to their features and a classification model was constructed based upon these analogies. The classification criteria were developed within the context of instructional design characteristics. For this present study, the Curtis and Reigeluth classification system was expanded to better reflect both the recommendations of recent research on analogy use in science education and to allow analogy types that were not readily classified in the previous research system to be included in this new classification. Subsequently, chemistry textbooks currently used by Australian chemistry students were examined for examples of analogies and each example was collected and analysed using the modified classification framework. Also, analysis was made of the frequency with which different types of analogies occurred in different content areas and different sections of the textbooks. This phase of the study is reported in Chapter 3 and addresses the following specific research questions:

1-1. How frequently are analogies included?

1-2. Are analogies used more frequently (a) for particular content areas or (b) at different stages of the textbook?

1-3. What structures and types of analogies are frequently used?

1-4. Which analogical instructional strategies have the textbook authors used?

Phase 2: An Analysis of the Views of Textbook Authors Concerning the Use of Analogies in Secondary Chemical Education.

In this phase of the study, authors of the chemistry textbooks used in Phase One of this study are interviewed to determine their views on analogy and its use in textbooks and teaching. In some instances, several interactions were required with authors to maximise data collection. Each interview was tape-recorded and verbatim transcripts produced. During each interview, examples of analogies found in the author's own textbook were used to focus the discussion and to assist in the agreement of terms used by the researcher and interviewee. The specific research questions that were addressed in this second phase of the study (see Chapter 4) are as follows:

2-1. Are authors' views about analogy related to a particular view of learning, instruction or set of educational experiences?

2-2. (a) What are the views currently held by textbook authors concerning analogy and analogy use, and (b) what reasons are provided for inclusion or exclusion of analogies in instructional materials?

2-3. What personal preferences are held for analogies in different positions such as advance organiser, embedded activator, post-synthesiser and marginalised?

2-4. What personal appeal is there for a model to promote a structured mapping approach to analogy inclusion in textbooks and teaching such as the Teaching-With-Analogies model (Glynn, 1991)?

2-5. What changes would the author make to a later edition of his or her own textbook if provided with a more thorough repertoire of trialled analogies?

Phase 3: An Interpretive Examination of Six Teachers' Use of Analogy During Secondary Chemistry Lessons in Two Countries.

This part of the study follows work carried out by Treagust (Treagust, Duit, Lindauer, & Joslin, 1990; Treagust et al., 1992) to bring a specific focus upon chemical education at the senior secondary school level. The researcher used case study research methods and adopted an interpretive analysis method (Erickson, 1986) to observe and tape-record instructions given in the chemistry classes of six chemistry teachers – four in Australia and two in England. These chemistry teachers were chosen as a result of their experience in teaching senior chemistry students and their locations adjacent to the two research centres (Perth in Australia and York in England). Both spoken and written curricula presented by the teachers were examined for examples of analogy usage. Following a sequence of observed lessons, several private, tape-recorded interviews were conducted with each of the teachers. Each interview involved the examination of several analogies used by that teacher in his or her normal classroom instruction. These analogies were used to focus discussion and this reduced the risk of misunderstandings when relating theoretical and technical aspects of analogy use and structure to classroom practice. Principally, the findings of this study reported in Chapter 5 of the thesis were obtained from the lesson observations and interviews. Initially, the following nine research questions were addressed in this phase of the study:

3-1. Why do teachers choose to use analogies for a given concept?

3-2. Do teachers use variations in their normal teaching styles or approach when using analogies?

3-3. Do teachers use any aids to assist in analogical transfer of analog familiarity for students?

3-4. Do teachers believe that students find difficulty when using the analogies provided for them by the teacher?

3-5. What type of analogies do teachers use most frequently in their explanations?

3-6. Were the analogies used by teachers related to, or similar to, analogy examples found in students' textbook materials?

3-7. Were the analogies planned or were they spontaneously presented? If they were spontaneous, were they generated at the time or mentally retrieved from prior experiences?

3-8. When teachers used analogies in the classroom, was there evidence that they attempted to take students' prior knowledge into account?

The data collected from this study were reassembled as four emergent research questions:

E3-1. Why did the teachers choose to use analogies when teaching chemistry?

E3-2. What evidence was there of the planning or spontaneity of analogy use?

E3-3. How did the characteristics of the analogies vary from teacher to teacher and from the textbook analogies available?

E3-4. How did the teachers choose to present their analogies to their classes?

Phase 4: The Development of an Instrument to Measure Students' Analogy Mapping Effectiveness.

This phase describes the development of an instrument suitable for the assessment of students' use of analogies in the classroom setting near the time of instruction. The researcher deemed it important that such an instrument be designed in close association with the teaching-learning setting of the chemistry classroom and, to that end, iterative developmental trials in school settings were sought to best achieve this goal. To guide the development of the analogy mapping instrument, which is described in Chapter 6, the researcher considered that a suitable analogy mapping instrument should have the following framework:

4-1. Be able to be used by teachers in classroom settings both as an evaluative tool and as a teaching/learning device;

4-2. Characterise analogy as a process of active comparison between two separate domains;

4-3. Be flexible with respect to content matter so that transferability across the curriculum is high.

Phase 5: An Investigation into Chemistry Students' Ability to Identify Mappable Attributes in Common Analogies.

The previous phase of the study described the development of an instrument for analogy mapping designed to be used both as a research tool and as a teaching/learning device. In the two studies described in Chapter 7, the instruments, consisting of a series of "Analogy Maps", were trialled with Year 11 students in Western Australia to document the types of mappings drawn, the ease with which they were drawn by students of different abilities, and the way in which differing types of analogies influenced the students and their mapping attempts. For this final phase of the research programme, the following research questions guided the investigation:

5-1. How was the ability of students to suitably map an analogy affected by the analogy factors of (a) presentational format and (b) level of enrichment?

5-2. Was there evidence that analogy maps can assist in the identification of, and challenge to, students' alternative conceptions?

5-3. What evidence existed to show that analogies contribute to the formation of alternative conceptions?

5-4. Did students who performed better at chemistry perform better in the analogy mapping tasks?

Limitations of the Study

Several issues have been identified here as limitations of the studies in this thesis. Finding schools in which to conduct classroom-based research of this type is often difficult. Invariably, teachers who are selected or willing to be involved in these studies tend to be of the sub-group who are interested in professional development and confident in their practice. While research involving teachers such as these is valuable, caution needs to be exercised when considering the generalizability to other school systems and less professional teaching staff.

Secondly, in studies involving classroom observation, the presence of the researcher in the classrooms influences both how teachers teach and how students respond to instruction. As the researcher was an experienced chemistry teacher and a preservice science teacher educator, his presence in the classroom may have caused the teachers to be more careful in both their content use and their pedagogical approaches. As the observation schedule continued, however, the presence of the researcher should have influenced teacher and student behaviour less.

Further, within the context of data collected by classroom observation, it should be clarified that the researcher's work did not focus on student learning per se, and so he is unable to justify statements concerning the quality, or otherwise, of student learning that occurred as a result of analogies used by the teachers. While it may be determined that most analogies are spontaneously provided, the stimuli for these responses rests subtly between the teacher and student. While the researcher brings to the observation his experiences as an educator, analogy prompts related to a local knowledge of school culture and personal interests may pass undocumented.

Summary of Chapter and Structure of Thesis

This chapter has described the nature of analogy, research problems, rationale and significance for the study, and outlined how the structure of the thesis facilitates the investigation of the research problems. In the following chapter, issues relating to the structure and function of analogies are more fully discussed and the outcomes of research already done in the area of analogies in science education is described and analysed. Specifically, discussion is brought to focus on textbook analogies and teachers' and students' use of analogies. From there, the researcher builds a case for the research methods chosen for much of the study.

Chapters 3 through 7 report the five phases of the research described above. Chapter 8 provides the research overview and discusses the contribution of the thesis to theory building and the implications of the research. Suggestions for future research are provided and comments are made regarding the dissemination of the research findings.

CHAPTER 2

REVIEW OF THE LITERATURE

Overview

To address the research questions identified in the previous chapter, the researcher investigated several decades of research into the use of analogy in science and science education. Evidence of the recent growth in interest in this topic may be gleaned from the recent decision of the *Journal of Research in Science Teaching* editorial committee to publish a Special Issue on the topic of *The Role of Analogy in Science and Science Teaching* (December, 1993). While it is the case that analogies have been identified frequently within both the historical development of science and the teaching of science, for the purpose of this study the researcher principally limited the literature investigation to the use of analogy in science education rather than science per se. If teaching and learning is viewed from the perspective that students construct their knowledge in much the same way as a scientist might, however, there could be little clear delineation between these two applications.

This chapter provides both substantive and methodological frameworks for the thesis. The chapter begins with an analysis of analogy itself, considerations of its use historically in the development and functioning of science, a discussion and analysis of the different types of analogies described by literature sources, as well as a presentation of the stated advantages and constraints of using analogies in science education. This is followed by a description of what the literature reports concerning the presentation of analogies in various instructional modes. The final sections of this chapter outline literature providing guidance concerning the research methods that should be engaged to address research questions such as those outlined in Chapter 1.

The chapter concludes with a brief discussion of suitable directions for future research on analogies in science education.

The Nature of Analogy

The Historical Use of Analogies in Science

The use of analogies is well linked to science in both historical and contemporary settings. Shapiro (1985) proposed that analogies are traditionally used both in explaining science and in the processes of science. In Campbell's early (1920) treatise on physics (reported in Campbell, 1957), he proposed: "in order that a theory may be valuable it must have a secondary characteristic; it must display an analogy. The propositions of the hypothesis must be analogous to some known laws" (p. 129). Further, he suggested that the "reason why the perverse view that analogies are merely an incidental help to the discovery of theories has ever gained credence lies . . . in a false opinion as to the nature of theories" (p. 130). The ability to construct fruitful analogies between fields, Stephen J. Gould (1983) believes, is the common denominator of genius. Arber (1964) proposed that Darwin's theory of natural selection depended largely upon an analogy between the controlled breeding of domestic animals and plants, with the whole development of the organic world. The early development of electronic theory saw examples such as Maxwell's use of the analogy with hydrodynamic systems (Dupin & Johsua, 1989) and Rutherford's solar system idea of atomic structure (Gentner, 1980, 1983). Of Einstein, it has been reported (Dreistadt, 1969) that he thought "with signs and more or less clear images which he voluntarily reproduce[d] and combine[d] in a vague play aimed to be analogous to certain logical connections he [was] searching for" (p. 160).

Analogy Use in Problem Solving and Explaining

In attempting to solve problems on their own, students tend to sort through their own experiences to find some similarity to the problem at hand (Flick, 1991). Alternatively, in educational settings, analogy may be provided as part of the instruction so that transfer can take place into the problem to be solved. This was the procedure used by Holyoak, who has contributed much to the development of the underlying theory of how analogies work, in several studies that investigate the ability of students to transfer from analogous situations in different logical problems (see, for example, Gick & Holyoak, 1983; Holyoak, 1985; and Holyoak & Koh, 1987).

This perceived usefulness of analogy to students solving problems was investigated by Gabel in a series of chemistry-related studies over the last decade (Friedel, Gabel, & Samuel, 1990; Gabel & Sherwood, 1980, 1983, 1984; Gabel, Sherwood, & Enochs, 1984) with limited effect due to students' lack of familiarity with the analogs selected for the research. This was found to be a limitation despite efforts in the latter of these studies to ensure analog familiarity prior to attribute transfer.

Studies also have addressed the engagement of analogy as a tool of explanation in settings such as textbooks (Curtis & Reigeluth, 1984), tutorial modes (Nickerson, 1985), and in constructivistic teaching by approaching new content analogically through mastered content (Dupin & Johsua, 1989).

The Mental Processes of Analogy

Cognitive Assimilation

Analogies are believed to work by the evolution of new cognitive schemata (Duit, 1991). Schemata are packages of knowledge encompassing related concepts and ideas which are "sometimes related to the organisation of conceptual knowledge or to all one knows about the physical, social, or mental world" (Alexander, Schallert, & Hare, 1991, p. 333). This statement would appear to support the relationship, or comparison, of target knowledge with analogical background knowledge from the real world. This prior knowledge of analogical domains is believed to allow for the mapping of new information at an "unconscious" or "intuitive" level (Flick, 1991, p. 228). Relatively little has been determined from empirical studies, however, about the actual learning processes that are associated with analogy-assisted learning as most of the early studies measured recall of learned materials only (Shapiro, 1985).

Relation to Piagetian Stages of Cognitive Development

In a study that examined the effects of analogy treatment upon students' reading performance, Simons (1984) concluded that the effectiveness of analogy is due to its three chief functions – one of which was concretisation. Analogies have been found to be employed most often when the target has a Piagetian formal or abstract nature and the analog is at the concrete stage. The suggestion by Licata (1988) that this is because much science content is beyond the limits of our own senses is borne out well in the discipline of chemistry, for example, where there is a need to examine the submicroscopic realm in which direct sensory experience is not possible. The provision, by analogy, of extra visualisation methods is seen by researchers (Brown, 1993; Curtis & Reigeluth, 1984; Duit, 1991; Shapiro, 1985) to initiate important concrete visualisation processes in the learners' minds and hence, allow for more efficient learning.

Analogy Use and Achievement

Studies examining the effects of analogy use on achievement have produced varied results. Gabel and Sherwood (1980) researched the relationship between analogy usage and students' abstraction level and found that chemistry instruction incorporating analogies may have been effective for students demonstrating lower formal reasoning ability but not especially useful for the students with higher formal reasoning ability. Students operating at the concrete or transitional stages of development required assistance if abstract or formal cognition was to occur. Students in a study by Dreistadt (1969) improved their ability to solve problems when exposed to subtle pictorial analogies although the students "usually were not conscious that the analogy helped them or they were only vaguely conscious of how the analogies helped them" (p. 169). In physics, Bullock (1979) found no positive effect of using analogies on student understanding of specific physics concepts while other studies founded in science education (see, for example, Gilbert, 1989) generally produced similar results – the latter suggesting the possibility of some negative effects.

Training in Analogical Transfer

Reasons proposed for the lack of improvement in student achievement as a result of analogical treatments have centred around the problems that students have in effecting analogical transfer and students' unfamiliarity with the chosen analog domains. In an attempt to address the former issue, several researchers have examined ways in which students can be trained in analogical processes. Alexander, White, Haensly, and Crimmins-Jeanes (1987) found that analogical training was effective for older students and for gifted and average students. Klauer's (1989) findings that analogical transfer is domain-specific and that it does not occur spontaneously supports the need to instruct on the application of the analogical structure – especially in the matching (mapping) of constituents. Klauer further suggested that one of the difficulties for researchers and teachers in this respect is that of finding suitable analogy exemplars from which to teach.

Types of Analogy

Analogy-related literature highlights a range of types of analogies and structures for analogies. These include pictorial-verbal, personal, multiple, and bridging analogies (Curtis & Reigeluth, 1984; Duit, 1990, 1991). It also is evident that the presentation by a classroom practitioner, or textbook author, has considerable influence upon the mode of operation of an analogy. For example, some teachers and authors may invite students to formulate their own analogies, others will guide the students in the use of a presented analogy, while in other instances, the analogy requires only passive consideration by the students.

Pictorial-verbal Analogies

Given that one of the main emphases of analogy usage in chemistry education is to make abstract concepts more easily grasped by the concrete or transitional thinker, the use of a diagram or picture to present the analog is seen to be most advantageous. In pictorial analogies, some diagrammatic or photographic illustration of a real life situation represents part, or all, of the analog domain. Most pictorial analogies are accompanied by some verbal explanation and, hence, are usually referred to as pictorial-verbal analogies.

One significant advantage of using a pictorial format for the analog is that it improves the likelihood that the analog is sufficiently familiar to the learner (Duit, 1991) by illustrating those attributes that the author considers to be shared with the target domain. In addition, researchers believe that the visualisation process is very important in the learning of concepts and that the pictures prompt this process to aid understanding (Curtis, 1988; Curtis & Reigeluth, 1984; Shapiro, 1985; Zeitoun, 1984). Further, in a study that examined the effects of incorporating pictorial analogies with analogical study guides for teaching cell biology, Bean, Searles, Singer, and Cowan (1990) found that students learning under this environment obtained a greater understanding of the cell than those with the analogical study guide alone.

Personal Analogies and Anthropomorphisms

Marshall (1984) provides several personal analogies relating chemical principles to human behaviour, money, and food. These analog domains are believed to be readily accepted by students and they are also areas with which it can be confidently presumed that students are familiar; Marshall suggests that this type of approach is more enjoyable for students. Similarly, personal analogies may involve the students in a physical activity such as a role-play. In an article encouraging chemistry teachers to use analogies to help students understand difficult content, Licata (1988) draws from the analog domains of food, television, students in a class, a dance, sport, and money. It should be noted, however, that science educators and researchers caution that personal analogies may cause students to give intuitive feeling to inanimate objects and concepts (Duit, 1991; Marshall, 1984).

Multiple Analogies

As most analogs and targets have few (perhaps only one) shared attributes, it is evident that all of the attributes of the target will rarely be covered by one analog alone. Thus, it is often useful to use several analogies to cover any one particular target. One example from chemistry is the greenhouse analogy and the clothing analogy for the global warming (greenhouse) effect. While the garden greenhouse concept aptly portrays the trapping of heat energy, the attribute of increasing carbon dioxide concentration is difficult to match with this analog. A description of how body heat loss is reduced when more layers of clothing are added, however, may better map the concentration attribute.

Bridging Analogies

Bridging analogies are an attempt to overcome one of the limitations of analogies – that of the cognitive gap between the analog and the target being too "large" or complex for the students to mentally traverse. Bridging analogies present a series of small analogical steps that direct the learner towards the relationship. Brown and Clement (1989), exponents of the bridging analogy method, propose that they be used when the student is unable to accept a normal analogy relation (see also, Brown, 1994; Clement, 1993). It should not be considered a simple approach, however, as planning is needed due to the lack of suitable bridges for the analog-target gap. Indeed, in a self-critiquing footnote to his recent article, Clement (1993) acknowledges that some aspects of a chosen anchoring example used in a bridging analogy sequence produce a lack of consensus. He went on to comment that he had been unable to find a better anchoring example.

Prior Content Based Analogies

The interconnectiveness of new content knowledge with prior content knowledge makes the latter a natural source of analog material for addressing conceptual content. Researchers (Glynn et al., 1989) believe that this type of analogy is particularly effective in textbooks because "the author can be reasonably confident that the earlier concepts (which function here as analogs) are part of most readers' knowledge base. Plus, these analogies are particularly powerful because they prompt readers to connect related concepts and form conceptual systems" (p. 387). However, they caution that students may carry forward a misunderstanding of the old content (analog) into the new target content.

Advantages and Constraints of Analogy Use

Advantages of Analogy Use

Analogies are believed to help in three major ways in that they provide visualisation of abstract concepts, help compare similarities of the students' real world with the new concepts, and have a motivational function.

Visualisation Process

While the importance of the visualisation process in the understanding of chemistry has already been stated, it is especially evident that there is a need for teachers to provide visualisation aids when explaining structural attributes of submicroscopic entities such as atoms and molecules as well as functional attributes of molecular processes such as chemical equilibrium or ionic diffusion. However, in a study that engaged college chemistry students in a two week course incorporating analogically-based instruction on stoichiometry (Friedel et al., 1990), it was discovered that students with high visualisation skills were actually penalised by using analogies. It could be presumed that these students needed no further assistance in this regard and the extra involvement of the analog domain may have hindered their learning.

Pictorial-verbal analogies may help the visualisation process also and hence aid understanding. In an analysis of 216 analogies found in science textbooks for secondary students, Curtis and Reigeluth (1984) found that chemistry textbooks contained a high percentage of pictorial analogies (29%) compared to the total science average of only 16%.

Real World Linkage

The presentation of a concrete analog facilitates understanding of the abstract concept by pointing to the similarities between objects or events in the students' world and the phenomenon under discussion. Analogs are selected from a domain that is owned by, or familiar to, the students concerned – one of the reasons that Duit (1990) considered analogy use to be in agreement with constructivist perspectives on learning science. This interest in constructivism stems from an awareness that, rather

Analog Unfamiliarity

A significant constraint on the use of analogies in teaching is the possible unfamiliarity of the learner with the analog selected. Several empirical studies on the use of analogies in chemistry instruction have been hindered by this problem. For example, Gabel and Sherwood (1980) found that a significant proportion of students sampled in their study did not understand the analog which clearly shows the need for caution in teaching with this method. In addressing this problem, both Curtis and Reigeluth (1983) and Freidel et al. (1990) propose that instruction using the analogy will not be fully successful unless time is spent in first ensuring that the students sufficiently understand the analog. The effectiveness of an analogy may be more a function of the familiarity of the analog than its level of concreteness and, therefore, visual effect (Curtis, 1988).

As mentioned above, one method of ensuring adequate knowledge of the analog may be to use part of the course content already covered as a type of analog. This procedure is used by textbook writers although there are problems that previously held alternative conceptions could be simply transferred to the target domain (Duit, 1991).

Analogical Reasoning and Cognitive Development

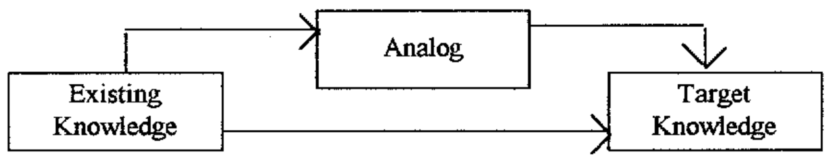
A second area of constraint with analogy usage relates to the Piagetian stages of cognitive development. There is general agreement, though a lack of empirical studies, that analogies can assist students who primarily function at lower cognitive stages. However if these students lack visual imagery, analogical reasoning, or correlational reasoning, then the use of analogies is believed to be limited (Gabel & Sherwood, 1980). In addition, those students already functioning at a formal operational level may have already attained an adequate understanding of the target and the inclusion of an analogy may add an unnecessary information load resulting in new alternative conceptions being formed by the students.

Incorrect Transfer of Attributes

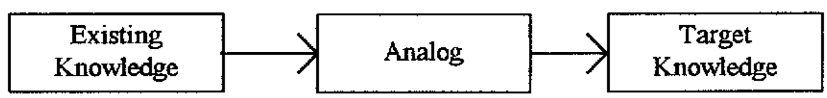
The nature of any analog for a target concept is that it has some shared attribute(s) with the target. Licata (1988) argues, however, that the unshared attributes are as instructive to the students as are the shared attributes. No analog shares all its attributes with the target as, if it did, the analogy would become an example of the target concept. Nevertheless, unshared attributes may be a cause of misunderstanding for the learners if transferred from analog to target. In an attempt to limit the effects of this constraint, Reigeluth has proposed that to be "most useful, the analogy should be as similar as possible to the idea being learned" (Reigeluth, 1983, p. 208). This avoids the possibility that the differences may be greater than the similarities.

Empirical research that addresses students' use of analogies to solve chemistry problems identified the lack of effective analogical transfer as a major barrier to students' efficient use of analogy (Friedel et al., 1990). Another related constraint occurs when the students attempt attribute transfer in an inappropriate manner. Rather than using the analog attributes as a guide for drawing conclusions concerning the target, students may incorporate parts, or all, of the analog structure into the target content (Thiele & Treagust, 1992). This could be represented as in Figure 2-1. One of the results of this incorrect transfer is that students, when questioned concerning the nature of the target content, will answer with direct reference to analog features.

The generally agreed perspective is that when analogies are used during classroom instruction, discussion should take place to assist in the delineation of boundaries, to aid concept refinement, and to improve analogical transfer processes (Brown & Clement, 1989; Klauer, 1989; Licata, 1988; Webb, 1985). Allowing for student involvement and discussion at the classroom level also will provide feedback to the instructor if incorrect attribute transfer has occurred. Teachers should not assume that the students are capable of effecting correct analogical transfer but, rather, should provide explicit instruction on how to use analogies and provide opportunity for considerable classroom discussion on the subject. However, the belief of Gabel and Sherwood (1980) that teachers should not teach the grounds and limitations themselves but should let the students do that, provides an interesting alternative perspective to this.



Desired use of analog to show the relationship between the existing and target knowledge structures. Analog attributes are used only to draw conclusions concerning the target.



Undesired effect due to incorporation of the analog into the framework relating existing knowledge to target knowledge.

Figure 2-1. Incorporation of analog in new knowledge.

Analogical Access and Inferential Power

For an analogy to be most useful to students, there should be some point of easy access. This is commonly a simple surface similarity or a key word or phrase (Holyoak, 1985). The surface similarities that provide this analogical access, however, are rarely those required to form the appropriate in-depth conclusions about the target. These higher order inferential conclusions often require the identification of less-obvious similarities. If a student attempts to draw conclusions from the surface similarities, oversimplification may result in the formation of misconceptions (Duit, 1990). Teachers may need to provide guidance for students where extraneous surface similarities might interfere with students' understanding of the higher-order mappings.

For these reasons, some instructors choose not to use analogies at all and thereby avoid these problems while, at the same time, they forsake the advantages of analogy use (Glynn et al., 1989). This issue has been recently raised by Brown (1993, p. 1287):

> [If the] goal of helping students make intuitive sense of initially confusing or counterintuitive ideas is an appropriate one in instruction, then the use of analogies and analogical reasoning may need to be much more widely encouraged.
>
> Critics of the use of analogies in science instruction would argue against this conclusion, because any analogical model will be misleading if pushed too far or employed in contexts for which it is inappropriate. This is basically the argument that analogies can be *too* generative and should thus be avoided. . . . However, rather than downplaying the use of analogies and analogical reasoning, it would seem wise to take advantage of this generativity while taking precautions against inappropriate over-generalization.

Underlying much of the research literature analysed for this present study was this tension. Harrison and Treagust (1993) have recently added to the debate by arguing that – at least in the case of refraction of light – there is little alternative to analogically-inclusive models of instruction as evidenced by a review of 47 physics textbooks. Authors shy away from what Brown (1993) refers to as "full-blown expert" models (p. 1288). In this instance from the physics of light, discussing the vector addition of light "particles" at the interface between the air and glass media is beyond the understanding of most high school students.

The Presentation of Analogies in Different Instructional Modes

Analogies in Science Textbooks

Analogies are included in textbooks for similar reasons to their use by teachers in classroom instruction. Unlike teachers, however, writers of textbooks are unable to receive immediate feedback on learning outcomes and are unable to remediate student learning if necessary. Because of this, textbook authors are encouraged to anticipate incompatibility and therefore solve problems in advance when incorporating strategies such as analogies in their textbooks (Curtis & Reigeluth, 1984). Fortunately, most textbook writers are themselves experienced teachers in the discipline and can provide suitable explanations when analogies are used. Friedel et al. (1990) have argued that one of the advantages of the textbook medium is that the author could expect some support from the classroom teacher in extending the analogy and highlighting possible limitations. Several studies (De Jong & Acampo, 1992; Treagust et al., 1992), however, have concluded that there is insufficient evidence that this can be taken for granted.

Glynn et al. (1989) have produced a useful work on the use of analogies in physics textbooks. They proposed that analogies based on prior content can be created from coursework presented earlier in the unit as this provides "assurance that the earlier concepts (which function here as analogs) [are] part of every student's knowledge base" (p. 226). Considerable difficulty must be experienced by textbook authors when deciding upon analogs that will be familiar to their broad and unmonitored readerships. Glynn et al. (1989) consider a modern physics text *Conceptual Physics* (Hewitt, 1987) to be exemplary in the use of prior work analogies due to Hewitt's willingness to fully identify common and uncommon attributes. *Conceptual Physics*, however, is an American textbook written for the new conceptual approach to physics. Due to international readerships, authors have less scope in the range of suitable analogs as fewer analogs would be familiar to the wide range of backgrounds and experiences of students. As indicated earlier, some researchers cast doubt over the effectiveness of using analogs based upon past coursework as they fear that students will promote alternative conceptions from the old area to the target.

Researchers have further identified some special difficulties related to the inclusion of analogies into science textbooks. The requirement for additional length to the text has been found by Gilbert (1989) to have a negative attitude effect, while others (Dupin & Johsua, 1989; Friedel et al., 1990; Simons, 1984) have raised doubts as to the effectiveness of using the extra space for the analogy rather than for further discussion of the target.

Frequency of Analogy Use in Textbooks

Concerning the frequency of the use of analogies in written text, most researchers would agree that it is limited. Curtis and Reigeluth (1984), on observing that chemistry texts contain more analogies per textbook than other science areas examined, concluded that the use of analogy depended primarily upon the nature of the content and the preference of the authors. In a later study – a comparison of analogies found in social science textbooks with those in science textbooks – Curtis (1988) found that social science textbooks contained, on average, only 2.5 analogies per textbook; about one third of that found in science textbooks. Of the 26 social science textbooks studied, 25 of them had less than 6 analogies. In addition, Curtis (1988) observed that the analogies tended to be simple in structure rather than extended. Glynn et al. (1989) also observed – even in science texts – many simple, one line analogies and few extended analogies. Not having the recourse to discussion with the learners, these researchers argue that textbook authors need to adopt active roles in assisting their readers to use analogies to solve problems, find solutions, and generate hypotheses (Glynn et al., 1989).

Models to Guide Analogy Presentation in Textbooks

Several models have been developed by researchers for assisting textbook writers to present more extended analogies in a manner that will reduce the possibility of misinterpretation by the learners. One such model is the Teaching-with-Analogies model (Glynn, 1989, 1991) which also can be used as a guide to teachers' use of analogies. The Teaching-with-Analogies (T-W-A) model was presented by Glynn for physics textbooks based on their consideration of textbooks such as Hewitt's *Conceptual Physics* although the model should be readily transferable to chemistry. The key stages of the T-W-A model, as presented in Glynn (1991, p. 230), are shown in Figure 2-2. It has been the subject of several curriculum developments and in-service initiatives (see, for example, Glynn, 1992; Glynn & Duit, 1993; Harrison & Treagust, 1993; Thiele, 1992; Thiele & Treagust, 1991a).

Some doubt has been expressed by Simons (1984) about the efficiency of analogy when presented in a sequenced format. As a result, he has proposed that if analogies

1. Introduce target
2. Cue retrieval of analog
3. Identify relevant features[a] of target and analog
4. Map similarities
5. Draw conclusions about target
6. Indicate where analogy breaks down

[a] Note: The T. W. A uses the term "features" rather than "attributes".

Figure 2-2. The Teaching-with-Analogies (T-W-A) model.

are to be used more frequently in textbooks and oral communication, they should be presented in such a way that the students are "free to decide for themselves whether they wish to use them" (p. 526). There is a need for research to investigate the effects of different sequences of analogy steps on student understanding.

Teachers' Use of Analogies

Frequency of Analogy Use by Teachers

Although Duit (1991) proffers that analogies are used by both novices and professionals when solving problems, he considers that they are rarely used spontaneously in the teaching mode. Duit's claim supports Leatherdale's (1974) suggestion that analogies are "presented in an occasional, opportunistic discursive way subject to the whims of the teacher, the vagaries of the course and the idiosyncrasies of the textbooks" (p. 215). Dagher and Cossman (1992) found some evidence of the use of analogy in an examination of verbal explanations identified in the analysis of the transcripts of 40 science lessons. Of the 225 explanations recorded and classified from 88 observed lessons, 28 were considered analogical. Other researchers (Treagust et al., 1989, 1992) have examined the use of spoken analogy by science teachers by observing 40 high school science lessons. Despite good analogies being available for that target area – occasionally being also included in the students' textbooks – these authors found only six clear indications of analogy use. The researchers considered that, of the six observed analogies, only three included any overt comparison of attributes. The other three were limited in scope; simple-comparison type analogies that were not extended to show shared or unshared attributes.

The researchers also formed the conclusion that teachers with a weaker understanding of the content area and a lesser degree of preparation for that lesson are less likely to use analogies than those who are more knowledgeable in the content and who are more prepared (Treagust et al., 1989). The importance of the preparation of an analogy before instruction has been highlighted by Glynn et al. (1989) who recommended that careful examination of all aspects of an analogy is a prerequisite to its effective use. This is due to the stated necessity for analogies to be discussed with the students in the classroom. Further to commenting that "an instructor should point out the limitations of an analogy," Webb (1985) concluded that if students have correctly understood the analog and the target, then "they should themselves be able to point out some limitations of the analogy" (p. 646). This discussion also will allow for the teacher to determine, through questioning, whether the students have successfully effected analogical transfer.

A further explanation put forward by Treagust et al. (1989) for the low frequency of analogy use in spoken instruction is that teachers lack a suitable repertoire of successful analogies from which to draw. One outcome of this study was the initiation of in-service education programs for science teachers enabling them to increase their repertoire of analogies and to develop their skills in presenting them (Treagust, 1993).

Models to Guide Analogy Presentation by Teachers

Several models have been developed by researchers to assist teachers and curriculum developers present more extended analogies in a manner that will reduce the possibility of misinterpretation by the learners. These models include the General Model of Analogy Teaching (Zeitoun, 1984), the Teaching-with-Analogies model (Glynn, 1989, 1991) referred to above, the "modeling analogy" approach proposed by

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.

Figure 2-3. The General Model of Analogy Teaching (G. M. A. T.).

Dupin and Johsua (1989) and the Focus-Action-Reflection (FAR) Guide to analogy presentation (Treagust, Venville, Harrison, Stocklmayer & Thiele, 1993).

Zeitoun (1984) provided a reasonably comprehensive General Model of Analogy Teaching (G. M. A. T.) in which nine stages were developed. This model adopts a holistic approach to teaching via analogy in which teachers take into account students' prior content and analog knowledge. Implicit in the G. M. A. T. is a high degree of planning necessary for the successful presentation of an analogy. It should be realised that these stages are not really suitable for the spontaneous use of an analogy in spoken instruction (for example, in assisting a student on a particular problem or difficult concept) but are more suitable for the development of special instructional materials. To have the suitable analogy available to assist that student with a particular problem requires the teacher to possess a repertoire of suitable analogies. The nine stages (as found in Zeitoun, 1984, p. 118) are shown in Figure 2-3. Some of these steps highlight the significant advantage that the spoken analogy has over the textbook written analogy in that evaluation of the outcomes and remediation can follow where necessary.

The T-W-A model has already been discussed with respect to textbook design. The T-W-A model is, however, readily transferable into the teaching domain as has been illustrated recently by Harrison and Treagust (1994).

Following a discussion on the water model used in physics education to explain aspects of electrical circuits, Dupin and Johsua (1989) encourage teachers to consider five important characteristics of good analogy systems in what they refer to as "modeling analogies". These characteristics (outlined fully in Figure 2-4) include the analogy: allowing the new idea to be presented in a concrete form, being less

1. Such an analogy must put a new idea in a concrete form.
2. It must have a descriptive function.
3. The analogical system must be less complicated than the initial one.
4. The analogy does not necessarily constitute a real, complex situation.
5. The time spent on the analogical system must be economic from a teaching point of view.

Figure 2-4. An extract from the "Modeling Analogies" guidelines (Dupin & Johsua, 1989).

complicated than the initial system, being economic in terms of time required, and – where limitations exist – being easily resolvable. These guidelines are framed as a useful checklist for teachers without being as structured as the two models above. For this reason, "modelling analogy" may be a more acceptable approach for teachers.

The fourth model approach for teaching with analogies is *The FAR Guide for Teaching and Learning Science with Analogies* (Treagust et al., 1993; see also Treagust, 1993). Informed by the other models, this model approach is being trialled

FOCUS	CONCEPT	Is it difficult, unfamiliar or abstract?
	STUDENTS	What ideas do the students already have about the concept?
	ANALOG	Is it something your students are familiar with?
ACTION	LIKES	Discuss the features [a] of the analog and the science concept and draw similarities between them.
	UNLIKES	Discuss where the analog is unlike the science concept.
REFLECTION	CONCLUSIONS	Was the analogy clear and useful, or confusing?
	IMPROVEMENTS	Refocus as above in light of conclusions.

[a] Note: The FAR Guide uses the term "features" rather than "attributes".

Figure 2-5. The Focus-Action-Reflection (FAR) Guide for Teaching and Learning Science with Analogies (Treagust et al., 1993).

in Australian schools presently. The model involves teacher analysis both before and after an analogy is presented to students and is viewed as a tool to improve: teachers' presentation of analogies; teachers' maintenance of an effective analogy repertoire; and students' learning of abstract concepts. The FAR Guide is shown in Figure 2-5.

Students' Use of Analogies

Very little has been reported about students' use of analogy in science lessons to solve problems or to understand abstract content. Andersson (1986) reported that some students used analogies when asked to describe chemical changes and Wong (1993a, b) has discussed a process by which students are encouraged to create, apply, and modify their own analogies. Bean et al. (1990), in a study that focused on the formation of analogical study guides, commented that their students were able to generate analogy attributes themselves. In fields outside science education, Gick and Holyoak (1980, 1983) conducted several experiments to determine if students could solve written puzzles of a non-science nature more easily when they had first been exposed to analogous stories. They found that this procedure was only successful when several analogs were employed. While these studies have indicated that students are able to use analogies – and perhaps do use them – empirical studies reporting *how* students use analogies are not readily found in the science education literature.

Appropriate Research Methods for Inquiry into Analogy Use

As this thesis comprises a series of six studies where different research questions and types of research questions are addressed, the methods vary between the studies. Much of the planning for these studies was based, however, upon the framework of case study approaches to educational research (Merriam, 1988; Yin, 1989) and, to a lesser extent, of qualitative methods in science educational research (Erickson, 1986). In particular, studies Three, Five and Six, were informed by principles of case study research and, for this reason, the remainder of this chapter is dedicated to outlining the principles of this kind of research with an emphasis on the type of research activities conducted. Erickson's notion of interpretive research, especially with respect to the reporting of research using assertions (Erickson, 1986, p. 146) guided the reporting of most of the empirical studies. Where other methods were adopted, they have been described within the context of the reported study.

In reporting their research, Curtis and Reigeluth (1983) commented upon the need for testing mechanisms not involving pencil and paper tests to measure recall when studying students' use of analogy. In other studies reporting the use of analogies to teach physics concepts, case study research methods were chosen as they allowed for more insightful, structural hypotheses (Zietsman & Clement, 1990) and a richer source for the exploration of the factors influencing the experiment (Brown & Clement, 1989). The success of the methodological approach reported by the above mentioned researchers influenced this researcher's approach towards the case study method, aspects of which are presented below.

Merriam (1988) and Yin (1989) both present informative discussion on aspects of qualitative case studies. Information from these texts has been used to collate the following statements relating to studies of this type. The significant aspects of qualitative case study work includes the assumptions that (a) processes, rather than outcomes, are sought; (b) there is no attempt to manipulate variables or apply treatments; (c) the researcher is the primary instrument in data collection and analysis; and (d) field work plays a major role in the study procedure.

Case study research allows for a particularistic focus on a phenomenon or programme. The method can examine a specific instance and yet still illuminate a general problem. In these studies, particular phenomena of analogy use were examined. While each study had several aspects, all related directly to analogical phenomena in chemistry classrooms. The descriptive nature of this methodology allows for "thick" description – a complete, literal description of the incident or entity being investigated (Merriam, 1988, p. 16). Descriptive studies attempt to examine as many variables as possible, to use "vivid" materials including quotations and interviews, and to present the information gathered from the viewpoints of different groups. Observation of classroom lessons and interviews with textbook authors, teachers, and students allow for a large collection of descriptive data from several sources, separate yet interrelated.

Case studies such as these tend to be heuristic and inductive in nature (Merriam, 1988). Heuristic studies are those that provide illumination to the reader that aids the understanding of a problem or phenomenon. In describing the events of classroom interaction, learning procedures, and the results of interviews, researchers aim to explain the relationships and variables that might arise as a result of instruction using analogies. Inductive studies tend to discover new relationships and generate hypotheses or assertions rather than verify predetermined hypotheses. The scarcity of literature providing the results of normal classroom teaching using analogies has resulted in a lack of clarity concerning those factors that may, or may not, be influential variables. Several studies have addressed the identification and clarification of those undefined variables (Brown & Clement, 1989; Zietsman & Clement, 1990). It should be noted, however, that the prior experiences and reading of the researcher has resulted in the formation of several assumptions that could have predisposed the researcher to form the basis of informal hypotheses. This issue is discussed further in the Limitations sections of these studies.

In addition to the heuristic and inductive characteristics, knowledge gained from case studies tends to relate well to our own experience and, therefore, allows for generalisation as a result of the compatibility of the reported findings with readers' own experiences.

In several parts of this thesis, surveys are used as data collection instruments in studies. These methods have not violated the research design, however, as the major research questions in that phase still address how analogies are used and the instrument investigates analogy use in classroom chemistry instruction – the case under examination. In addition, data collected were of a qualitative nature principally with the reporting of words and descriptions rather than numerical summaries.

In an effort to improve the reliability and generalisability – weaknesses of qualitative case study research – these studies describe analogy use from several aspects (textbook authors, teachers, and students) and at several different sites (different schools and classrooms). Where a study observes a series of different, though related, cases at different sites, Merriam (1988) describes them as cross-case studies. In this thesis, the case under research is the use of analogies in a particular instructional setting. As the studies examine several classrooms in several schools, the design adopts the cross-case nature.

Yin (1989, p. 41) also refers to "units of analysis" when attention is given to one or more subunits of a "case" such as the different perspectives of the textbook authors, teachers, and students in this study. Each of these units, although interrelating in the classroom environment, can be examined separately and hence, the study adopts an embedded, rather than holistic, nature. Further, guidelines are provided by Yin (1989) concerning the operation and reporting of a cross-case study. It is suggested that each case is conducted and reported separately initially, and then (after a full single case data collection and analysis) cross-case conclusions may be drawn, theory modified and implications developed. It is naive to expect considerable agreement between the investigations of the different units, however. In a discussion paper on triangulation, Mathison (1988) identified possible results of the collection of data from different sources. With reference to four related studies, "the outcome was occasionally convergence upon a single conclusion, more frequently the outcome was inconsistent findings or, on some occasions, contradictory findings" (p. 15). Her suggested approach is that we "attempt to make sense of what we find and that often requires embedding the empirical data at hand with a holistic understanding of the specific situation and general background knowledge about this class of social phenomena" (p. 17).

Recommendations for Further Study

The literature reports several areas in which current educational research is lacking. For example, Curtis (1988) recommended further work be done to consider the effectiveness of different types of analogies and how analogies used by teachers' vary from those found in textbooks. In commenting upon the difficulty teachers have in communicating knowledge "bound up in personal conception," such as is found in many analogical statements, Flick (1991) proposed that "science education can benefit by a better understanding of how personal experience can be applied to instruction" (p. 217).

Glynn (1991) has suggested that there is a need for further use of models for analogy inclusion and that these models need validation and implementation in classroom settings. Further, Alexander et al. (1987) have commented that there are very few studies in the "dynamic and uncertain context" of the classroom, and that, especially in the field of science, further studies are required.

Summary

This chapter has reported, with reference to relevant literature, descriptions of the structure and function of analogy in science education and the methodological framework adopted for the thesis. The following five chapters describe six studies into authors', teachers' and students' use of analogies in chemistry education.

Chapter 3 reports an investigation of chemistry textbooks for examples of analogy use and describes the application of a classification framework to investigate the nature of the analogies contained therein. Chapter 4 reports the findings of a series of interviews with the authors of the chemistry textbooks used in the Chapter 3 study. Chapter 5 describes an investigation into six chemistry teachers' use of analogies. Chapter 6 details the development of the Analogy Maps used in Chapter 7 to investigate students' use of analogies to understand chemistry concepts. Finally, Chapter 8 overviews the findings of these empirical studies.

CHAPTER 3

STUDY ONE – THE NATURE AND EXTENT OF ANALOGY USE IN CHEMISTRY TEXTBOOKS USED BY AUSTRALIAN SECONDARY STUDENTS

Overview

The first phase of the present study aims to examine the nature and extent of the use of analogies in chemistry textbooks currently used by secondary students in Australia. This phase is an extension of previous work in which ten chemistry textbooks were examined for analogy usage in the specific content areas of energy effects, reaction rates, and chemical equilibrium (Thiele, 1990). In this study, chemistry textbooks (only those currently used by Australian chemistry students) were studied in their entirety for examples of analogies, which were collected and analysed using a modified framework from Curtis and Reigeluth (1984). Further, analysis was made of the frequency with which different types of analogies occurred in different content areas of the textbooks.

Description of the Framework

There are many criteria by which analogies (spoken, written, or pictorial) can be classified, as their modes of operation vary markedly between applications. To this end, several researchers such as Curtis and Reigeluth (1984) and Glynn et al. (1989) have presented frameworks suitable for both the evaluation and classification of analogies. One of the most comprehensive studies on the identification and classification of analogies in textbooks is that presented by Curtis and Reigeluth (1984) who studied 26 science textbooks which included elementary general science textbooks [6] and textbooks of senior science subjects such as chemistry [4], physics [2], earth science and geology [3], and biology [10]. A total of 216 analogies were

1. *Analogical relationship* – considers the nature of the analog/target relationship;
    - *Structural* – same physical appearance or general structure
    - *Functional* – same behaviour or function
    - *Structural-functional* – combines both attribute qualities
2. *Presentational format* – of the analogy on the page;
    - *Verbal* – analogy explained in words alone
    - *Pictorial-verbal* – allows inclusion of diagrams, etc.
3. *Condition* – of the abstraction of target and analog domains;
    - *Concrete/concrete* – concrete analog for a concrete target
    - *Abstract/abstract* – abstract analog for an abstract target
    - *Concrete/abstract* – concrete analog for an abstract target
4. *Position* – of analog with respect to target concept;
    - *Advance organiser* – Analog presented before the target
    - *Embedded activator* – Analog presented at point of target conflict
    - *Post synthesiser* – Analog presented after discussion of target
5. *Level of enrichment* – degree of mapping indicated;
    - *Simple* – No discussion of shared analog-target attributes stated
    - *Enriched* – Some discussion of shared attributes
    - *Extended* – Different attributes of the analog are used to teach different targets or more than one analog for a target
6. *Pre-target orientation* – authors' attempts to highlight analogy;
    - *Analog explanation* – the analog is described to ensure familiarity with the learner
    - *Strategy identification* – the author advises that it is an analogical statement
    - *Analog explanation and strategy identification* – both of the above present
    - *Absence of pre-target* – neither are present

Figure 3-1. A paraphrase of Curtis and Reigeluths' (1984) criteria for classification of textbook analogies.

examined, grouped and, from the groupings, key classification criteria were created. These classification criteria are presented in a paraphrased fashion in Figure 3-1.

This same framework, with no reported alterations, was later used by Curtis (1988) to compare analogies found in science textbooks with those in social studies textbooks. Hence, Curtis and Reigeluths' classification system was a useful starting point for further research. However, in both studies, classifications were made using the actual analogies identified and instructional design qualities to determine the criteria rather than basing the classification on the findings of research studies. Hence, the classification criteria may be limited for some analogies that do not fit well into the existing criteria.

While the researcher involved in this present study decided to adopt the principles and structure of Curtis and Reigeluths' classification system, several adaptations and clarifications were made to the criteria to allow for all of the analogies to be classified and to allow for aspects of research into analogy use to be more easily addressed. Firstly, an analogy was recorded as being pictorial-verbal only if the picture represented the analog domain, not the target domain. Secondly, while a stated limitation was still considered to be an example of enrichment, another classification criterion of *Limitations* was added to the framework to specifically record evidence of either a general statement (*General*) warning of the problems of analogy use, or of a specific statement (*Specific*) highlighting some unshared attribute or limitation. Thirdly, under the category of *Position*, a subcategory of *Marginalised* was added as the researcher identified analogies that were positioned in the margin of the text. Further, the researcher classified the *Content* area of the target domain for each analogy as well as determining where the analogy was found with respect to its position in the textbook as a whole (*location*). It was intended that these criteria of *content* and *location* would provide information concerning the chemistry content areas where analogies were used most frequently and identify where those particular concepts are presented throughout the textbook. In this thesis, this modified framework is referred to as the Analogy Classification Framework (see Figure 3-2). It comprises nine criteria, six of which (3 through 8) were initially presented by Curtis and Reigeluth (1984).

Using the Analogy Classification Framework, the researcher's intention was to examine closely the nature and extent of analogy use in chemistry textbooks used by Australian high school chemistry students. For the purpose of the study, the following specific research questions were addressed:

1-1. How frequently are analogies included?

1. The *content* of the target concept – what aspect of chemistry is being considered by the target concept?
2. The *location* of the analogy through the textbook – at what stage of the curriculum is the analogy being presented?
3. The *analogical relationship* between analog and target – do the analog and target share structural or functional attributes?
4. The *presentational format* – is the analog verbal or pictorial-verbal?
5. The *condition* or level of abstraction of the analog and target concepts – do they have an abstract or concrete cognitive level?
6. The *position* of the analog relevant to the target – is it before, during, or after the presentation of the target, or is it presented in the margin?
7. The *level of enrichment* – to what extent is the mapping between analog and target domains done by the author?
8. The *pre-topic orientation* – is there evidence of further *analog explanation* of the analog domain and/or have the authors included any *strategy identification* that will indicate that the text has an analogical nature?
9. The presence of any stated *limitations* or warning which highlights to the students where possible attribute mismatches may occur.

Figure 3-2. The Analogy Classification Framework.

1-2. Are analogies used more frequently (a) for particular content areas or (b) at different stages of the textbook?

1-3. What structures and types of analogies are frequently used?

1-4. Which analogical instructional strategies have the textbook authors used?

Method

Ten chemistry textbooks were closely examined for the presence of analogies. The textbooks used had been identified by state syllabus organisations as current, generally used textbooks for Australian senior secondary chemistry education. Only one of the textbooks was not published in Australia – that was a British publication. A list of those textbooks examined is found in Appendix 1.

A portion of text or a picture was considered to be analogical if it was aligned with the working definition of analogy described on page 3 (Chapter 1) and/or it was stated by the author/s as being analogical. Each analogy was photocopied and analysed in respect of the nine criteria of the Analogy Classification Framework shown in Figure 3-2.

Results and Discussion

The findings of the study are presented in terms of the Analogy Classification Framework criteria. Further, most of the criteria are supported by a stated assertion.

Research Question 1-1: How Frequently are Analogies Included?

A total of 93 analogies were identified from the ten textbooks. The number of analogies found in each book varied considerably with five books having less than six analogies while the other five had between 12 and 18 analogies. Each analogy was further examined independently by a second researcher knowledgable about chemistry teaching at this level and the use of analogies in teaching. There was an original agreement of 93% for the classifications with the remaining classifications agreed upon following consensus discussions.

> Assertion 1-1: Analogies were used sparingly in these ten chemistry textbooks with five of the textbooks having fewer than six analogies.

Research Question 1-2: Are Analogies Used More Frequently (a) for Particular Content Areas or (b) at Different Stages of the Textbook?

1. Content Area Analysis (R.Q. 1-2a)

The content area of the target concepts was classified into 13 categories. It should be noted that the 'content area' relates to the target concept specifically and not the heading of the general chapter or section being studied. While most of the targets relate directly to the themes of the textbook chapters, the target may relate to an incidental concept beyond the focus of the chapter. For example, an analogy that helps students to visualise the structure of the DNA molecule would have been classified as 'biochemistry' rather than 'organic chemistry' despite it being in the organic chemistry chapter of the textbook.

Table 3-1

Analysis of the Frequency of Analogy Use for Particular Content Areas

Content Area	n	%
Acids and Bases	6	6.4
Analytical Methods	3	3.2
Atomic Structure	21	22.6
Biochemistry	6	6.4
Bonding	12	12.9
Chemical Equilibrium	5	5.4
Chemical Processes	1	1.1
Energy	11	11.8
Industrial Processes	1	1.1
Nature of Matter	8	8.6
Organic	5	5.4
Periodic Table	2	2.3
Reaction Rates	3	3.2
Solutions	3	3.2
Stoichiometry	6	6.4
Totals	93	100.0

Table 3-1 indicates that a considerable proportion of the analogies (21, 23%) relate to 'Atomic Structure' – including electronic arrangement such as the rotating propeller analogy for the region of electronic influence. Other areas in which analogies were used more frequently were found to be 'Bonding' (12, 13%) and 'Energy' (11, 12%) – including collision theory. The submicroscopic nature of these target concepts emphasises the role that analogies play in providing additional visualisation for some chemistry concepts.

2. Location: Analogy Location in Textbook (R.Q. 1-2b)

The page number of each analogy was used to determine a decile measure (0-9) of the analogy's location within the textbook as a whole. For example, if an analogy was found on page 210 of a textbook containing 400 pages, then the analogy 'location' would be designated as a decile number of 5. Data shown in Table 3-2 suggests that the analogies tend to be used more frequently in the earlier stages of the textbook except for a number in the 7th decile. This could indicate that conceptual targets are encountered in two phases – initially when the new work is being introduced and also, at a later phase, when more difficult concepts are being presented.

Table 3-2

Analysis of the Decile Position of the Analogies in the Textbooks as a Whole

Location (Decile)	n	%	Cum %
0	21	22.6	22.6
1	12	12.9	35.5
2	14	15.0	50.5
3	9	9.7	60.2
4	9	9.7	69.9
5	4	4.3	74.2
6	9	9.7	83.9
7	12	12.9	96.8
8	3	3.2	100.0
9	0	0.0	100.0

Assertion 1-2: Analogies were found to be more frequently employed in content areas characterised by non-observable processes and structures and the analogies were more frequently used towards the beginning of a textbook.

Research Question 1-3: What Structures and Types of Analogies are Frequently Used?

3. Analogical Relationship: Structural and Functional Analogies

The relationship between the analog and the target may be one of either structure or function. In a *structural* analogy, the shape, size, or colour, etc., of the analog is shared by the target. In a *functional* analogy, the function or behaviour of the analog is attributed to the target. A *structural-functional* analogy is one that shares both structural and functional type attributes. Of the 93 analogies that were examined in this study (see Table 3-3) only 16 (17%) were classified as structural, 45 (48%) as functional, and 32 (34%) as structural-functional. Researchers have concluded that the essential power of analogy lies in the functional area from which more useful conclusions can be drawn (Duit, 1991). The structural aspect, however, is believed to be important in providing initial access due to the obvious similarities between the analog and target domains (Tenney & Gentner, 1985).

Table 3-3

Summary Table of Analogies Showing their Analogical Relationship, Presentational Format, and Condition

		Analogical Relationship			Presentational Format		Condition		
Book	n	Struc	Func	Struc Func	Verbal	Pict/ Verbal	Con/ Con	Abs/ Abs	Con/ Abs
A	17	2	10	5	8	9	1	0	16
B	1	0	1	0	1	0	0	0	1
C	5	1	1	3	3	2	0	0	5
D	3	0	2	1	2	1	0	0	3
E	12	0	8	4	1	11	0	0	12
F	4	0	2	2	3	1	0	0	4
G	14	6	7	1	11	3	0	4	10
H	14	3	6	5	13	1	1	0	13
I	5	2	1	2	2	3	0	1	4
J	18	2	7	9	5	13	5	0	13
Total	93	16	45	32	49	44	7	5	81

4. Presentational Format: Verbal and Pictorial-verbal Analogies

As shown in Table 3-3, 44 (47%) of the identified analogies had a pictorial representation of the analog. Further analysis revealed that *pictorial-verbal* analogies are frequently positioned in the margin as an anecdotal package of helpful information. As Table 3-4 illustrates, however, *verbal* analogies are rarely found in a marginalised position. This indicates that authors may wish to use pictorial-verbal analogies more frequently but tend not to sacrifice copy space. Those authors writing texts with marginalised comments tend to make use of the opportunity to use this space for pictorial-verbal analogies.

Table 3-4

The Frequency of Use of Marginalised and Pictorial Analogies in the Textbooks

	Marginalised	Body	Total
Verbal	5	44	49
Pictorial-verbal	25	19	44
Total	30	63	93

5. Condition: Degree of Abstraction of Analog and Target Domains

The abstract nature of chemistry creates the requirement for explanation of submicroscopic processes and structures in a manner that is meaningful to the students. Hence, it is expected that analogies employed in chemistry textbooks will frequently employ concrete type analogs to explain abstract target concepts.

Subsequently, the analog and target domains of each of the analogies were classified as being either concrete or abstract. A domain was considered to be concrete if it was either readily observable or considered, by the researcher, to be consistent with the life experiences of chemistry students. As expected, 81 (87%) of the analogies were classified as *concrete/abstract* – that is they comprised a concrete type analog domain and an abstract target domain. Only 5 (5.4%) of the analogies employed an *abstract/abstract* analogy while the remainder (7, 7.5%) comprised a *concrete/concrete* analogy. These results, shown in Table 3-3, lend credence to the proposition that analogies are usually drawn from concrete type domains.

6. Position: Analog and Target Placement on Text Pages

While there is a lack of empirical studies supporting the preferential placement of analogies in various text positions, researchers have postulated that the efficacy of an analogy may relate to whether the analog is presented before or after the target domain. For example, Glynn's (1989) Teaching-With-Analogies model for text instruction using analogies proposes that the analog domain be presented in the text after the introduction of the target domain yet prior to conclusions being drawn about the target. In this situation, the analog has been placed as an *embedded activator*

(Curtis & Reigeluth, 1984). However, where a clearer separation between analog and target domains is required, the analog domain may be introduced prior to an examination of the target concept (*advance organiser*) or following a complete treatment of the target as a *post synthesiser*. It also is possible, as mentioned previously, for textbook writers to employ the margin space – where present – in the textbook to present analogies. This *marginalised* presentation also may indicate that an author considered the analogy to be non-essential.

Table 3-5

Summary Table of Analogies Showing their Position and Level of Enrichment

		Position				Level of Enrichment		
Book	n	Marginal	Adv Org	Emb Act	Post Synth	Simp	Enrich	Extend
A	17	7	1	7	2	10	6	1
B	1	0	0	1	0	0	1	0
C	5	1	0	4	0	0	3	2
D	3	1	0	2	0	1	2	0
E	12	7	0	3	2	8	3	1
F	4	0	0	4	0	1	3	0
G	14	0	2	12	0	4	9	1
H	14	0	2	12	0	9	3	2
I	5	0	0	5	0	3	2	0
J	18	14	2	2	0	6	3	9
Total	93	30	7	52	4	42	35	16

An examination of the 93 analogies identified in this study revealed that most (52, 56%) were presented as embedded activators (see Table 3-5) while 30 (32%) were marginalised. This marginalised position was used extensively in three textbooks that had margin spaces; the other textbooks showed scarce evidence of marginalised analogies. The infrequent use of analogies as advance organisers or post synthesisers (seven and four respectively) could be due to the attempts of authors to enhance the enrichment of the analog-target relationship that is facilitated when analogies are presented as embedded activators.

7. Level of Enrichment: The Extent of Mapping

The extent of mapping done by the textbook authors was classified using Curtis and Reigeluths' (1984) criteria of *level of enrichment* as follows:

a) *simple* – states only 'target' is like 'analog' with no further explanation;

b) *enriched* – indicates some statement of the shared attributes or limitations; and

c) *extended* – involves several analogs or several attributes of one analog used to describe the target.

The textbook analysis found that the use of simple analogies is still fairly common (42, 45%) despite some research suggesting that students require assistance when relating the correct analog attributes to the target (Gabel & Sherwood, 1980; Webb, 1985). Only 35 (38%) of the analogies were enriched, while the remainder (16, 17%) were extended. Further, with reference to Table 3-5, three of the five textbooks having 12 or more analogies contained considerably more simple analogies than enriched analogies. This finding could indicate that authors who employ analogies more frequently also are less likely to conduct detailed mapping procedures and may be underestimating the cognitive requirements for students to effect the appropriate analogical transfer necessary.

> Assertion 1-3: There was considerable use of both pictorial-verbal analogies and concrete/abstract analogies although simple analogies were found to comprise a substantial proportion of the total.

Research Question 1-4: Which Analogical Instructional Strategies Have the Textbook Authors Used?

8. Pre-topic Orientation: Analog Explanation and Strategy Identification

To avoid the problems of analog unfamiliarity and incorrect attribute transfer, some textbook writers provide background information concerning the relevant attributes of the analog domain. This *analog explanation* attempts to ensure that the student is focussing upon the appropriate attributes at the time of analogical transfer. The explanation may constitute a simple phrase of only a few words through to a paragraph thoroughly explaining the relevant analog attributes. Table 3-6 shows that 56 (60%) of the analogies had some analog explanation – 11 of which had both analog explanation and *strategy identification*. This finding is similar to the results of other studies (Curtis & Reigeluth, 1984; Thiele, 1990) which have found between 66% and 69% of the analogies had some analog explanation.

Table 3-6

Summary Table of Analogies Showing their Pre-Topic Orientation, and Limitations

		Pre-topic Orientation				Limitations	
Book	n	Analog Expl	Strat Ident	Both	None	None	Specific
A	17	7	0	0	10	17	0
B	1	1	0	0	0	1	0
C	5	1	0	4	0	4	1
D	3	2	0	1	0	3	0
E	12	5	0	3	4	12	0
F	4	2	0	1	1	4	0
G	14	5	4	2	3	13	1
H	14	6	0	0	8	13	1
I	5	4	0	0	1	4	1
J	18	12	0	0	6	14	4
Total	93	45	4	11	33	85	8

9. *Limitations of Analogies*

Given that analogies can be misconstrued by students, it has been suggested that authors should include some warning about the *limitations* of the analogy or the analogical process. Subsequently, each analogy was examined to see if it included: a) a general statement of the limitation of analogy use; or b) a statement relating specifically to the unshared attributes in the analogy.

No general statements concerning analogy use were made in any of the textbooks. In addition, only eight specific warnings or limitations were expressed (see Table 3-6) with four of the eight stated limitations included in one of the textbooks. The infrequent use of stated limitations would suggest that authors are either assuming that the students are capable of effecting the analogical transfer themselves or that the teacher – in the course of normal classroom teaching – will assist in this regard.

Further, it was found that only 15 (16%) of the analogies included any statement identifying the strategy such as "an analogy" or "analogous". It could be considered that if *strategy identification* was used more frequently, then the effect would be similar to the addition of a warning in that it will direct students towards the correct cognitive procedure (Glynn et al., 1989).

> Assertion 1-4: Sixty percent of analogies used analog explanation to aid students' understanding although stated limitations or warnings by the authors were infrequent.

Conclusions

From this study of analogies in chemistry textbooks used by high school students in Australia, it is possible to draw conclusions regarding the effect that the nature of chemistry has upon the presentation of analogies in the chemistry textbooks.

Analogies were used sparingly in these ten chemistry textbook with five of the textbooks having fewer than six analogies. While the other textbooks did employ analogies more frequently, the overall mean of 9.3 analogies per textbook underscores this paucity. Analogies were found to be more frequently employed in the content areas of atomic structure, bonding, and energy. These content areas are characterised by non-observable processes and structures that are often reported as being difficult for students to understand. The considerable use of both pictorial-verbal analogies and concrete/abstract analogies adds support to the proposition that the explanation of an abstract chemistry concept is assisted by analogies which promote visualisation processes or which present some student world comparison of the target concept.

Analogies were observed to be more frequently used towards the beginning of a textbook. Abstract concepts such as atomic structure and bonding are frequently introduced early in the textbooks as they are generally considered to be prerequisite to many later concepts. The finding that analogies are used more often at the start of a textbook could indicate, however, that the authors are using more "student friendly" strategies towards the commencement of their senior chemistry course – these strategies use the foundation of students' common life experiences rather than attempting to build on students' early chemistry knowledge.

Simple analogies were found to comprise a substantial proportion of the total number of analogies and the use of stated limitations or warnings by the authors was infrequent. It is possible that textbook authors may be underestimating the difficulties that students are reported to encounter when attempting analogical transfer. Research (Duit, 1991; Curtis & Reigeluth, 1984) suggests that authors and editors should employ enriched, rather than simple, analogies for all but the most elementary relationships if the target concepts are to be better understood as a result of using the analogy. It is possible that the authors have assumed that the classroom teacher will accept that responsibility. However, there has been little research published to document either the existence or the outcome of this occurrence, and this issue is the focus of the research reported in the next chapter.

Further research is required if we are to understand more fully the processes that students employ when using analogies. Future studies focusing on both the teachers' and students' use of analogies will allow for better curricular design that includes analogies to further aid students' understanding of chemistry concepts. In addition, these studies should report not only on the end result of analogy use (such as those by Gabel and Sherwood, 1980, 1983, 1984) but also on the processes as they occur. For this reason, interview and observation techniques will be particularly applicable. Further research is needed on how students use analogies in learning complex chemistry concepts, so as to advise authors and teachers concerning the more effective use of analogies both in textbooks and in the classroom. This advice to authors should command a high priority because, while it is generally assumed that teachers' repertoires of analogies are primarily derived from their reading of textbooks (Treagust et al., 1992), there is a considerable lag between research and practice due to the time taken to produce textbook materials.

Limitations of the Analogy Classification Framework

Most of the analogies were easily classified using the Analogy Classification Framework as is indicated by the high degree of agreement between the researcher and a second researcher (93%). However, two types of statements originally considered to be analogical were problematic in this respect. The first of these was a purely metaphorical word which is frequently highlighted by apostrophes or quotation marks in the text. Examples are electrons situated in *shells*, and representing a *packet* of energy. Secondly, some analogical phrases or terms have become so much a part of the language of chemistry that they may not be considered initially to have come from another domain. Examples are metal ions being held together by a *sea* of electrons, a *family* of hydrocarbons, and the longest carbon *chain*; these examples involve terms that, although they are strictly analogical, have become part of the colloquialism of chemistry. These two types of statements are by no means exclusive of each other. Terms or phrases such as these have not been included as analogies in the analysis because the researcher considered that they did not adequately fit within the framework of either Glynn et al.'s (1989) definition or the classification of even a simple analogy. These statements were referred to as metaphoric statements only as there is no clear evidence of an intent to actively compare two separate domains.

Summary

This chapter reported both the further development of a framework with which analogies can be analysed for research and evaluation as well as the analysis, using that framework, of 93 analogies from ten chemistry textbooks. While it is reasonably simple, though time-consuming, to conduct this analysis, little can be drawn of the intentions of the textbook authors who initially decided to include, or not to include, these analogically-inclusive strategies in their textbooks. Research that sought to further address these questions should precede further investigation into analogy types and structures. While research studies may promote a particular style of analogical presentation, if this style is for some reason difficult for authors to employ in the textbook setting when constrained by publishers, editorial teams, price, and clientele, then the findings of research into analogy use lacks credence. Secondly, there is a tendency for those researching analogy-inclusive instruction to optimistically wish that research findings from teacher-based instruction be readily generalisable to textbook-based instruction and visa-versa.

For these reasons the following chapter of this thesis describes Study Two in which the authors of most of the textbooks used in this present chapter were interviewed to determine their views on analogy use in chemistry textbooks and teaching.

CHAPTER 4

STUDY TWO – TEXTBOOK AUTHORS' VIEWS CONCERNING THE USE OF ANALOGIES IN SECONDARY CHEMICAL EDUCATION

Overview

In the previous chapter, the researcher reported an analysis of 93 analogies found in ten chemistry textbooks. While the nature of the content area influenced the frequency of analogy inclusion, it also was found that the included analogies were often variant in style and setting from recommendations provided by researchers of science education and instructional design studies reported previously. The first study in this thesis revealed the variability with which analogies have been included in various textbooks, with five of the 10 textbooks having between one and five different analogies only, while the other five textbooks contained between 12 and 18 different analogies.

Despite the marked variation in frequency of analogy use in textbooks, however, no research has been identified as to why authors choose to include or omit analogies from their textbooks. Indeed, if analogies are useful in explaining abstract chemistry concepts in student world language, then it could be expected that there be more uniformity among their frequency of use. Alternatively, if it is considered that due to their many stated limitations analogies are not an appropriate tool for inclusion in textual material for students, why are they included at all?

In addition to the areas of concern stated above, a decade of research into the use of analogies has provided some theoretical perspectives of the profile that a successful analogy should adopt. For example, Glynn (1991) and Zeitoun (1984) have presented model approaches for analogy teaching and the inclusion of analogies in textual materials. While these reports are more recent than several of the textbooks under study, it is important to consider that the implications of these studies are not reaching curriculum designers and textbook authors. If this is the case, then it can be expected that future editions of textbooks by these and other authors will continue to present analogies in what science education researchers consider to be a less than efficient and effective manner.

The study reported in this chapter begins to investigate some of these currently unanswered questions related to textbook authors' views of analogy and analogy use.

Research Questions

The purpose of the second study was to determine, from interviews with most of the authors of the textbooks examined in the earlier study, their awareness of and attitudes towards the use of analogies in textbooks for secondary school chemistry students. In addition, data were sought relating to the authors' backgrounds in chemistry and chemical education. With these data, the researcher's intention was to ascertain if the tendency to include analogies in textbooks was predicated on a particular educational perspective or view of learning. The interview protocols were designed to address the following research questions:

2-1. Are authors' views about analogy related to a particular view of learning, instruction or set of educational experiences?

2-2. (a) What are the views currently held by textbook authors concerning analogy and analogy use and (b) what reasons are provided for inclusion or exclusion of analogies in instructional materials?

2-3. What personal preferences are held for analogies in different positions such as advance organiser, embedded activator, post-synthesiser and marginalised?

2-4. What personal appeal is there for a model to promote a structured mapping approach to analogy inclusion in textbooks and teaching such as the Teaching-With-Analogies model (Glynn, 1991)?

2-5. What changes would the author make to a later edition of his or her own textbook if provided with a more thorough repertoire of trialled analogies?

Method

Semi-structured interviews were conducted with seven authors referred to here by their surnames only: Simpson, Garnett, Lewis, Bucat, McTigue, Sanders and Derbogosian. Although none of these authors acted in a sole capacity, Garnett, Bucat and McTigue were senior editors of their textbooks and the remaining four authors made significant writing contributions. These seven authors represent eight of the ten textbooks analysed in the first study. Of the remaining two textbooks, one of the authors was no longer in a position to be involved in an interview due to failing health and the other was overseas at the time of the data collection between 1991 and 1993. Figure 4-1 shows the authorship of the textbooks discussed in Study One of the research programme.

Textbook in Study One	Number of analogies	Author interviewed in Study Two
A	17	(Failing health)
B	1	Garnett
C	5	Bucat
D	3	Bucat
E	12	Simpson
F	4	Lewis
G	14	McTigue
H	14	(Overseas)
I	5	Sanders
J	18	Derbogosian

Figure 4-1. The cross-matches between textbooks discussed in Study One and authors interviewed in Study Two.

The interviews were conducted in a semi-structured manner (Yin, 1989), following the protocol shown below, and lasted between 60 to 80 minutes. Six of the seven interviews were conducted in person and the other interview (with McTigue) was conducted via a long distance telephone conversation which was tape recorded with his permission. Wherever possible during each interview, examples of analogies identified from the author's own textbook were used to focus discussion and to assist in the definition of terms used by the interviewer and interviewee. All of the interviews were tape-recorded and full transcripts were produced. The researcher then considered the transcripts in an interpretive manner (Erickson, 1986) to address the research questions above. In the Results section below, five character codes (e.g. pmp01) are used to cross-reference data to the interview transcripts. The first two letters identify the author (e.g. Peter McTigue) while the remaining characters identify the page number (page 01).

The results of the first study (see Chapter 3) have indicated that Simpson, McTigue and Derbogosian used analogies more frequently (12, 14 and 14 analogies respectively) while the textbooks written by the other four authors contained between one and five analogies. The textbook by McTigue contained almost four times as many words as the other textbooks, however, and – on an analogy by word count analysis – was therefore considered to contain a similar number of analogies to the textbooks by Garnett, Lewis, Bucat and Sanders.

The base interview protocol is presented below and each question is referred to one of the five research questions for this study. In keeping with the methodological approach adopted, the results section of this study examine confirming and dis-confirming evidence for each of the research questions, and assertions are used to categorise key findings. The research questions were ordered to facilitate a logical interview sequence whereby the interviewer sought a sense of personal familiarisation prior to embarking on conceptual information related to the topic.

Interview Protocol

Protocol questions 1a through h refer to research question 2.1: Are authors' views about analogy related to a particular view of learning, instruction or set of educational experiences?

1a. Would you briefly summarise your secondary and tertiary educational background (as a student)?

1b. Having had and observed many chemistry instructors, what characteristics would you identify as being common to good chemistry teachers?

1c. Would you briefly summarise your own teaching experience?

1d. How did you become involved in curriculum development?

1e. Where did the basic structural foundation for the book come from?

1f. How did you envisage that it would be most effectively used by chemistry teachers and students?

1g. Were there any constraints that you felt at the time of writing that influenced its presentation, style, format, target audience, etc?

1h. If so, what were they; what effects do you feel they had?

Protocol questions 2 through 5 refer to research question 2.2 (a): What are the views currently held by textbook authors concerning analogy and analogy use, and (b) what reasons are provided for inclusion or exclusion of analogies in instructional materials?

Let us move on to consider your chemistry teaching:

2a. Can you recall instances in your recent chemistry teaching where you have used analogies?

2b. Could you describe one of these analogies and what influenced you to use it?

Here is a question from a Physical Science student resource book (see Figure 6-1c).

3a. What are your impressions on the value of such a question?

3b. Do you believe average Year 12 chemistry students are able to draw correct correspondences between the diagram and the approach of a chemical system to equilibrium?

3c. Would you envisage any problems with the incorporation of a similar type of question in your textbook?

On page [number] of your textbook, you relate [identification of the analog] to [identification of target concept],

4a. Could you explain why this was considered to be useful?

4b. Are there any characteristics of the [analog domain] that students might incorrectly attribute to the [target domain]?

4c. If so: do you consider it appropriate that a warning of this incongruence be included in the text or figure description?

On page [number], reference is made to the area of influence of a single electron as being like a [direct quotation from textbook]. Students do not readily accept that the electron is essentially everywhere at the same time.

5a. Do you know of any analogous situations that might model this? If not: Here is one from another textbook (see Exhibit)

5b. What advantages and/or disadvantages do you consider that there are in including (or not including) these analogies in the text?

Protocol question 6 refers to research question 2.3: What personal preferences are held for analogies in different positions such as advance organiser, embedded activator, post-synthesiser and marginalised?

6. Here is a page relating to geometric isomerism from an organic chemistry textbook (see Figure 4-2a). Would you please read the page, and then indicate where in the text you would best insert the analogous picture (see Figure 4-2b) illustrating restriction to bond rotation? Please mark this place on [Figure 4-2a] at one of the black dots and provide some reasons for your choice.

Protocol question 7 refers to research question 2.4: What personal appeal is there for a model to promote a structured mapping approach to analogy inclusion in textbooks and teaching such as the Teaching-With-Analogies model (Glynn, 1991)?

7a. Do you recall ever having seen a model that serves as a guide to good analogy presentation in textbooks?

7b. If so; could you recall any parts of the model?

7c. If not: here is a simple six step model (Glynn's T-W-A Model)

7d. How do you feel about following such an approach?

Protocol question 8 refers to research question 2.5: What changes would the author make to a later edition of his or her own textbook if provided with a more thorough repertoire of trialled analogies?

8. If you were to publish another text, and you were supplied with a comprehensive bank of analogies that had been trialled with teachers and students, would you be more likely to use them? Explain why/why not.

Results

Research Question 2.1: Are Authors' Views About Analogy Related to a Particular Set of Educational Experiences?

Since the academic and educational involvement of the authors may substantially influence their approach to analogy, data were collected concerning the authors' backgrounds. Five authors (Simpson, Garnett, Lewis, Bucat and McTigue) held doctorates in chemistry completed at early stages of their chemical education experience and five of the seven (Garnett, Lewis, Bucat, Sanders and Derbogosian) had completed formal education studies at either graduate level, graduate diploma level or Masters level. Four of the authors (Garnett, Lewis, Sanders and Derbogosian) had experience teaching secondary chemistry prior to their involvement in their respective textbooks and Garnett also had tertiary education experience in the areas of chemistry and science education but was no longer a practicing high school teacher at the time that the textbook was written. The other authors (Simpson, Bucat and McTigue) had each had considerable experience as chemistry educators at the tertiary level with emphases in chemistry for undergraduates.

Six of the seven authors had been involved in some aspect of curriculum development prior to their work with their textbook. Simpson, Garnett and Bucat had some prior experience writing laboratory manuals for senior chemistry students. Garnett, Lewis and McTigue had been involved in writing text materials for larger scale curriculum initiatives, while Sanders had several years experience as a chemistry curriculum officer with an Australian state education authority. Garnett indicated that he had completed a postgraduate unit on curriculum development and that it had always been a desire of his to take a significant role in the production of a textbook. Similarly, McTigue indicated that he had an interest in presenting concepts in written form that link together various aspects of the discipline of chemistry.

Any leaning towards a pedagogical style that would be particularly conducive or otherwise towards the use of analogies could become evident in discussing the characteristics of a good chemistry teacher. Five authors (Garnett, Lewis, Bucat, McTigue and Sanders) strongly emphasised that the need for a strong background in chemistry was by far the most important feature. Comments, such as that of McTigue, about the requirement of a teacher to be "totally on top of the discipline aspect" (pmp01), and by Bucat, of the need for a content knowledge "way in advance of the level you are teaching" as being "the only way that you can have comfortableness, enthusiasm, imaginative ideas, different ways of presenting things" (bbp01), suggests that these authors considered ease of teacher style was strongly dependent upon a foundation of good content knowledge. Having established this foundation, the authors tended to list some personal relationship characteristics of teachers such as their being interested in students and being able to suitably organise and select the content material. For example, having commented upon the need for chemistry teachers to know their subject matter, Sanders indicated that "secondly, you have to teach [from] where students start. You have to know where their knowledge is, and what their interests are, and start from that basis so that you can build on something" (rsp01). Factors that also were commented upon favourably were demonstrations of empathy, compassion, sensitivity, humour, and enthusiasm.

In contrast, the other two authors (Simpson and Derbogosian) expressed primary opinions that good teaching is predicated upon good teacher-student relationships. Simpson stressed the need for the teacher to be interested in the thought processes of students and to be "clear and precise, be fair and be prepared to admit that you are wrong" (psp04) while Derbogosian proposed that "it is really mostly important to get students interested" (mdp01).

Comparing these comments with the data in Figure 4-1, the following assertion is made concerning how the authors view the teaching learning process and their willingness to use analogies in textbooks.

> Assertion 2-1: Textbook authors who put most emphasis on the depth and correctness of the teachers' content knowledge tend to use analogies less frequently in textual materials. Authors who tended to use analogies more frequently viewed relationships with students, communication, and motivation to be more important.

Research Question 2.2a: What are the Views Currently Held Concerning Analogy and Analogy Use?

The authors' ideas of what did and what did not constitute an analogy indicated general agreement with each other and the researcher. Some variation in the discussion, however, followed Lewis's line of "all science is analogy" (plp06) due to the use of symbols in instruction and descriptions of invisible processes and entities. Bucat discussed and demonstrated what could be described as a rice analogy for particle theory relating to the states of matter. It was agreed that this demonstration, although being analogical in nature, could be better described as an analog model (bbp04).

Each author was asked to recount several analogies that they used in their own teaching. It was considered that this question would provide insight into the authors' personal views of analogies in teaching. McTigue was able to instantly respond with an analogy that he had recently used in a teaching situation; however, he had some prior warning of the questions due to the nature of the telephone interview arrangements. The analogy that McTigue recounted was one in which the target concept was the apparent movement of a positive charge through a semi-conductor as electrons move between semi-conductor "holes" when under the influence of an electric field. The analog for this system was the ionic proton transfer mechanism that occurs when an electric current is passed through a hydroxide solution. The protons jumping between hydroxide ions contribute a substantial proportion to the total conductivity of the hydroxide ion (pmp03). This is an example of an abstract-abstract analogy, a type rarely identified in the earlier textbook study. While it may be co-incidental, it is also likely that the tertiary education setting which McTigue was describing may be a more suitable environment for analogies of this type.

Sanders provided examples of classical analogies such as the use of ball bearings to illustrate atomic arrangements although, in response to a later question, he commented that he spoke of Mars Bars and Smarties when teaching the mole concept (rsp02). Derbogosian recounted several personal analogies (Marshall, 1984) such as skiing over the mountains for activation energy and ingredients in baking a cake for limiting reagents (mdp03).

Simpson, Garnett, Lewis and Bucat expressed some difficulty recalling analogies that they had used in their teaching. After some thought, Lewis gave an example of the pole-vaulting analogy for activation energy and catalysis (plp06), which he had adopted after seeing it on a chemical education video *Catalysis* (Imperial Chemical Industries, 1963). Garnett and Bucat proposed analogies relating to electronic behaviour – the ladder steps analogy for energy levels and the models of vibrating strings, plates and water waves for energy quanta (bbp05).

The researcher noted the value of the *CHEM Study* curriculum initiatives, especially the film series, as a source of analogies for these chemistry educators, many of whom had received their own foundational chemistry education during the late 1960s and 1970s when *CHEM Study* was popular in Australia. The materials in this curriculum package included textbooks, teachers' guides, 16 mm films (which were later converted into video format), laboratory guides and other sundry resource materials. Investigations of these materials (Merrill & Ridgway, 1969, Appendix C) reveal the intention of the *CHEM Study* film series:

> The films have been designed with two main purposes in mind: (1) To introduce into the classroom important experimental evidence which is difficult to introduce through student experiments and live demonstrations. (2) *To clarify, through animation, the mental models of structure and of dynamic processes which help scientists and students make sense out of the experimental evidence* [italics added]. Most of the films serve both purposes. In addition, several of the films attempt to convey the nature and excitement of scientific research. (p. 92)

Garnett recounted several analogies from his contact with the *CHEM Study* films and textbooks. These analogies included the mountain pass analogy for catalysis and the goldfish in the dumbbell-shaped bowl analogy for chemical equilibrium. Garnett suggested that he did not use analogies as frequently as he had done when he was teaching chemistry using the *CHEM Study* materials and, in explanation, he commented that he was well aware of the research indicating that some of these analogies may contribute to the students forming misconceptions (pgp06).

The difficulty that some authors had in recounting their own analogies may indicate a lack of use of analogy in their own teaching. Alternatively, it may indicate that, for these authors, analogies are used spontaneously to address a perceived misunderstanding or to answer a student's problem rather than as a planned strategy as one might use a demonstration or practical activity. The difficulty in recalling analogies also may indicate that analogies, when they are used, are presented in an expedient manner in which the instructor's intention is that the outcome be an attainment of the target concept only and the analog is best forgotten.

Simpson indicated several analogies in his textbook that he used in his teaching also. These included a diagram of cows that eat apples to become contented cows; an analogy that describes the concept of a chemical equation. He suggested that analogies lost something when they went to print because they could be presented in such a way as to foster interest and motivation more readily when used in the classroom (psp09). However he, like several others, indicated that analogy was something of a spontaneous strategy that he was more likely to use when attempting to explain an abstract idea to students after they had indicated that they did not clearly understand. For example, Lewis commented that "analogy is a very personal thing, something you might deal with on a one to one basis" (plp03). Despite freely acknowledging that he used analogies in his own chemistry teaching, Sanders also commented upon the need to change or adapt analogies and models to suit the changing circumstances of the lesson and pupils (rsp02).

In a similar manner, each of the authors seemed to be aware that there was a need for analogies to be discussed by both teachers and students when used in classroom settings. Having described his analogy for the semi-conductor, McTigue commented that the analogy had been created spontaneously by him as a result of being questioned concerning the target concept by some students after a lecture. In this situation, he could "push it [the analogy] to outrageous lengths, then, when they have seen the point, you can throw the analogy away and come back to the point you are trying to make" (pmp03). Similarly, Lewis suggested that when using analogies in whole class teaching, he would build the analogy and then destroy it to illustrate where the analogy broke down. He proposed that the instructional value was in the resulting discussion and evaluation of the unshared attributes rather than in the construction or presentation of the analogy (plp07). Garnett, when questioned concerning a particularly problematic analogy for chemical equilibrium, commented that "maybe the way to deal with it is to point out what is wrong" with the analogy (pgp07). Later, concerning the same analogy, he suggested that "I would not mind using it myself if I had control of the situation in a classroom situation," but he went on to indicate the lack of control available once the analogy is in textbook form by adding "but I would not like to stick it in a text where everybody is going to use it" (pgp08).

This theme of the inability to negotiate analogy once it is in text was discussed by several of the authors. For example, Simpson commented that "many analogies work much better in the teaching situation than they do as presented in books" (psp09). Garnett felt likewise and suggested that he preferred to use them himself "rather than put them in written form . . . I do not really want to lock an analogy into concrete" (pgp08). McTigue, commenting from a similar viewpoint, proposed that:

> I am a little wary about the use of analogies by writing them down in the sense that, if you put them in a textbook, . . . there is a danger that students can get the analogy confused with the reality. That is not true in every case obviously, but my experience has been that analogy can work very well indeed but not for everybody. The analogy that works for student A is lost on student B and I rather like using analogies in a situation where I do not have to commit myself. I can say much looser things than I would really want to commit to paper when I am arguing analogically with a student. (pmp03)

Similarly, Lewis responded that "I would be reluctant to use an analogy in a textbook because I do not know that you could ever, in words, provide an adequate representation for all students" (plp20). Later, he emphasised that when you are teaching you can respond to those students who do not understand the concept by an analogy or further explanation but that "you do not see the blank faces of the students you are writing the text for" (plp21).

> Assertion 2-2a: Textbook authors view analogies as pedagogical tools that require much flexibility of use. For this reason, they viewed unfavourably the frequent inclusion of analogies in textbooks.

Research Question 2.2b: What Reasons are Provided for the Inclusion and Exclusion of Analogies in Instructional Materials

Prior to the study, Garnett and Lewis had both been recently active in conducting educational research in science classrooms. Each of them commented that their ideas on student understanding and student learning had been significantly affected by their findings and that this also would have altered their perspective on students' use and understanding of analogies since writing their textbooks. Lewis, in his closing remarks in the interview, commented upon these changes thus:

> My opinions of analogy, my notion of how powerful and useful it is, have evolved considerably in the last two years. Had you been talking to me two years ago, you certainly would have got quite a different set of answers. (plp26)

The comments of these two authors could indicate that closer examinations of the difficulties some students have in understanding abstract concepts make teachers and textbook authors more wary of the use of pedagogical tools such as models and analogies due to the risk of misunderstanding or confusion.

One important feature that arose from the interviews was the degree to which the authors anticipated that the classroom teachers would engage themselves in explaining the content of the textbooks to their students. For example, when asked about the need to identify analogies found in the textbook with some strategy identification, Sanders remarked that he didn't know if they had described it as an analogy in the textbook but that "certainly I would teach it that way . . . I do not think we put teaching techniques in the textbook" (rsp03). This author went on to describe an example of how he taught using analogies directly from the textbook, highlighting things that the two domains had in common as well as any limitations. Derbogosian also was able to describe how she taught directly from the textbook and discussed the analogies with students in the classroom. She remarked, however, that while "it was the teacher's role to explain [what was in the textbook], . . . if the student was away, the textbook should be sufficient instruction" (mdp02). Further, Garnett indicated that his book was clear enough for students to work through themselves without undue difficulty (pgp05). These remarks indicate that textbook authors do not presuppose that teachers, in normal circumstances, explain analogies and analogy limitations to their students.

The authors made several comments about the interactions that students might have with the analogy and the process of analogy. When asked why he decided to include a particular analogy in his text, Bucat responded in terms of traditionally accepted advantages (see Chapter 2) for analogy inclusion by stating:

> There are two things. One is that it gives the student something to relate to. The other one is that analogies . . . are most likely to be used when we are talking about the sub-microscopic level and they cannot see them (cannot see the particles that we are talking about) and so we use an analogy that is in our experience, that is . . . something we can relate to and can visualise and then try to take back. (bbp04)

Lewis, supporting the first of these ideas, remarked that we use analogy "to help put something into a language that the students can understand . . . to make the complex commonplace" (plp07), while Sanders and Derbogosian referred to analogies "relating to real life activities" (rsp03) and being "something familiar" (mdp03), respectively. These authors have identified the "visualisation" advantage and the "student world" advantage, yet not the "motivational" advantage of analogy. Bucat considered that analogies should be part of our experience and something we can relate to. This is important when compared to the comments of Lewis who, reflecting on some research he conducted in classrooms, recalled a student making the statement:

> Analogies are very personal things. What's a good analogy for Mr X is not a good analogy for me because I do not think the same way that Mr X does. It's all right for Mr X – he knows the whole story. I do not! You are trying to present an analogy to me when you know what all of it means. You know what is coming up and you are aware of the history behind that. Here I am, as a student in the first couple of weeks of my senior chemistry course, being thrown into this same thing. I do not know what the end of the story is like. It's like trying to use information that I am going to get in chapters 7, 8 and 9 of my novel to answer a dilemma that I have in Chapter 1. (plp11)

Even taking into account the retranslation of the statement into Lewis's phraseology, this excerpt illustrates the student's high level of perceptiveness. Lewis went on to acknowledge that, while students' ability to deal with analogies should not be overlooked, the need for analogies varied markedly from student to student. He believed that the need is related more to academic performance and suggested that "there have got to be some students who will need a little bit more information and there will be other students who will say 'this is pretty tedious stuff'" (plp20).

> Assertion 2-2b: While the authors expressed several advantages of using analogies to teach abstract concepts, several cautioned that students' requirements for, and use of, analogies varies greatly and that instruction should cater for this variance.

Research Question 2.3: What Personal Preferences are Held for Analogies in Different Positions such as Advance Organiser, Embedded Activator, Post-Synthesiser, and Marginalised?

The authors were asked to carry out an activity in which they were to indicate where, on a page of text, they would insert a pictorial analogy related to geometric isomerism which had been provided. This would provide some evidence to the researcher of the authors' willingness to include pictorial analogies into the textbook and their preferences for the position of such analogies in the text. A copy of the textbook pages used for this exercise may be found in Figures 4-2a and 4-2b.

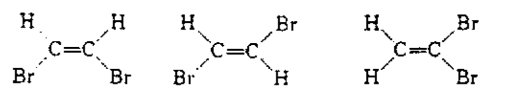
The approach to this task varied between authors, with some studying the text at length while others skimmed the text and focussed more carefully on the analogy. The initial response of Simpson and Bucat was to position the analogy in the page margin. This response was consistent with their textbooks which included a substantial number of marginalised comments, diagrams, anecdotes and some marginalised analogies. Bucat, when questioned concerning a marginalised analogy in his text, had commented that:

We did not think it was essential to put in or else we wouldn't have put it in the margin. Those things are things that we thought anyone could use this book without even referring to. So we thought it was useful to put it in – it might have been interesting for some to put it in. (bbp07)

2.8 Geometric Isomerism

An example of a substance in which there is free rotation around a carbon-carbon single bond is 1,2-dibromoethane ($BrCH_2—CH_2Br$). Although this substance has several conformers of different energies and different abundances (Figure 2.5), they cannot be separated or isolated, because of constant interconversion. Rotation is unrestricted because it does not affect the degree of orbital overlap in the σ bond between the two singly bonded carbons and the energy barriers between the conformers are small.

Such is not the case with 1,2-dibromoethene ($BrCH{=}CHBr$). In general, free rotation about carbon-carbon double bonds is not possible, since this would involve a decrease in orbital overlap of the parallel p orbitals composing the π bond (>C=C<). This is not a problem with σ bonds because they involve overlap in only one position. For rotation to occur, the π bond would have to be broken, a process that is not energetically favored. Owing to the restricted rotation in 1,2-dibromoethene, two isomers are possible—one in which the two bromines are on the same side of the double bond (*cis*, Latin, "same side"), and another in which they are on opposite sides (*trans*, Latin, "across").



cis *trans*
1,2-Dibromoethene 1,1-Dibromoethene

Unlike conformational isomers, these are distinct and isolable compounds. They are called *geometric isomers* because they differ in the geometric orientation of atoms, not in the structural (atom-to-atom) arrangement. For geometric (cis-trans) isomerism to be possible, each carbon involved in a carbon-carbon double bond must have two different groups attached. For example, 1,2-dibromoethene exhibits cis-trans isomerism, as illustrated, but 1,1-dibromoethene ($CH_2{=}CBr_2$) does not. Rotation around the double bond is still restricted, but it is evident that rotation would make no difference in the compound.

Example 2.6 Draw the two geometric isomers of $CH_3CH{=}CBrCH_2CH_3$.

Solution Isolate the doubly bonded carbons in your mind, and identify the two groups connected to each carbon: CH_3 and H; Br and CH_2CH_3. To get the first isomer, place two groups on each carbon randomly but oriented to the corners of a triangle. Interchange the two groups on one of the carbons to get the other isomer.

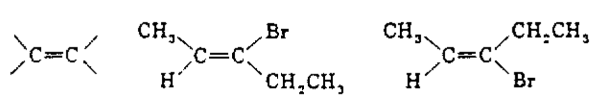
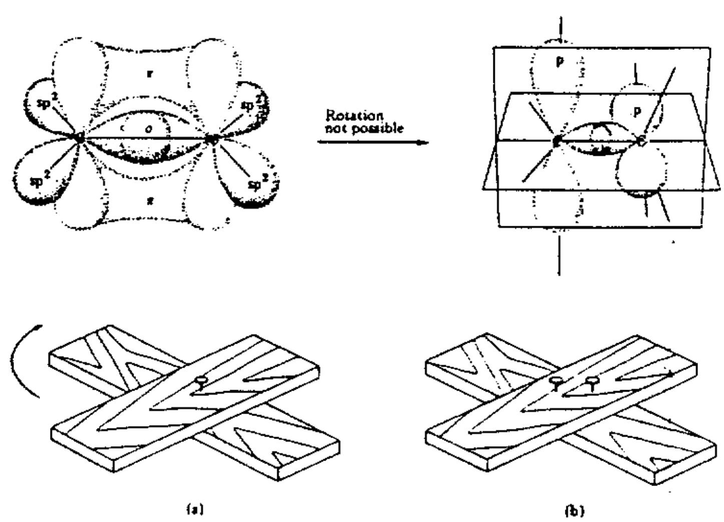


Figure 4-2a. Geometric isomerism activity given to authors. (Adapted from Bailey & Bailey, 1989, pp. 57-59.)

Further, on the analogy task being attempted, Bucat commented that:

> You put it off to the side because it is something you could allude to and is maybe useful but it does not interfere with the flow, and it is not necessary for the flow, and not everyone would need it, but it is there if you want to go that way. (bbp10)

Garnett and Lewis initially chose to put the analogy at the start of the text as an advance organiser (pgp09). Lewis's rationale for this was that, when reading textbooks, students tend not to look back to relate a current diagram or anecdote to an earlier mentioned concept (plp24). Garnett clearly considered that the pictorial analogy could act as "an organiser" although both he and Bucat later changed their minds to come to tenuous decisions that it should be embedded at the point of discussion concerning the target content in the text itself. McTigue, Sanders and Derbogosian also had considered that the analog should be inserted in the text at the point of target discussion where it would provide "greater understanding" (rsp04).



The difference between rotation about a carbon-carbon single bond and rotation about a carbon-carbon double bond is analogous to the difference in the ability to rotate (a) two pieces of wood connected by one nail versus (b) two pieces connected by two nails.

Figure 4-2b. Structural isomerism activity given to authors. (Adapted from Bailey & Bailey, 1989, pp. 57-59.)

Garnett analogically suggested that the placement of the analogy was similar to the positioning of laboratory work in the programme of content when he proposed that:

> You can use it just beforehand to introduce conceptual work, you can use it afterwards as a reinforcement, or you can use it separately if you are pushing some particular lab skills; lab process skills. And maybe as a general rule, seeing you are trying to use the analogy to make it more concrete possibly – and certainly more understandable – maybe the earlier you can get it in the better. (pgp09)

Simpson defended his proposal for a separated analogy "as another illustration in the margin or halfway in a little box by itself" by commenting that he did not find that presenting the analogy right at the beginning was particularly helpful. Rather, he used "analogies to solve problems rather than to pose them" (psp11).

> Assertion 2-3: Most authors favoured the analogy for geometric isomerism placed as an embedded activator although some support was evidenced for both marginalised and advance organiser analogies. No author proposed an analogy placed as a post synthesiser.

Research Question 2.4: What Personal Appeal is there for a Model to Promote a Structured Mapping Approach to Analogy Inclusion in Textbooks and Teaching such as the Teaching-With-Analogies Model?

With this question, the researcher wished to ascertain which, if any, of the authors recognised the Teaching-with-Analogies model or were aware of any other models relating to analogy presentation such as the General Model for Analogy Teaching (Zeitoun, 1984). In addition, the authors were asked to comment upon their perception of the usefulness of such a model for textbook presentation of analogies after having studied it for several minutes.

It was clearly apparent that none of the authors recalled ever having seen or used a model for analogy presentation. Lewis was aware of the work done by Clement on bridging analogies in physics (Clement, 1987) but that work was not related to textbooks. Garnett commented upon the similarity of the model to an established approach for the teaching of concepts (with attribute analysis, examples and non-examples) (pgp08). Lewis concluded that the model approach appeared to be "an incredibly tedious exercise" if there was not a shared authorship of the textbook (plp21). The other authors, however, appeared to accept the six step model as useful although some suggested variations and alterations. For example, Simpson, Bucat, Sanders and Derbogosian all acknowledged that they considered the best approach varied depending upon the analogy and the setting. The problem of extra length to a textbook was raised by Sanders who proposed that this model approach could be better placed in a teachers' guide to the textbook (rsp04) and Derbogosian cautioned that, while there was nothing wrong with the model, she would "never like to see a recipe for how you teach" (mdp05). McTigue, however, was content with the model as it was presented and indicated that it was common sense and that "most experienced teachers would do that without even being conscious that they were doing these things" (pmp04).

Other useful comments came from Garnett who suggested that the limitations of an analogy could be presented at the same time as the similarities; that is, before the conclusions are drawn (pgp08). Bucat attempted to clarify the conflict that arises over the use of an analogy to draw conclusions rather than to confirm a previously arrived at conclusion by remarking that:

> There certainly must be cases where the conclusion has already been made and, in an attempt to make sense of that conclusion, you might use the analogy. Though, I suppose what you are at least doing is drawing out the conclusions of what you have previously done before. (bbp08)

> Assertion 2-4: The authors indicated a general acceptance of the model approach for analogy presentation provided that due regard be given for flexibility in different teaching settings.

Research Question 2.5: What Changes Would the Author Make to a Later Edition of the Textbook if Provided with a More Thorough Repertoire of Trialled Analogies?

When asked if they would be interested in incorporating some of a bank of trialled analogies in a fictitious new edition of their texts, several of the authors indicated some reluctance. Lewis categorically stated that he "would not use them in the textbook" (plp22), while Garnett only agreed to the inclusion on the proviso that the "person writing the book felt comfortable" (pgp08). Similarly, McTigue agreed that he would consider them but he would "need a fair bit of convincing that an analogy was a valid one" (pmp05). Authors of the more recent texts (Sanders and Derbogosian) indicated little willingness to deviate from their current texts. On further questioning, however, four authors showed particular interest in having these trialled analogies available in the form of a teachers' guide. McTigue showed enthusiasm for the idea, while Bucat proposed that each analogy "could have a comment on each of the six steps" of the T. W. A model (bbp09). In addition, Lewis suggested that he "might be interested in putting them in a teachers' guide." He qualified his concession, however, by proposing that, even in a teachers' guide, there would be the need for some form of instruction to teachers that "clearly you do not just take these into the classroom cold and assume that all your students, at the end, will be enlightened" (plp22). Alternatively, Sanders suggested that although you could embed these analogies into another chemistry book, there would be demand for a "book of analogies . . . that is related to a number of chemical concepts that are pretty universal . . . that would be very useful" (rsp04).

> Assertion 2-5: Although being generally against the inclusion of analogies in future student textbook materials, the authors expressed appeal for the inclusion of analogies into teachers' guide materials or analogy resource books.

Conclusions

The purpose of Study Two was to determine, from interviews with most of the authors of the textbooks examined in the earlier study, their awareness of and attitudes towards the use of analogies in textbooks for secondary school chemistry students. Seven assertions have been drawn from this and these have been described above. The authors were from three Australian states and had a wide range of experience in chemistry and chemical education. In addition to this range of experience, each had formal qualifications in chemistry and experience in teaching the subject at either the secondary or tertiary level of education. Further, the textbook authors were individuals who were active and interested in the process of chemical education and were well informed on many issues related to chemical education. Several of the authors had conducted research in chemical education in recent times. The authors also had a range of experience in curriculum development with histories of prior textbooks, laboratory guides, and curriculum development work for education authorities.

The inclusion of analogies in the textbooks written by these authors reflect variations in their perceptions of the advantages and disadvantages of analogy use as well as reflecting variations in their backgrounds. Those authors who had undergone formal research in teaching and education tended to include and use analogies less frequently. The frequency of analogy inclusion in the textbooks, however, does not appear to be indicative of the willingness of the authors to use analogy in their own teaching. Rather, they are unwilling to set the analogy to print because of their belief that teaching with analogies should involve discussion or negotiation with students. This is not possible in a textbook situation.

In examining this issue of why authors chose to include analogies in textbooks, the authors' responses paralleled the accepted advantages for using analogies that have been identified in the literature cited in Chapter 2. These advantages are that (a) analogies provide an important visualisation function, (b) analogies provide something that students can relate to from their own real world experiences, and (c) analogies have a motivational function. While the authors' reasons for including analogies in their textbooks coincided with the first two of these advantages of analogies as reported in the literature – the provision of "student world" reality and the improvement of the visualisation process – they did not directly recognise the other reported advantage.

Contrarily, the authors' strong arguments against analogy inclusion were centred around the inflexibility of written text compared to spoken English in the fluid setting of the classroom. These authors have argued that analogies lose their power when set in print because they are most powerful in a one-to-one setting or in response to a perceived difficulty. Analogies, they have argued, do not suit the needs of all students, and therefore are not suitable for frequent textbook inclusion. There appeared to be a strong relationship between the authors' stated views on analogy inclusion and the findings of Study One, which measured frequency of analogy use in each of the textbooks. The strength of this relationship lends credence to the validity of the interview technique for these research questions.

Some of the authors saw analogy as a teaching technique rather than a learning technique and, from that perspective, considered them to be not suitable for student textbook inclusion. Rather, they saw that a teachers' guide would be a more suitable place in which analogies could be disseminated. One further argument against analogy inclusion in textbooks was the difficulty that students have in mentally transferring attributes of a foreign analog to a foreign target. This was powerfully portrayed in the vignette above in which Lewis recounted a comment from a student he had interviewed during his own research into teaching and learning science. From that vignette – about a student's understanding of Mr X's use of analogy – it can be inferred that the student was having to make his own construct of the analog based upon a partially formed view of the analog; the reverse process to what we normally expect to occur with analogically inclusive instruction. Further descriptions of this phenomenon can be found in Chapter 8 of this thesis.

When the authors performed the analogy placement exercise, it became evident that their preferences were for the analogy to be either embedded in the text or in a margin column as an "optional extra" for students who may require further or alternative explanation. There was little support for the analogy to be placed as an advance organiser and no support for it as a post-synthesiser. While this contextualised activity lacks generalisability, the similarity of these findings with the findings of the first study with 93 textbook analogies (see Table 3-5) – being embedded activator (52%), marginalised (30%), advance organiser (7%) and post-synthesiser (4%) – adds to its credibility. These findings also may reflect the authors' views of analogy as a strategy best employed by teachers in response to a perceived learning difficulty. It is unlikely that authors would wholly support analogies as advance organisers as these would require a degree of planning deemed inappropriate. Similarly, post-synthesiser analogies would seem trivial as these authors viewed analogy, not as an end in itself, but as a means to an end.

In this study, the researcher sought to ascertain whether the textbook authors were familiar with any developed models for teaching with analogies or including analogies in textbooks. The importance of this was twofold. Firstly, the question sought to verify the suitability of the dissemination methods of recently published models (Glynn, 1991; Zeitoun, 1984). While these models had, in the most part, been published subsequent to the textbook publications, the findings of these studies could be used to inform writers such as these. The second intention of the research question was to ascertain if the authors believed a model approach to be useful to guide instructional design or if it was flawed, at either a theoretical or pragmatic level.

It was clear that none of the authors recalled having seen a model for analogy-inclusive instruction. Neither did any author recognise the T-W-A model once they had been shown it by the researcher. These Australian authors' lack of recognition was not surprising as the T-W-A model had been published in several science education books in the United States, not in Australian journals, and the General Model for Analogy Teaching (G. M. A. T.) had been published in a science education journal that does not have a large circulation in Australia. In addition, the researcher later became aware of a new document (Gilbert, 1994), published through the Association for Science Education in the United Kingdom for British science teachers, which outlines various methods for teaching with models and analogies. Following the data collection phase of this study, the researcher published several articles that include discussion and analyses of the T-W-A model for Australian science teachers through state and national associations (Thiele & Treagust, 1991a, 1991b). If research in science education is to inform both further research as well as practice, it is imperative that this dissemination approach at two levels – the researcher level and the practitioner level – become standard practice.

Given that the authors were unfamiliar with the T-W-A model, and given the finding that these authors tended not to encourage analogy inclusion in textbooks, their acceptance of the model was, at best, guarded. While some authors identified the model as being too complex or tedious, most were dissatisfied with the concept that there was a correct order in which analogies should be presented. They did not, however, take issue with the content of the model, being generally accepting of the notion that overt mapping and limitations should be included.

The authors' advice, that a model approach such as the T-W-A may best be suited for analogies in teachers' guides or books of analogies, seems credible and is presented as part of the Implications section (see Chapter 8) of this thesis. The numerically ordered presentation of the T-W-A, however, was seen as a limiting factor by the authors as it proposed analogies to be presented as embedded activators only. However, the findings of the first study (see Table 3-5) revealed that 48% of the 93 textbook analogies were *not* presented as embedded activators. This comparison adds credence to the authors' reluctance to use the steps of the model in the order of presentation. Following the interviews, and as a consequence of the authors' comments on the apparent rigidity of the T-W-A model, the researcher held private correspondence with Shawn Glynn concerning the T-W-A model (Glynn, personal communication, February 10, 1992). While the six steps were numbered to convey the need for fulfilment of each step of the model, Glynn indicated that the order of these six steps was not designed to be prescriptive in either a textbook or a teaching situation. Hence, the authors' desire to maintain flexibility over the order of presentation of each of the model's steps does not violate the philosophy of the model. The willingness of the authors to accept a model approach to analogy, albeit a more flexible one, indicates the usefulness of such an approach. It also should be recognised that there is still a paucity of empirical research findings suggesting that analogy presented in the model format described earlier aids student understanding more than analogies presented in a non systematic manner.

As part of the dissemination originally planned for this study programme, the researcher had considered providing prospective authors of chemistry textbooks with item banks of trialled analogies. In this way, analogies that had been identified as contributing to the development of misconceptions in student learning could be avoided. Similarly, the analog familiarity for Australian students for each analogy could have been pre-determined. These authors, however, communicated a reluctance to include analogies in textbooks. Their support lay behind the addition of analogies to teachers' guides or to the publication of a separate document linking analogies to particular abstract concepts integral to the syllabi of most senior high school students in the English speaking, western world. Development of the authors' ideas on these issues forms part of the recommendations and dissemination of this research programme described in Chapter 8. The proposal to publish a separate document listing suitable analogies for chemical education is still under consideration and does not comprise part of this thesis.

Limitations

The assertion has been made that those authors who valued teachers' content knowledge more than communicative skills tended to use analogies less frequently in their textbooks. In considering this, and other assertions above, it is important to acknowledge that none of the authors operated in the capacity of sole author, although several had senior editorial functions with their textbooks. As the influence of co-authors has not been determined, caution is needed when considering the value of these findings.

Secondly, as mentioned above, the contextualised activity in which the authors were requested to position an analogy somewhere on a page of text about geometric isomerism lacked generalisability to other analogies. Further, the short time of five minutes that authors were allowed to do the task could have limited its effectiveness. Nevertheless, the credibility of the outcomes of the activity were somewhat supported by the findings reported in the previous chapter.

It is acknowledged that this type of interview research relies upon the reflections of the interviewee at that time. In this instance, the researcher had added knowledge due to the prior analysis of each of the textbooks. The real values of the authors, however, may best be determined by examining future editions of textbooks that are written by them in an attempt to verify if the trends that were voiced do eventuate.

Similarly, a more thorough investigation of how students interact with their textbooks, and the sense that they make of analogies therein, would greatly inform this research.

Summary

Having examined ten chemistry textbooks used by Australian senior high school students, this research programme investigated analogies contained therein using a classification framework. This investigation resulted in the emergence of further research questions related to the origins of the textbook analogies. These research questions were considered to be best investigated by direct contact with the authors of the textbooks; subsequently this study has attempted to relate these views to some of the lesser explained findings of the first study.

While, this second study revealed much about authors' views on analogies, it also provided a glimpse of the perspectives of classroom teachers on the use of analogies. Each of these seven authors considered education in chemistry in a holistic manner that included the interactions between students, teachers, textbooks and other curricular devices such as audio-visual materials and laboratory activities. In addition, each author was a chemistry teacher at either the secondary or tertiary level at the time of the interviews. The importance of the classroom teacher in an investigation of analogy use in chemistry appears paramount. The next study seeks to address that need by observing six teachers, from two countries, teaching chemistry in the naturalistic setting of the classroom and by analysing their use of analogies. Given the above limitations of the data from the interviews with the textbook authors, it is argued that richer data should be obtained by non-intrusive observations of teachers using analogies.

CHAPTER 5

STUDY THREE – AN INTERPRETIVE EXAMINATION OF SIX TEACHERS' USE OF ANALOGY DURING SECONDARY CHEMISTRY LESSONS IN TWO COUNTRIES

Overview

Having examined ten chemistry textbooks used by Australian senior high school students and determined the textbook authors' views on analogies, this study seeks to address research questions related to the use of analogies by chemistry teachers in a naturalistic setting. In this study, another aspect of chemistry students' learning experiences was investigated to determine factors related to analogy presentation; this time in the spoken format. In addition, other curricular devices such as audio-visual materials, hand-out work-sheets, laboratory activities and other student activities were assessed for analogical content simultaneously. Further, this study into teachers' use of analogies engaged constructs from the earlier studies in so far as the Analogy Classification Framework was adapted for use in a classroom observation mode.

Introduction

Recent international interest in the use of analogies in science education has been centred around several aspects of analogy including their instructional design characteristics, advantages and constraints, and the misconceptions that may result from their misuse. Despite the research generated from this interest in analogies in science education during the past decade, there have been few studies that have investigated or described the effectiveness of analogies presented in the natural environment of the classroom. Further, there is little research that indicates how teachers and students use analogies in that natural setting which is the focus of this present study.

Analogies can be presented to students in a variety of forms, as is the case also for models, demonstrations and other sense-making aids used by classroom teachers. Research into the instructional design characteristics of analogies used by teachers and in textbooks has contributed to the wider research agenda on analogies in science and science teaching. Within this research, analogy classification frameworks have been produced (Curtis & Reigeluth, 1984; Curtis, 1988; Chapter 3) which allow researchers to classify and compare written analogies. These frameworks also have the potential for transference to classify spoken analogies.

Studies relating to classroom use of analogies have tended to adopt qualitative research methodologies drawing heavily from observation and interview data. Within this approach, several studies (Arnold & Millar, in press; Brown, 1992; Brown & Clement, 1989; Clement, 1987; Zietsman & Clement, 1990) have been penetrating in that they have explored the way in which students reason when confronted with analogical situations in a science context. From a teaching perspective, Dagher and Cossman (1992) used observation methods to describe the nature of teachers' verbal explanations (some of which were analogical) from a large number of science lessons, while other studies have adopted a similar approach to examine teachers' use of analogies in chemistry (De Jong & Acampo, 1992), general science (Treagust et al., 1992) and social science subjects (Tierney, 1988). The results of these studies indicate that, while science teachers do use analogies when explaining concepts to students, they tend to use them infrequently and less effectively than researchers consider they might have done. In addition, Treagust et al. (1989) identified that the infrequent use of analogies was despite the presence of analogies in the students' textbooks for the topics being taught. This is an interesting outcome given that some textbook authors believe that science teachers should explain to their classes the analogies contained in the textbooks (see results for R.Q. 2-2b, Chapter 4).

Research Questions

Several reports on preservice and in-service teacher education have argued that 'cases', if properly documented, provide a powerful tool to help teachers come to know about teaching (see, for example, Carter & Richardson, 1989). McCorcle (1984, p. 206) proposed that the "unique advantage of the case method is its ability to examine a phenomenon *in situ*, in all the buzzing confusion that characterises organisational life. In this way, connections can be made between the phenomenon and the context in which it occurs." Similarly, previous research with exemplary teachers of biology (Treagust, 1991), chemistry (Garnett & Tobin, 1989) and physics (Tobin, Deacon, & Fraser, 1989) provided useful data for informing teacher education from different vantage points of best practice in science education. From this perspective, the present study sought to conduct an interpretive examination of six teachers teaching chemistry in the natural environment of their classrooms, with a focus on *how*, *when*, and *why* the teachers employed analogies in their explanations. It was anticipated that the setting, content being studied, personal interactions between teachers and students, and many other 'uncontrollable' factors would impinge on this analogy use, and that a description of analogy use would be most appropriately presented with the context in which that instruction occurred. In particular, the following eight research questions guided the planning, selection of teachers and general research design:

3-1. Why do teachers choose to use analogies for a given concept?

3-2. Do teachers use variations in their normal teaching styles or approach when using analogies?

3-3. Do teachers use any aids to assist in analogical transfer of analog familiarity for students?

3-4. Do teachers believe that students find difficulty when using the analogies provided for them by the teacher?

3-5. What type of analogies do teachers use most frequently in their explanations?

3-6. Were the analogies used by teachers related to, or similar to, analogy examples found in students' textbook materials?

3-7. Were the analogies planned or were they spontaneously presented? If they were spontaneous, were they generated at the time or mentally retrieved from prior experiences?

3-8. When teachers used analogies in the classroom, was there evidence that they attempted to take students' prior knowledge into account?

This study builds on those reported above in an attempt to describe how teachers of chemistry use analogies to explain abstract chemical concepts. It does not aim to measure the frequency of analogy use, but rather, as previously stated, to examine *how* and *why* teachers use analogies when they are teaching specific areas of the chemistry subject matter. In Chapter 3, it was reported that analogies were used most often for the topics of atomic structure and bonding. In addition, the topics of energy effects, reaction rates and chemical equilibrium have been identified as being highly conceptual in nature and subject matter for which analogies were often used in textbooks. Finley, Stewart and Yarroch (1982) found that students consider these topics to be among the most difficult topics encountered in chemistry. Sub-topics within these five chemistry topics include: electron configuration, orbital arrangements, shapes of molecules, properties of matter, factors affecting rates of reaction, potential energy diagrams showing transition states and activation energy, collision theory and its use to describe and predict reaction rates, catalysis, characteristics of systems at equilibrium, equilibrium constant and law expressions, Le Chatelier's Principle, and industrial applications of equilibrium.

Method

Of particular interest to the researcher were the processes of analogy-inclusive instruction and the structure of the analogy actually used. Consequently, in keeping with the qualitative approach for research into teachers' and students' use of analogies argued by Zietsman and Clement (1990) and supported by later studies (Dagher & Cossman, 1992; Treagust et al., 1992), an interpretive design (Erickson, 1986) was used to address this interest. 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 this study, the researcher has been an industrial chemist, a practising chemistry teacher, science teacher educator, and has conducted research into the use of analogies in textbooks, and consequently, was familiar with the chemistry content matter and had developed skills in the recognition and classification of the analogies as they are presented.

Selection and Description of Teachers

Six chemistry teachers, who will be referred to as Craig, Julie, Lucas, Neil, Steven and Warren, were selected for the research study. Craig, Julie, Lucas and Steven each taught senior chemistry (tertiary entrance level) in Western Australia; Neil and Warren taught senior high school (A-level, tertiary entrance level) chemistry in North Yorkshire, England. Data for the Australian teachers were collected from August, 1991 to March, 1992. Data for the English teachers were collected from October to December, 1992 while the researcher visited the United Kingdom as part of a post graduate study fellowship with the British Council.

Due to the profile of the researcher in the Western Australian chemical education community, most of the Australian teachers knew that the research study was related to analogies prior to the commencement of the study. Hence, there was little advantage in attempting to conceal this. The teachers from England knew only that the study addressed how chemistry teachers explained abstract concepts to students. Each of the six teachers, regardless of what they knew or suspected of the study, was continuously encouraged to teach in their normal style despite the presence of the researcher in their classroom.

Each teacher was chosen due to his or her good chemistry content knowledge, experience in teaching chemistry, proximity to the research centres in a Western Australian and North Yorkshire city, teaching programme addressing appropriate content at a suitable time of the year, and willingness to have a researcher observe them and their students for a three week period.

Craig and Julie taught chemistry at the same church affiliated, independent co-educational high school located close to the city centre – a school in which the science staff were involved in several professional networks. This school had a predominance of girls in the senior chemistry classes due to the close proximity of a popular boys' school. In addition, the senior classes had a large proportion (around 80%) of students who were born outside Australia – mainly in Asia. Craig had taught chemistry for five years and held an undergraduate degree in chemistry. For this study, his Year 12 chemistry class comprised eight students (six girls and two boys) although he also taught Years 8, 9 and 10 science and a Year 11 chemistry class. Julie had eight years teaching experience, including some teaching in the United Kingdom prior to migrating to Australia. She had completed postgraduate studies in chemistry, and had worked as an industrial chemist prior to entering the teaching profession. As Head of Science at her school, Julie had some administrative tasks as well as her Year 8-10 science and Year 11 physics teaching commitments. Observed by the researcher was Julie's Year 12 chemistry class, consisting of eight female and three male students.

Lucas taught chemistry at a church affiliated, independent boys' high school, with exceptionally good science facilities. He held a doctorate in chemistry and his teaching experience spanned 18 years. Lucas had taught in several Australian states and he had considerable expertise in curriculum development. Lucas was observed teaching his Year 12 chemistry class which consisted of 19 male students. He also had a class of Year 11 chemistry and had administrative duties in his school.

Steven taught chemistry at a church-affiliated, independent girls' high school where the science department staff had reputations for producing academic students and for being involved in professional science activities. Steven had completed postgraduate studies in chemistry, physics, and soil science, had considerable experience in curriculum development and had been involved in syllabus determination at the Year 12 level. His teaching career spanned almost 20 years. For this research study, Steven was observed teaching his Year 12 chemistry class which consisted of 17 female students. He also had a class of Year 11 chemistry students and had administrative duties in his school.

Neil had 19 years teaching experience at the time of the study. He held an honours degree in chemistry and a postgraduate qualification in education. Neil had interests in industry-education links and he had helped organise industry visits for six years. Neil taught in an independent co-educational school in North Yorkshire – a school with a long history and a chemistry department that worked well together as a team. Neil, who was Head of Chemistry at his school at the time of the study, had chemistry teaching commitments at the third, fifth and upper sixth form levels as well as with the lower sixth (Year 12) chemistry class that was observed for the study. That class comprised 13 students (seven male and six female).

Warren had 27 years teaching experience. He had an honours degree in chemistry and held qualifications in education. Warren was interested in study skills, student learning and learning styles and had recently conducted in-service sessions for staff members at his school on related topics. In addition, he had contributed to the production of a book on electrochemistry for students. His school was a government run "Sixth Form College," which catered exclusively for students in their 12th (lower sixth) and 13th (upper sixth) years of schooling. Warren's class for this study was an upper sixth (Year 13) class consisting of eight male and four female students. Although Warren taught a lower sixth form, the content being covered (volumetric analysis) at the time the researcher was in the region was considered not to be appropriate for the study. Warren also had some administrative duties at the college due to his work as a year coordinator.

While the numbers of students in Julie's and Craig's chemistry classes were small in comparison to the other classes, the researcher did not consider that the number of students would influence unduly the nature of the analogies used to explain the chemistry topics encountered. Hence, the low student numbers was not considered to be detrimental to the study. Similarly, four of the five schools in this study were independent, church-affiliated schools and, while there is little evidence to suggest that this would influence the nature of teacher explanations, readers do need to be aware of the nature of the schools and the collegial relationships that exist between these teachers and the researcher. Hence, it is cautioned that this does provide a limitation regarding the generalisability of the findings to other school types. Julie, Steven and Lucas were known to the researcher through professional contacts, Craig was introduced through Julie while Neil and Warren were introduced to the researcher through colleagues at a regional university in North Yorkshire. The researcher was keen to limit the number of teachers in this study to six so that he could ensure to be present for each lesson and so that all relevant data could be properly documented.

Documentary Resources

The corpus of material collected in this study included field notes and audio tapes of lessons, interviews with teachers, students' work, teachers' teaching materials and audio visuals shown to students during their instruction. To effect this, the researcher was present for a sequence of lessons lasting approximately three weeks in which each teacher taught from the topics of atomic structure, bonding, reaction rates, energy effects and chemical equilibrium. A total of 64 lessons was observed comprising eight each for Craig and Steven, 10 for Warren, 11 for both Julie and Neil, and 16 for Lucas. This difference in observation frequency was indicative of the length of time that each school allocated to a teaching period and whether double and triple 'periods' were timetabled. The researcher did not attend when topic tests were scheduled or when the teacher was absent and a substitute teacher was present. The researcher audio-taped the teachers' explanations and full transcripts of any analogical explanations were produced from the recordings. A total of 58 analogies were observed to have been used and names for these analogies are listed in Figure 5-1. Two analogies were used by more than one teacher: both Warren and Neil used the water transfer analogy for chemical equilibrium and both Julie and Lucas used the ball/dance analog to describe aspects of molecular collisions. Where an analogy was used more than once, the frequency of use is displayed in parenthesis next to the analogy name in Figure 5-1. If a particular analog was used to describe different target concepts, it was classified by the researcher as two separate analogies. This occurred when Julie revisited the analog of the ball/dance after several days to explain how chemical concentrations can influence the rates of forward and reverse reactions differently.

ANALOG DOMAIN	TARGET DOMAIN
Energy Effects	
Academic ability of physics students	Fraction of molecules with energy greater than activation energy
The student ball/dance	Activation energy
Pole vaulter attempting a vault	Activation energy
Pushing a car over a hill	Activation energy
Role play of student couples	Formation of an activated complex
Car precariously balanced at the top of a hill	High energy of the activated complex
Reaction Rates	
Students hurdling hurdles of different heights	Rates of various reactions having different activation energies
Student relationships	The effect of reactant mixing on reaction rate
Marathon runner cooling off by lying in a cold bath	The effect of increasing surface area on the rate of reaction
Collisions between children in the playground	The effect of increasing concentration on reaction rate
The student ball/dance (2)	Increase in molecular velocities causing an increase in the number of collisions
Coconut shy fairground attraction	Effect of increased concentration on the number of successful collisions
The student ball/dance	Decrease in the reaction rate as it proceeds in one direction
Climbing through Swiss mountain passes	Effect of catalysts on reaction mechanism and rate
Pushing a car around a side road	Ease of catalysed reaction mechanism
A pig fixed on a barbecue spit	Specific fixation of a reacting species to a catalytic site
Chipmunks storing food before winter	Exothermic and endothermic reactions
Personal banking and savings	Exothermic and endothermic reactions
Breaking apart a pen and its cap	Energy required to break chemical bonds
One of the "products" of an exothermic reaction being heat	Release of energy in exothermic reactions
People moving around	Particle motion
Chemical Equilibrium	
Water flowing in and out of a sink	Constant dynamic properties in a steady state open system
A recycling tap/sink/drain water system	Constant dynamic properties in a steady state closed system
A "stalemate"	Constant dynamic properties in a steady state closed system
Elastic band returning to its original size	Tendency of a chemical system to revert to equilibrium
Gravitational effects on a body	Tendency of a chemical system to revert to equilibrium

Figure 5-1. Analogies used by the chemistry teachers during the observed lessons.

Chemical Equilibrium (continued)	
Saturated sugar content in coffee	Processes at chemical equilibrium
Iodine in alcohol and water	Processes at chemical equilibrium
Not "frozen"	Processes at chemical equilibrium
Physical equilibria with iodine in various solvents	Chemical equilibria and reversibility
Water/water vapour in a closed system	Chemical equilibria and reversibility
People moving in and out of a shop	Rates of forward and reverse reactions for equilibrium
Water being transferred between two bowls (2)	Rates of forward and reverse reactions for equilibrium
Good and bad missionaries rate of evangelisation	Competing forward and reverse rates of reaction
Person walking up a down escalator	Competing forward and reverse rates of reaction
Pushing down the accelerator of a car	Changes in the rate of the forward reaction
Actively moving body to stay warm	Response of an exothermic system to a decrease in temperature
Person walking up a down escalator	Effect on yield of favoured forward or reverse rates of reaction
Constants in the discipline of physics	The dependence of the equilibrium constant on temperature
Having an ace to play, an ace card	Advantage of using a catalyst in a commercial equilibrium process
'Jam butties' on a conveyor belt	Advantage of using a catalyst in a commercial equilibrium process
Members of a family sharing a car	Compromise between reaction rate and yield in an industrial exothermic process
Water reservoir	Chemical buffer systems
Lots of money in a bank account	Chemical buffer systems
Atomic Structure/Bonding	
Ball on top of hill	High energy of atomic orbitals
Dumb-bell shape	Shape of p-orbitals
Shells and orbits	Orbitals
Taking photographs	Theorised electron positions at any instant
Scaffold structures	Molecular arrangement of ice
Musical cymbals	Arrangement of an atomic lattice
Miscellaneous	
The fine print of a legal contract	Conditional statements relating to the equilibrium constant
The visible spectrum	Colour mixtures of transition metal ions
Getting a prickly pear to beat someone with	Danger of trying to correct ozone problems by releasing chemicals into the atmosphere
Sibling rivalry	Competing ionic species in equilibria
Domestic spin drier for clothes	Extraction cone for crystallisation of ammonium nitrate pellets
Wobbling jelly in a bowl	Temporary delocalisation of electrons

Figure 5-1 (Continued). Analogies used by teachers during the observed lessons.

The Analogy Classification Framework

Each analogy was examined using the Analogy Classification Framework (see Figure 3-2) at the time of presentation; handwritten notes made during the classes were used to record the researcher's interpretations of the implementation of the analogy with the class. The Analogy Classification Framework was used without modification and classifications were made using the seven classification criteria for each of the 58 analogies.

Once each observation period had concluded, the researcher interviewed each of the six teachers. The interview, which lasted approximately one hour, involved the examination of one or more of that teacher's analogies to focus discussion on theoretical and technical aspects of analogy use and structure within classroom practice. In the interviews, it was the researcher's intent to determine why the teachers chose to use analogies in the manner in which they used them and to determine their beliefs as to theoretical aspects of analogical instruction and learning. The interviews were conducted at the end of the observation schedules so that the interview discussions would not influence the nature of the teachers' explanations. Despite a time lag of up to six weeks between the commencement of the observation period and the interview, when prompted concerning a particular analogy used, no teacher appeared to have difficulty recalling the rationale for, and substance of, a particular analogy. Full verbatim transcripts were prepared of the six interviews and these data were considered in conjunction with the data from the classroom observations.

Data Analysis and Interpretation

The data were analysed and interpreted at three levels. The first level was begun during the classroom observations. This involved the classification of the analogies using the Analogy Classification Framework and the writing of interpretive comments about what was occurring with respect to analogical instruction in the classroom. After the researcher reread transcripts of each analogy and the observation notes, several analogies were reclassified. To assist in the triangulation of the data collection, and in accordance with the methodological position adopted, copies of student textbooks, work-sheets, notes and any supplementary materials, including audio-visual materials, were examined for evidence relating to the study (Mathison, 1988; Yin, 1989).

At the second level of analysis and interpretation, the field notes and the interview transcripts were carefully scrutinised and data were examined in terms of the eight research questions described above. It was found, however, that many of the data that were deemed relevant to the study did not fit readily under the eight research questions. Hence, the data were reorganised and resorted under the four emergent research questions below. This redetermination of the research design was considered to be consistent with the methodological position adopted and the nature of the data collected. The four emergent research questions were:

E3-1. Why did the teachers choose to use analogies when teaching chemistry?

E3-2. What evidence was there of the planning or spontaneity of analogy use?

E3-3. How did the characteristics of the analogies vary from teacher to teacher and from the textbook analogies available?

E3-4. How did the teachers choose to present their analogies to their classes?

Having assembled the data according to these emergent research questions, a third level of analysis and interpretation took place as patterns within the data set were organised under sixteen assertions. For each assertion, supporting evidence was identified to indicate the foundation for the assertion and, where possible, non-supporting evidence also included. Prior to reporting data attributed to these emergent research questions, some preliminary issues relating to the nature of analogy are described below.

Preliminary Issues

In discussing analogies and their use with these chemistry teachers, a shared meaning for 'analogy' was considered by the researcher to be of great importance. Earlier research by Treagust et al. (1992) indicated that some teachers used the term 'analogy' to describe what the authors of that study called 'examples'. In this study, there was good agreement between the researcher and the six teachers. This shared meaning was exemplified during the interview with Warren about an analogy that may be described as being on the fine line between analogy and example – that of a Winchester bottle half full of water being used as an advance organiser *analogy* for chemical equilibrium. This system may also be described as an *example* of a general equilibrium (or physical equilibrium) situation. Below is part of the researcher's (R) interview with Warren (W):

R: One analogy was the Winchester bottle half full of water for establishing equilibrium.

W: Yes.

R: Another was the . . . [interrupted]

W: With respect, that one isn't an analogy, it is an actual example, isn't it?

R: We need to talk about that, as to whether it is an actual example of an equilibrium situation that is analogous to a chemical equilibrium situation.

W: Aha, I see. It *is* analogous to chemical equilibrium, but it *is* equilibrium in its own right. (jli01)

A second preliminary issue was for the researcher to separate instructional analogies from analogies that were used simply as part of the teachers' normal language or as part of the accepted language of chemistry. In the first instance, some phrases of speech were clearly analogical but were not used as part of the explanation of a chemical concept. These included Warren suggesting to the students that they had "slipped into automatic drive" once they had successfully used the skills of calculating the pH of a solution given the concentration of the hydrogen ion (jlt23). 'Analogies' such as these were not considered to be instructional analogies and, hence, were not classified as being analogy for the purposes of this study.

In the second instance, some terms have analogical roots historically, but are not considered to be instructional analogies as the terms have become part of the language of chemistry. Examples of these terms include *buffer* solution, delocalised *sea* of electrons, activation energy *barrier* and the *p*-orbital having a *figure-8* shape. For the purposes of this study, these well used chemical terms were not considered as analogies either.

The third preliminary issue involves the nature of chemistry and chemistry teaching. As chemical concepts are revisited from Year 8 to Year 12 and beyond, simplified models become more elaborated and refinements of a more conceptually abstract nature take place. For example, an atom is a very small positive particle to a Year 8 student but by the time the student has reached Year 12, the nucleus, electron clouds, sub-atomic particles, orbitals, spin, isotopes, etc., have all been added to the atom. In effect, since science is unable to describe exactly what an atom is, we are teaching sequential models. When an analogy (or alternative representation) is used to explain part of atomic structure, for example, it could be argued that the target concept itself is only another alternative representation. This aspect of chemistry teaching was raised by Neil in his interview:

R: Are you suggesting that some model or analogy that has been used earlier is going to be problematic in their [the students'] later learning?

N: Yes, I think it is but I'm not sure how you get around it. Whether you [should] not develop that model in the first place or whether it is better to get over some sort of idea you want to initially on something that is not quite the truth and then redefine that model.

R: Do you see all of what you teach in chemistry as being models and analogies?

N: Well, not everything, but to a large extent – yes – and constantly refining them. I mean, the [students] are always saying "are you going to tell us something else that is not quite the truth?" "Well, no, just redefining what I am doing." And I think that is development – it is progression. Let's face it. If we look at our chemistry over A-level work, the topics at A-level are virtually the same as the topics at the lower level. We are just taking them and extending them a little bit further so you have got to redefine your model. (pni02)

The aspect of 'truth' versus a model was also part of Warren's interview when he responded to a question about analogical limitations by commenting on the 'reality' of the target concept being pursued:

R: How important is it to identify to the students the part of the system or analogy that you are using which doesn't match reality, if I can use that term loosely to describe the chemistry of the system that you want to obtain?

W: Well, the problem is that you are two steps away from reality rather than one and that is the trouble.

R: Let's say, rather than 'reality,' the chemistry you are trying to communicate.

W: The model.

R: Right

W: I mean, in the case of [chemical] equilibrium, of course you are still dealing with a model based upon the kinetic approach to equilibrium and that is still a model. It is a theory. It is not just something that is true in the absolute sense. (jli06)

Here, Warren identified clearly the target concept as being a model (or alternative representation) in itself. These vignettes emphasise the difficulty in characterising and delineating analogies and models. They are presented here, however, to support the decision of the researcher not to describe the chemistry content being taught as analogy even though parts of the content did have the characteristics of alternative representation. This complex relationship may be represented pictorially as in Figure 5-2.

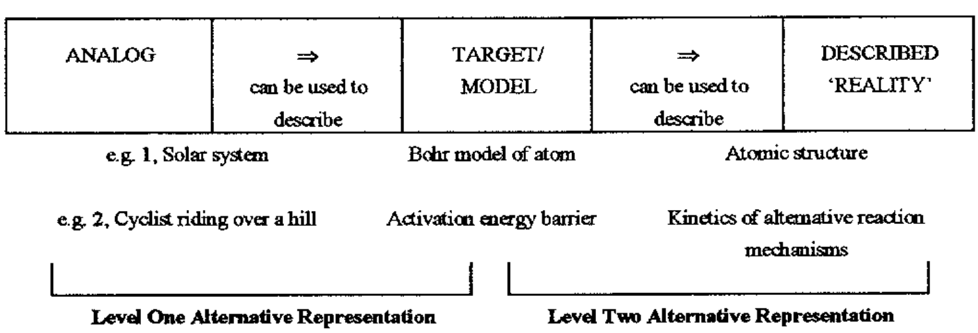


Figure 5-2. Two levels of alternative representation.

Much teaching at the high school level remains at a Level One status although better developed concepts in senior high school approach Level Two. For the purpose of this study, only Level One alternative representations were identified as being analogies. Further, the content matter that may have been described as a model or an analogy was not considered as analogous unless it was referred to as such by the teacher.

Results

The first three assertions (Assertions 3-1a, 3-1b and 3-1c) relate to the first research question concerning why teachers choose to use analogies when teaching chemistry. The fourth and fifth assertions (Assertions 3-2a and 3-2b) provided evidence for the planning or spontaneity of analogy use, the second emergent research question. Assertions 3-3a through 3-3h systematically organise the findings for the third emergent research question based upon the Analogy Classification Framework analysis into the characteristics of analogies. While the use of seven assertions to describe this data set may appear to lack conciseness, the systematic linking of Assertions 3-3a through 3-3h with the seven criteria of the Analogy Classification Framework selected proved fruitful. The remaining three assertions (3-4a, 3-4b and 3-4c) relate to the findings for the fourth emergent research question on how teachers choose to present analogies in their chemistry classes.

Emergent Research Question E3-1: Why Did the Teachers Choose to Use Analogies When Teaching Chemistry?

There was evidence in the classroom observations that teachers used analogies when they were having difficulty explaining some aspect of the chemistry content. On occasions, students would respond to the teachers' questions with incorrect or inappropriate answers. Often, this was a prompt for providing an analogical explanation. For example, Lucas was observed to use analogies with individual students who had come to him at the end of the lesson to clarify a point with which they were unsure (plt02).

Steven commented, in the post-topic interview, that "you can see the strange looks . . . and then you will grasp for analogy at that point to try to make the point clearer" (dsi01) while Craig's interview revealed that he believed he used analogies "in response to blank faces or slightly puzzled gazes" (bci01). In a discussion of why he talked about jam butties to explain equilibrium rate and yield, Warren remarked that it was "an analogy borne of frustration" as he believed the concept was "glaringly obvious but it was very clear that one or two people still hadn't grasped what we were getting at" (jli01). All six chemistry teachers in this study appeared able to ascertain that the students were having difficulty without overt messages to that effect from the students. This was possibly a result of their past experiences teaching chemistry enabling them to anticipate which of the concepts would cause difficulties for the students. Remarks such as "I realise that a bit of extra clarification or explanation is needed" by Craig (bci01), and that analogies were "purely spontaneous reactions to a stimulus" by Lucas (pli01) suggested that the ability to determine, on the spot, when students were not making sense of the instruction may have been an important clue to the opportunity to provide analogical assistance.

Neil commented that "if a group, or a student, is having particular problems, then one tries to search around at that moment to overcome the difficulties that [the] particular student is having." Neil also believed that he used analogies more often for topics with which he had problems when he was a student.

There was evidence from the lessons observed that more analogies were employed for less academically able students. This may have been as a result of these students being less able to offer answers, or correctly answer, the teachers' questions and hence their lack of understanding became evident. Indeed, Steven indicated that analogies would be less necessary with more academically able students when he suggested that, for these students "you may not need so many analogies because the message gets through at a level without using them" (dsi02). Although Neil thought that, "to a large extent, the less-able would probably want more analogies," he reported that:

> I just take the class in front of me and give them the analogies, give them the different models as is necessary and I think they need to pick it up. With some questioning, you can usually judge how well they have picked it up – who has and who hasn't. (pni04)

While the teachers may have felt that the analogies were presented for the benefit of the less academically able students, the researcher noted one occasion in Julie's class where less able students showed some discomfort with the relationship that existed between an analogy and its target (crt16). This was despite the presumption that the analogy had originally been included for the benefit of those students.

> Assertion 3-1a: The teachers used analogies when they felt that the students had not understood.

The sub-microscopic processes and the abstract nature of molecular chemistry created the need for alternative representations such as concrete models and analogies. In attempting to explain how ionic or molecular collisions must occur with sufficient energy for a chemical reaction to proceed, Lucas invited his students to put it in their own "frame of reference" by suggesting to them that they were "trying to visualise" the molecular system (plt01). While Craig used only five documented instances of analogy, each one described sub-microscopic processes such as the dynamic nature of particles at chemical equilibrium, how increasing the concentration of a reactant would increase the reaction rate, and the minimum energy required for a reaction to take place.

Difficulties arose for students in Warren's class as they attempted to solve K_p and K_c problems for the NO_2/N_2O_4 equilibria. When Warren said to the students, "Think of a gas syringe – sometimes a little thought picture will help," the researcher expected that an analogy would follow. However, Warren went on to say:

> How can you visualise this? [silent pause for several seconds] Well, to be honest with you, I have some trouble visualising this too. I tend to resort to a

> sort of mathematical approach by looking at the relationship between P and P^2. (jlt25)

Warren avoided using an analogy in the above instance, by opting to stay within a mathematical framework. Indeed, the researcher noted Warren's mathematical approach to chemistry as a whole (jlt27).

> Assertion 3-1b: The teachers considered that the analogies provided necessary additional visualisation.

Data also emerged supporting the notion that Warren thought analogically also when he was asked the origin of the banking and reservoir analogies for chemical buffer systems:

> Even as mature adults, I think, we tend to flip between concrete and abstract. I don't think there are many of us who think entirely in the abstract and I think we are forever drawing upon analogies, concrete examples, and so I probably thought about those when I thought about buffers in the first place. (jli03)

Other teachers, Julie and Lucas, indicated that they thought analogically and that this influenced their teaching methods. For example, Julie commented in the interview that she used analogies because that was the way she thought and she believed that the students primarily thought that way too. She stated that "most concepts are difficult for kids . . . so you go with real life experience – they can grasp it then" (cri27).

> Assertion 3-1c: Some teachers believed that their own thought was predominantly analogical.

Emergent Research Question E3-2: What Evidence Was There of the Planning or Spontaneity of Analogy Use?

Most of the analogies that were presented by the teachers appeared to be direct responses to subtle stimuli provided by the students, as has been discussed above. Two of the Australian teachers, Julie and Lucas, had pre-planned some of the analogies presented early in the observation programme. This was possibly a response to the presence of the researcher in the classroom and partial knowledge of the research focus. After several observations, however, teachers appeared to use analogies more spontaneously. In the interviews, it was suggested by Lucas, Julie and Steven, that those analogies which were pre-planned tended to be those used every year in their teaching anyway.

Julie acknowledged that she would never have written analogies down in her preparatory teaching notes as she changed them from year to year depending upon the students and their experience (cri27). Of the 17 analogies that Lucas was observed to use, he did have two analogies included in his teaching notes. One of these was a new analogy that he had recently discovered while examining the Salter's A-level Chemistry packages (Ramsden, 1992). He had been impressed with the analogy of the water flowing into a sink as a contextual introductory approach to the ozone layer and he had decided to use it with his chemistry class (plt08). This decision was made prior to him being invited to be involved in the study. The other analogy that he had recorded in his teaching notes was one that he had used in prior years.

Craig felt uncomfortable with the prospect of a planned analogy as he felt strongly that the success of analogy had more to do with timing and placement than with planning. He commented that "the idea of hitting on something on the spur of the moment can possibly be more effective because it is a response to . . . an appreciated difficulty" and that "in response to a perceived difficulty, they [analogies] can be finely tuned at the time and made more relevant rather than 'Well, this is the analogy'" (bci04). Neil supported this idea by arguing that analogies should be "short, snappy things" rather than complex things which will make life very hard for the students (pni09). Despite this reluctance on the part of most of the teachers to document their analogies in their teaching notes, however, there was support for the notion that each teacher mentally maintained a working repertoire of analogies that were retrieved in response to stimuli from the students. Steven's interview remark, that "you build up a sort of knowledge bank of these [analogies] and then you modify it a bit" (dsi01) added emphasis to this notion.

Those analogies that were spontaneously presented or generated often exhibited clear surface similarities which tended to be the source of analogical access structures. For example, analogies for molecular collisions often drew analogs from other types of collisions, analogies for rates of reaction often drew from other rate-related analog domains, and a similar occurrence was evident for concentration-related analogies. As was to be expected, this was the case most frequently with functional analogies rather than structural analogies.

On several occasions, Julie invited her students to create and recall analogies on the spot to describe newly learnt chemical concepts. Students frequently began with a simple term, such as collision, rate, or concentration in the search for a suitable analog. These student analogies did share some appropriate surface similarities, however, they often lacked depth and had little potential to draw more powerful connections between the two domains.

> Assertion 3-2a: There was little evidence that the teachers pre-planned their analogies.

All four of the classes that were observed in Australia used the same chemistry textbook. That textbook was examined in an earlier stage of the study and found to contain only two analogies which were in topics other than those being taught in the classes at that time. Both of the student textbooks used in the classes in England were scrutinised for analogies. While several were found in each textbook, they were not the same as those used by the teachers. Hence, for each of the six classes it was assumed that the normal student textbook had not supplied the teachers and students with analogies from which they could work.

Some teachers tended to draw upon analogies which employed an analog domain from the experience of the teacher more than the experience of the students. For example, Craig, who used the mountain pass analogy for activation energy and catalysis, described a mountain system in Switzerland rather than direct the students' thoughts to the hill regions nearby to the school (bct18). Another Australian teacher, Steven, used the activities of chipmunks in snow covered countries to describe endothermic and exothermic processes (dsi05). While many students may have been familiar with these ideas, it is possible that other examples, akin to Australian conditions, may have been more relevant to the students. There were examples, however, of where the teachers did use analogs that were directly relevant to the students. In several instances, teachers referred to a forthcoming student dance or ball (plt04). This appeared to have a reasonably motivational effect, do doubt due to some added intrinsic interest for the students.

Lucas showed that his repertoire of analogies had been enhanced by his professional activities including his reading and viewing of chemistry-related materials. As previously mentioned, one of his analogies had come from the Salter's A-level Chemistry packages he had reviewed. When Neil was asked the origin of the scaffold structure analogy for the molecular arrangement of ice, he commented that "it is something that I tend to use year in and year out but it has always occurred to me, perhaps because of my interest in the construction industry. I always said I should have been a builder instead" (pni01). Steven had developed a considerable repertoire of analogies over the years – many of which he had developed from first principles himself. He commented, during the post-topic interview, that analogies "come from your experience of everyday life and you see similarities in the system you're trying to describe" (dsi01). For these chemistry teachers, one of the experiences of "everyday life" was teaching other subjects such as Physics. Julie referred to the scores of physics students on a graph to communicate the basics of the Boltzmann distribution. Lucas used several analogies that drew analog domains from physics or physical aspects of chemistry to describe or develop new chemistry concepts. For example, he contrasted the temperature dependent equilibrium constant with the nature of a physical constant in physics (plt32). Also, Lucas compared the driving tendency of a reaction to reach chemical equilibrium with the tendency of objects to settle at the lowest possible gravitational potential energy, and demonstrated the concept by noisily dropping a plastic object to the desk from a considerable height (plt34).

On several occasions Lucas explained chemical concepts to students who had given clear indication that they did not understand by their inability to answer questions correctly or by their asking questions directly of him. In some of these instances, Lucas was observed to look around him for some object or prop about which he could base an analogous explanation. For example, the plastic object mentioned above and an elastic band (in a later incident for the benefit of one student only) were used to describe how a system tends back to a state of equilibrium after a disturbance (pli01). Also, a white-board marker had its cap removed to describe how energy is required to break bonds in a chemical system (plt13). With the latter analogy, Lucas attempted an extension to show that energy is released as a system is restored with the formation of bonds (by replacing the cap). The researcher, identifying this extension as having a less suitable attribute match, discussed this analogy with Lucas during the post-topic interview and discovered that he traditionally snapped a chalk piece in two but, due to an update in the classroom facilities, there was no chalk readily available (pli02).

Both of the teachers in England used the water transfer analogy to develop the concept of chemical equilibrium. In this analogy, the teachers arranged two glass bowls – one of which was originally half full of water. Taking two plastic scoops or beakers, they then began to transfer water from the left-hand bowl into the right hand bowl. Simultaneously they attempted to transfer water from the empty, right side bowl to the left. As this simultaneous scooping continued, the net flow of water from the left to the right eventually ceased such that an equilibrium position was maintained despite the continuation of the transference. Both of the teachers talked the students through the analogy and related it to the chemistry under study. In addition, each extended it to discuss the workings of either a catalyst or of increasing the temperature. Having discussed this analogy with the teachers during the interviews, the researcher drew the conclusion that this demonstration was commonly used by chemistry teachers in England when introducing equilibrium. Indeed, there was evidence from both of the lessons that some of their students had seen similar demonstrations in previous years and, in the case of Neil, some had seen it at a special chemistry Christmas lecture put on by the teachers at that school for students and interested parents. All of these 'device' analogies were functional in nature and were somewhat more loosely fabricated than conventional 'analog models' (Gilbert & Osborne, 1980) such as ball and stick representations of molecular structures.

While the textbook used by Lucas's students contained only two analogies, a short videotape on the topic of reaction rates that the students viewed as part of their instruction contained several analogies (plt07). When asked, Lucas recounted that the videotape was one that he used annually with Year 12 chemistry students. In Neil's class, several computer simulations were displayed to the students as they studied the topic of chemical bonding. One page of text that accompanied some representations of atomic and molecular orbitals had the following display:

> Hydrogen atoms are usually found joined or combined to other atoms. To separate a single atom of hydrogen, it is necessary to give it a lot of energy. So a single hydrogen atom, like this [indicating the accompanying diagram], will contain a large amount of energy, like a ball at the top of a slope. When a hydrogen atom combines with another atom, it usually loses energy (like the ball rolling down the slope). To enable it to lose energy, the atom can join with another atom of hydrogen so that the two electrons occupy the one electron cloud. (pnt11)

Despite showing the T. V. screen to the students, and commenting upon the pictures, the teacher made no reference of the presence of the analogical text on the display. Indeed, as the size of the text was too small to be read by students at the back of the class, some would not have been aware that an analogy had been included in their instruction.

Assertion 3-2b: The teachers tended to draw upon their own experiences or their own professional reading as a source of analog domains.

Emergent Research Question E3-3: How did the Characteristics of the Analogies Vary from Teacher to Teacher and from the Textbook Analogies Available?

One of the intentions of the research was to examine the analogies used by the teachers to see how the characteristics of these analogies differed between teachers and how they differed from the characteristics of analogies examined in the textbook study (see Chapter 3). The Analogy Classification Framework was used for this examination. Tables 5-1 and 5-2 provide summaries of the Analogy Classification Framework results for each teacher.

Table 5-1

Summary Table of Analogies Showing Their Analogical Relationship, Presentational Format, Condition, and Position

		Analogical Relationship			Presentational Format		Condition			Position		
Teacher	n	Struc	Func	Str/ Func	Verb	Pict/ Verb	Con/ Con	Abs/ Abs	Con/ Abs	Adv Org	Emb Act	Post Syn
Craig	5	0	5	0	4	1	0	0	5	0	5	0
Julie	13	1	9	3	8	5	1	0	12	0	13	0
Lucas	17	0	14	3	7	10	2	2	13	3	13	1
Steven	10	0	3	7	7	3	1	0	9	1	9	0
Neil	7	1	1	5	5	2	1	0	6	1	6	0
Warren	6	0	4	2	4	2	0	0	6	1	5	0
Total	58	2	36	20	35	23	5	2	51	6	51	1
%	100	3	62	35	60	40	9	3	88	10	88	2

The use of functional (36, 62%) and structural-functional (20, 35%) analogies was far more frequent than structural analogies (2, 3%). While it is tempting to argue that this result more likely reflects the nature of the content area rather than a particular choice by the chemistry teachers, the data for the textbook study are not dissimilar (see Chapter 3). The only structural analogies used were the dumb-bell shape representation for the *p*-orbital, and the use of a graph of students' scores in Physics to represent a Boltzmann curve. The enthalpy graph of a chemical reaction was a frequent focus for the structural part of structural-functional analogies. Other foci for structural-functional analogies were the topics of atomic structure and bonding. Neil, who was teaching on these topics for approximately half of the observation schedule, used structural-functional analogies almost exclusively.

Assertion 3-3a: The teachers used predominantly functional analogies.

While the majority of the analogies were presented in verbal format, 23 (40%) analogies were presented with a pictorial component (see Table 5-1) drawn on the black/white board by the teacher. Lucas used ten such analogies while the other teachers used analogies in the ratio of approximately one pictorial to two verbal analogies. Julie commented that she used pictorial analogies as an aid to the students' imagination and because it helped her to express what she saw in her own mind which she believed to be predominantly pictorial (cri29). Craig made use of a pictorial analogy to describe the structure of the Swiss mountain range and mountain pass in his analogy for catalysis (bct18) and Lucas used diagrams of analog domains on the white-board as a basis for drawing conclusions about the target concept. He would often write the target and analog attributes/ideas in different coloured pen (plt22) or differentiate the target ideas from the analogical diagram with a vertical separating line (plt08). For the purpose of this study, the demonstrations such as the water transfer analogy and the Winchester bottle performed by the British teachers were classified as pictorial.

Assertion 3-3b: Both verbal and pictorial-verbal analogies were frequently used in the lessons.

Fifty one (88%) of the analogies were of the concrete/abstract type where the teacher used concrete-type analogs to describe an abstract target. This was especially obvious with the analogical 'device' type analogies referred to above. As was to be expected, teachers rarely found the need to support concrete targets with analogies (5, 9%). Even less frequent, as shown in Figure 5-1, was the use of an abstract analog to support a chemical concept (2, 3%). These data support the assertion that these teachers used analogies in an appropriate way as a bridge from concrete student knowledge and experiences to new, abstract concepts.

As previously mentioned, when asked about the concreteness of analogies, Warren commented that: "I don't think there are many of us who think entirely in the abstract and I think we are forever drawing upon analogies" (jli03). He went on to describe his "favourite analogy" of bicycle parts for chemical stoichiometry – one that he used so frequently that the students had come to regard it as a joke. But he stressed that the analog had to be familiar to the students and further emphasised this by describing how he taught electrostatics: "Whenever I talk about like charges, I immediately move to magnetism because they [the students] have actually got hands-on experience in that and I think that it is a very important difference" (jli05).

> Assertion 3-3c: The teachers overwhelmingly used concrete analog domains to describe abstract targets.

Both Craig and Julie used analogies only as embedded activators – that is, they introduced the analogy after they had worked the target to a point where clarification was required. As has been described, analogies were often used in response to the students in the class not understanding the target. Steven confirmed that he would prefer to be:

> dealing with the chemical concept and bring in the analogy at the point that I thought that it was necessary to amplify or clarify the chemical concept. I think I'd do it that way more than start from the point of view of the analogy and then work through to the concept (dsi02).

The other three teachers used predominantly embedded activators (see Table 5-1) although, between them, they did use six analogies as advance organisers.

For a planned analogy like the water transfer analogy, there was support for the advance organiser approach from Neil. When asked why he chose to use the analogy prior to the development of the topic, he responded:

> It is a lovely start to get over many of these essential ideas of rates of reaction and position of equilibrium one side or the other. It covers the first side of the notes really. And, if I've done a set of notes, there's not much point in doing that [the analogy] if they understood what I've done on the board. So, it is really an aid to understanding the notes they are going to make. (pni07)

Only one example of a post-synthesiser was identified, this being a metaphoric one-line statement by Lucas to deal with a side issue. It should be noted that the analogies provided by the teachers for individual students, such as during after-class questions, were not classified as post-synthesisers despite their presentation after the target as this was not considered to be a valid classification. Rather, as they were a response to a student question and embedded within an explanation, they were classified as embedded activators.

> Assertion 3-3d: Analogies were most frequently presented as embedded activators rather than as advance organisers.

Analysis of the analogies employed in teaching chemistry revealed that the teachers had used simple analogies (19, 33%), enriched analogies (27, 46%), and extended analogies (12, 21%) with little clear preference for any one type as shown in Table 5-2. In addition, all of the teachers used each of the three types on at least one occasion. In the post-topic interview, the researcher questioned Lucas as to why he chose to develop some analogies and not others, to which he responded that he saw some analogies as being more powerful than others and, hence, he was more likely to map those more fully. Analogies that were less powerful he "just lets ride." When asked the same question, Craig introduced the additional factor of the brevity of a simple analogy over an extended analogy when he proposed that a "more developed analogy costs a lot of time and so you've got to be sure . . . that it is going to be useful" (bci02).

Table 5-2

Summary Table of Analogies Showing Their Level of Enrichment, Pre-topic Orientation, and Limitations

		Level of Enrichment			Pre-topic Orientation				Limitations	
Teacher	n	Simple	Enriched	Extended	Analog Expl Only	Strategy Ident Only	Both	None	None	Specific
Craig	5	1	3	1	3	0	0	2	4	1
Julie	13	3	6	4	11	1	0	1	12	1
Lucas	17	7	6	4	11	0	3	3	11	6
Steven	10	4	5	1	9	0	0	1	10	0
Neil	7	3	3	1	3	0	0	4	5	2
Warren	6	1	4	1	3	0	1	2	5	1
Total	58	19	27	12	40	1	4	13	47	11
%	100	33	46	21	69	2	7	22	81	19

Simple analogies often comprised sharp metaphoric statements such as a surface catalyst holding a reacting species "like a pig on a barbecue spit" (crt13), or a system having reached chemical equilibrium as having reached "a stalemate" and not being "frozen" (bct20). Enriched analogies, having one attribute clearly mapped by the teacher, included sibling rivalry for competing species in a complex equilibrium system where particular species were identified as being the "big brother" and the "little brother" (dst07). Extended analogies, having several or many mapped attributes, included Lucas's elevator analogy for a system at equilibrium (plt22) and Julie's school dance or ball (crt02). In both of these analogies, many characteristics were drawn out of the analog domain and applied to the target concept. So much so, that both of these analogies were used by the respective teachers over several consecutive lessons.

While there were clear examples of attempts to map between the two domains such as in the water transfer analogies, a strategy often employed was to use analog and target terms interchangeably throughout the explanation. Alternatively, there was rapid swapping between the domains as the teacher drew conclusions. Another style of mapping was observed in which students were invited to either answer questions about the target domain from a stated analog attribute or to suggest how the analog could be better shown to represent the target concept (crt21). This mapping did prove problematic for less-academic students or those who may have been confused with the analogy. For example, a student in Julie's class exhibited much difficulty when asked to do a related task. In Julie's interview, she commented that:

> [this student] in particular, has got some problems understanding [chemistry concepts] and so I think that an extended analogy would be too much for her anyway. . . . So maybe, with [student's name], I think she has to break up her information into very small bits and so she has to have a different analogy for each bit (cri33).

The researcher noted other instances where academically less-able students appeared to be confused by extended analogies. In several of these instances, it was possible that the time and effort allocated to understanding the analogy may have interfered with the students' ability to transfer appropriate attributes to the target domain and the analogy may have contributed additional 'noise' to the learning task (Johnstone & Al-Naeme, 1991).

> Assertion 3-3e: The teachers varied the extent of mapping depending upon perceived needs and circumstances.

It has already been emphasised that some of the analogies had been drawn more from the teachers' experience than from the students' experience. This may have resulted in a degree of analog unfamiliarity such that students did not make the correct connections between the analog and target domains. Attempts at special analog explanation, a description of the analog's attributes, to overcome that problem were of interest to the researcher.

There was evidence that analog unfamiliarity was a problem in some instances. For example, when Julie attempted to relate the responses of an exo/endothermic equilibria system to temperature change with the homeostatic principles of the human body, some students were clearly confused. One of the students remarked that she "understood all of that [pointed to the target content on the board] but now I'm confused" (crt21). In the interview, Julie attributed the difficulties encountered to the students' lack of biology background. In another instance, Julie started to use the pole-vaulter analogy for activation energy but stopped mid-sentence and went back to the target. She later commented that it just "didn't feel right" as most of the students in the class did not like sport and many would actively avoid it. Hence, the analogy was abandoned, the teacher deciding that there would have been a lack of analog familiarity and student interest and motivation (crt08).

Neil, who used the scaffold structures analogy to aid his description of the collapsing of ice as it melts, introduced it to the students by saying "think of a scaffold. Do you know what a scaffold is?" The researcher noted that he took a look around the class, satisfied himself that students were cognisant of what scaffolding was, and then continued. Neil commented later that "there is no point in making the analogy if they don't know what scaffolding is" (jli01). When Craig introduced an analogy of a 'coconut shy' for the effect of increasing the concentration of reactants upon reaction rate, he asked the students if they knew what a 'coconut shy' was. Receiving several responses to the negative, he briefly explained the workings of the traditional English fair-ground attraction:

> You can imagine if you went to a coconut shy. Do you know what a coconut shy is? [Pauses while a few students shake their heads.] You don't know what it is? Have you ever been to a fair? You get this ball and you throw it at the coconut and if you hit the coconut and knock it off [its stand], you keep the coconut. Let's say you are a pretty average shot and you have got five balls and your average is one out of every five balls will knock a coconut. . . . But if you pay for 15 balls, . . . how many coconuts will you get? You will get three coconuts, all right? So, you would have got more coconuts even though you still only get one in five. That is what is happening here [referring to the chemistry concept]. You are getting a small proportion of successes, some of them will react. But if you have more tries – that is a greater number of collisions – you will get the same proportion of successes but because you

are having many more collisions, you'll have an increased rate of reaction. (bct17)

In discussing this analogy with colleagues, the researcher noted that North American colleagues appeared unfamiliar with the 'coconut shy' concept and this would not prove a worthwhile analogy for students from this part of the world. Similarly, while observing Warren teach chemical equilibrium, the researcher was amused to observe that teacher describe industrial yields of chemicals as being similar to 'jam butties' on a conveyor belt (jlt26). While the researcher was left somewhat unsure of just what a 'jam butty' was (it is a jam sandwich), the students appeared to understand the relationship.

Seeking to ascertain analog familiarity and providing analog explanation appeared to reduce the effect of the original analog unfamiliarity. As has been described above, Craig also used a pictorial analog in another example to provide additional explanation for an unfamiliar situation. In his interview, Lucas stressed the importance of open two-way communication between the teacher and the students when an analogy is used so that the teacher can efficiently ensure the students' understanding of the analog.

Lucas was observed to have used analogies for individual students who asked questions after the formal lesson had concluded. Generally, those students were not Australian by birth and analogical unfamiliarity may have been a problem. In one instance, Lucas described the instantaneous dipole that is formed by variations in electron position by referring to the wobble of jelly in a container. Before finishing the analogy, however, Lucas checked with the student that he understood what the teacher meant by "jello or jelly." In the interview, Lucas stressed the advantage of one-to-one communication with students when using analogy, as it allows teachers to more efficiently solicit student understanding of the analog domain (pli03).

The analysis of all analogies used by the teachers showed that 44 (76%) of the analogies included some form of analog explanation, this result being generally higher than other studies relating to textbook analogies have revealed. This result may indicate that the teachers are more willing to embellish the analogy for their students. It also may have been a result of the heightened awareness of analogy due to the presence of the researcher in the classroom for the Australian teachers who were aware that the investigation was related to teachers' use of analogies.

> Assertion 3-3f: When analogies were used, analog explanation was frequently employed by the teachers.

When asked whether she thought it was important to state to the students that some instruction was analogical, Julie proposed that "some of the kids are a bit lacking in experience and so you have got to sometimes define for them, like you would in any experience, this is the reality and this is the 'whatever'" (cr127). Similarly, Steven believed that "we need to distinguish between the reality and the method used to describe the chemical reality" (dsi01). Despite these comments, only five instances of pure strategy identification were recorded representing less than ten percent of all analogies. These were instances in which the teacher referred to the analogy as "an analogy" or "analogous," etc. Julie referred to one explanation as being "an analogy" after the event and Lucas used the term three times over the topic. Craig proposed that there needed to be an obvious indication that an analogy is being used. He said that the identification tended to come in the opening sentence in the form of "It's as if" or "like" (bci01). The data were re-examined to determine if these less-pure forms of strategy identification were employed by the teachers and this was found to be the case. For example, Lucas often used the phrase "It is as if . . . ", Craig said "You can imagine if . . . ", and Steven introduced the analogy by proposing "Let me give you something that will help."

In contrast, the distinct change in Julie's teaching style when she used analogies left the students in no doubt that an alternative representation was being employed. A lighter atmosphere pervaded the lesson and the teacher frequently laughed at these times. In Lucas's class, this distinction was not as clear – he often used the terms "model" and "real-world model" to describe the analogical component of any instruction (plt28). He suggested that he would be unlikely to use the term "analogy" as he doubted that the students would understand the meaning of the term (pli04).

> Assertion 3-3g: The teachers rarely used pure strategy identification to explain the use of analogy.

Statements concerning the limitations of the analogies were obvious end-points of Lucas's thorough mapping of most of the analogies. In some cases, the students questioned aspects of where the analogy "broke down" and in other instances Lucas extended the target to show that the analogy would not be suitable for a particular attribute. Julie stated some limitations also, as evidenced by one of her students (John) who made up and described his own analogy for catalysis by describing how a shy girl is helped, by her more socially adept twin sister, to date a male friend. Having highlighted the positive aspects of the analogy and praised the student, Julie redirected the classes' attention back to the analogy:

> What is the big BUT in John's story? [Questioning pause.] Listen, what didn't John finish off with, or what didn't he tell us was always going to be the consequence of that story. . . . The shy sister was always going to come off with the man. . . . Catalysts speed it up, but would it make a reaction go that was never going to go? [Students respond in the negative.] So bear in mind that with John's little story, it may take a long time but eventually they were always going to get together. (crt16)

Again, Julie intertwined the analog and target in her explanation, in this case drawing on the students' developing notions of catalysis to reform the analog.

In the case of the water transfer analogy, Neil's first attempt resulted in the two glass bowls having approximately equal amounts of water in them at equilibrium which may communicate the misconception that equilibrium means equal amounts rather than equal rates. The researcher quizzed Neil about the importance of identifying the limitation of that demonstration to the students:

> Yes, very important. I don't want them to go away with an artificial concept, to reinforce misconceptions and that [the equal water levels], if one didn't swap the beakers over, would have [reinforced misconceptions]. Because, I think, the biggest misconception with equilibrium is that it is right bang in the middle – the halfway point. (pni06)

In Neil's demonstration of this analogy, he repeated the transfer in front of the class, having swapped one of his transfer containers for a smaller one. The end result of this second transfer was that a suitable equal rates equilibrium was eventually established with significant differences in the two water levels. Nineteen percent of the analogies used by the teachers had associated limitations, which was much more than the nine percent of analogies with associated limitations from the textbook study (see Table 5-2).

> Assertion 3-3h: Clear statements of analogical limitations more frequently accompanied teachers' analogies than did those found in textbooks.

Emergent Research Question E3-4: How Did the Teachers Choose to Present Their Analogies to Their Classes?

While the nature and structure of the analogies used has been discussed above, it was considered important to describe also the manner in which the teachers used analogies and any particular strategies that they employed while using them.

The researcher noted a lessening of the formal atmosphere in most classes when teachers used analogies. In some cases, the content and phrasing of the analogy was such that students would laugh or smile. This may have been due to the teachers indicating that this was a side issue to the target concept. Alternatively, the nature of the stories and the occasional use of students' names in the analogies seemed to increase general student motivation. As mentioned above, Warren's bicycle analogy had become a joke for the students as he continually revisited it. In a teaching instance, Julie used the analogy of the school dance/ball several times to help students understand the factors affecting rates of chemical reactions (crt02). In doing so, she identified some students by name and included them in particular activities related to the dance. This involved these students into thinking about the concept which increased the relevance for students and hence, heightened their motivation. The use of students' names in verbal analogies tended to occur more frequently with passive, personal analogies.

Julie saw this type of teaching as being an important variation in her normal style. She commented in the post-topic interview that, while she saw analogy as "a less formal way to teach," there was a need for some humour as "to sit there, like the kids have to do, would drive [her] insane" (cri30). Steven also said that when he taught with analogies he would "become a bit more animated and act out a role a bit and throw [his] hands a bit more, use [his] voice a bit more" (dsi02). Craig too, was prepared to act in a "more humorous way" when using an analogy although he didn't see this as a change in behaviour that was especially related to analogy use. Rather, it was another facet of his teaching behaviour designed to attain particular learning outcomes (bci05).

In a similar manner, both Julie and Lucas saw analogy as a teaching strategy that was most effective within the context of a teaching environment where the teacher was well aware of the individual interests of students. The use of these interests in the analogy was considered to enhance their relevance and interest. Lucas suggested that, as he had just started teaching that class of students, he did not yet know their interests and that this lack of current knowledge influenced his use of analogy. Later in the year, he would know "which one is a basketball player, a rower, a debater" and be able to present the analogies to suit (pli03). Julie, who commented on student teachers that she had observed attempting to teach with analogies, remarked that the student teachers have "got to make sure that they are aware of where the students are coming from. . . . It's worth investigating what the students' likes and dislikes are, to get to know them" before you use analogies" (cri35).

> Assertion 3-4a: Teachers tended to adopt a less formal manner when analogies were being used.

Possibly as a type of strategy identification, the teachers sometimes commenced the analogy with a statement to the effect that it was clearly an unreal situation. Lucas, who used an analogy of the rates of spread of good and evil forces through an isolated village community to illustrate competing forward and reverse rates within atmospheric ozone equilibria, introduced the analogy by remarking, "I'll tell you a silly story" (plt11). Later, before commencing another analogy for competing rates, he discussed with the students what they would do "before we move on to what some of you might consider a fairly trivial issue – our person going up a 'down' escalator" (plt21). Steven used an analogy of feuding neighbours throwing bricks over each others' fences to explain the same concept of competing rates at equilibrium. When the students laughed after the analogy had been shared with them, Steven suggested to them that it was a "silly one, but the silly ones are like cartoons and they stick there" (dst03). Similarly, Craig proposed that "the more ridiculous [they are] the better, as long as they are accurate and effective" (bci02).

When Craig was using the mountain pass analogy for the effect of a catalyst on reaction energy requirements, he initially described a personal event where he had difficulty climbing a high mountain in Switzerland. Later, he said to the students; "But, if Dawn were doing it, she would say 'No, no, Mr. [teacher's name]. Let's go by an alternative pathway, let's go over the Saddle,'" a nearby mountain pass (bct18). This had the effect of drawing all students (especially Dawn) in to the analogy which may have offset the lack of analog familiarity described above. Julie used several role plays that were analogical in nature (analog models using humans to model particles). This also involved the students though in a more active role (crt15). Some students were invited to role play an equilibrium reaction A + B $\rightarrow$ C to describe the effects of changes in pressure (by a change in volume) on the equilibrium position. Though the students appeared comfortable while engaged in the role play, the researcher was not convinced that the students were able to draw suitable conclusions. To form molecule C, students A and B stood together with linked arms. For the unaware student, this A-B combination, as C, appeared to take the same space as A and B separately. Hence, a discrepancy existed between the monatomic status of gas C, and the apparent diatomic molecule A-B. With the representation of molecule C taking up twice as much space as molecule A or B, the misconception that the volume of any gas is proportional to the size of its molecules rather than to the number of molecules present may have been supported.

Passive roles were used as Julie fabricated stories related to human relationships to discuss reaction rates, by identifying the names of students in the class. Also, in relation to the personalisation of analogy, Julie was observed to make several anthropomorphic analogical statements such as comparing a chemical system at equilibrium to a sense of personal satisfaction and comfort. For example, she made statements such as "happy in equilibrium" and "we try to get back to what we like" (crt21).

> Assertion 3-4b: The teachers appeared frequently to devalue the content of the analog domain when presenting analogies to students.

While the researcher had anticipated that he would observe teachers using analogies, he was interested to see Julie invite students to put newly learnt chemical information "in their own words" and recount it analogically using their own experiences (crt04). At the conclusion of the topic, when questioned about the rationale for this approach, Julie suggested that if students were able to transfer the target back into some analogical framework, then they had shown better evidence of conceptual understanding than if they had just repeated the textbook's or teacher's terminology in their responses. Over the years, this method had become an entrenched strategy in her teaching repertoire (cri28).

Of particular interest to the researcher were the expectations that teachers had of students in respect to analogy use. The ability of the students to use the analogy at the moment of application and later perhaps as a study device or aid was considered to be related to this. There was evidence from the observations and interview that Steven saw the analogy as being only of temporary value. Steven expanded upon this in the interview when he suggested that the analogy is a means to an end and not an end in itself:

> [The analogy] has no importance in itself. . . . The only importance is to help you to know what to do in a chemistry problem situation. Once you know what to do, and the steps involved, then this is irrelevant and has no further purpose. (dsi04)

Julie's expectations were similar. Having discussed the analogy of the shy twin sister described above, she instructed the students to ensure they "never write the analogy down" (crt15).

In an attempt to determine if the students carried the analogy into their cognitive arrangement of the target, the researcher examined the students' responses to several essay type questions on reaction rates that were written at the end of the topic. These essays (each between one and three pages in length) were written by students of Julie and Craig. Of the 18 essays examined, only two contained any evidence that analogies had been included in the instruction. This evidence was in the form of the metaphoric terms "activation energy barrier" and "alternative reaction path" (crt25). However, these terms are used in the language of chemistry textbooks to such an extent that they are not usually considered analogical. A small number of the students used anthropomorphic statements to describe chemical systems such as "the system tries to keep its temperature constant" and "the system will try to partially counteract this change." There was no indication that the anthropomorphic statements were related to the analogies employed or that they were more frequent as a result of the style of instruction.

During the post-topic interviews, Lucas, Neil and Warren all indicated that they saw a more lasting role for analogy and hoped that the students could retain the analogy for later use (pli06, jli08, pni08). There was disagreement, however, as to whether the students should copy the analogies from the white-board into their study notes. In fact, after using an extended pictorial analogy that had been thoroughly mapped, Lucas told the students that "at this stage we should close the model." He then proceeded to erase from the board all details relating to the elevator analog leaving only those target details that were concluded from the analogy (plt23). When the researcher questioned him about this strategy during the post-topic interview, Lucas remarked that it was not a prepared strategy and he could not recall having done it for any particular reason (pli06). Contrarily, Neil indicated to the researcher that he had included analogies into the handout notes for younger students and that he encouraged students to revisit these analogies if they found them fruitful (pni05).

> Assertion 3-4c: There were different expectations of how students should treat analogies in learning about target concepts.

Conclusions

Sixteen assertions have been drawn from this study into chemistry teachers' use of analogies to explain abstract concepts. The assertions are described above for each of the four emergent research questions. The six teachers observed in this study each used analogies to illustrate the abstract nature of the chemistry that was being taught. While analogies were occasionally planned as part of the teachers' strategies for particular lessons, most were used as a response to stimuli from students or groups of students. These stimuli may have been puzzled looks on students' faces, questions from students or the students' inability to correctly answer a question proffered by the teacher. Related to this was the finding that almost 90% of the analogies were presented as embedded activators which supports the observation that analogies were used in a reactive mode rather than a pro-active mode. The students who provided the stimulation for an analogical explanation were often from the less academically able sub-group. This observation suggests that analogical explanation may be offered more frequently to less academically able students whom the teachers believed required additional visualisation. This supports the findings of Friedel et al. (1990) that analogies may be more effective for students of lower formal reasoning ability but not especially useful for the more capable students. In some cases, analogies were demonstrated using specially provided equipment (the Winchester bottle and the water transfer apparatus); in other cases, the teachers used 'device' analogies to provide concrete representations of abstract concepts. The argument that analogies are used to provide additional visualisation at a concrete level is further supported by the Analogy Classification Framework analysis indicating that 88% of the analogies comprised a concrete analog to explain an abstract target (see Table 5-1).

Be they spontaneous or planned, the analogies that were used for the topics of atomic structure, bonding, reaction rates, energy effects and chemical equilibrium were similar to those found in chemistry textbooks with some slight adaptations for context. The textbooks that were used by the students, however, did not appear to contribute to the analogy repertoires of the teachers. While there was evidence that audio-visual and computer programmes shown in some of the classes did contain analogies, the teachers provided no elaboration of these analogies for the benefit of the students. On occasions, the students' names and their interests were used as a context for a particular analogy and this appeared to have a motivational impact upon the students. Analogy sources were varied with evidence that teachers' (a) own learning experiences, (b) professional reading, (c) curricular alternatives such as audio-visual devices, and (d) informal discussions with colleagues were all useful sources. The British teachers shared the water transfer analogy and, from speaking with other chemistry teachers in England, the researcher identified this as a common way to introduce or represent chemical equilibrium at the high school level. In the early 1990's, the researcher conducted many seminars and workshops in Australia on the topic of analogies in chemistry teaching. During these meetings, teachers have often discussed their favourite and well-used analogies, yet the water transfer analogy has not been mentioned and, to the researcher's knowledge, it remains relatively unknown. The historic background of this analogy, and its resulting influence on students' conceptions of chemical equilibrium, may prove an interesting future study. The other analogies used by the British teachers did not appear particularly country specific ('jam butty' aside) and, given the great similarity between the chemistry curricula of the two countries and the culture of the two societies, this was not surprising.

Teachers sometimes drew on analogs that were the province more of the teacher than the student and this appeared to result in difficulties for some students. This problem of analog unfamiliarity was sometimes reduced by drawing the analogs from what are frequent student experiences. Alternatively, some teachers asked their students if they were familiar with the analog at the commencement of the analogy. Approximately 40% of the analogs had a pictorial component and the pictorial analogs were employed in a variety of methods including some 'demonstration' analogies such as the water transfer analogy for chemical equilibrium. The extent of mapping varied markedly between analogies with some having well mapped attributes and limitations and others left as short sharp statements. Despite this finding, as illustrated by the data in Table 5-2, each teacher appeared to use a spread of simple, enriched and extended analogies.

When considering how these teachers used analogies, the researcher contends that two key competencies were demonstrated by these teachers which, when functioning together, facilitated the provision of useful analogical explanations for some of the abstract concepts that were part of the subject matter being studied. The first of these competencies lies in the teachers' good content knowledge; the second in their experience with how students learn and the need for alternative representations for some students. It was evident to the researcher that these teachers' abilities to use an analogy to the advantage of their students, to map clearly, to extend the analogy when appropriate and to identify suitable limitations, was dependent upon their skills with respect to these two competencies. In addition, each of these teachers had a good relationship with their students and the students generally appeared to be attentive to the instruction and actively involved in the class. The proposition that beginning teachers, and/or teachers who do not have a strong subject matter knowledge and may be less aware of the students' prior knowledge, may encounter difficulties when attempting to teach with extended or more complex analogies is one that warrants further investigation.

Limitations

In this study, the presence of the researcher in the six classrooms would have influenced both how the teachers taught and how their students responded to instruction. As the researcher was an experienced chemistry teacher and a preservice science teacher educator, his presence in the classroom may have caused the teachers to be more careful in both their content use and their pedagogical approaches knowing that they were being observed by an experienced peer.

For the Australian teachers, it is likely that their partial knowledge of the research focus could have resulted in analogies being used more frequently and in a more elaborated manner. This researcher contends, however, that this limitation does not significantly devalue the findings of the study. Support for this position comes from three sources. Firstly, frequency of analogy use was not part of the research focus of this study which investigated *how* and *why* teachers use analogies in their chemistry teaching. Secondly, the results for the Australian teachers were similar to the results for the British teachers (see Tables 5-1 and 5-2) in all of the seven classification criteria from the Analogy Classification Framework. Lastly, the overall results for this study into teachers' use of analogies are not dissimilar to the findings for the use of analogies in textbooks as reported in Chapter 3 of this thesis. Despite these arguments, there is little doubt that the better approach was the one used with the British teachers who knew only that the researcher was interested in observing how they explained abstract concepts to their students.

As mentioned above, interpretive research of this type is subject to the nuances of the researcher/s at the time of data collection and through subsequent analysis iterations. This was especially the case for observations of what was happening with the students in the classroom. Information about students' reactions to the introduced analogies could not be re-analysed as it was not picked up on the tape recorder. An alternative approach would have been to use a video camera to record classroom incidents and explanations but this could have caused greater deviations from normal behaviour by both teachers and students.

A further limitation of this study relates to the use of the Analogy Classification Framework to classify the teachers' analogies; this framework was designed for use with textbook analogies and left unmodified for the teacher study. Classification criteria describing the position of the analogy proved difficult to classify. The sub-criteria of "marginalised" was not used, even though teachers such as Lucas used analogies for the benefit of one or two students. The other three sub-criteria also were difficult to classify as, due to the elaboration of the analogy, the analogy often related to several parts of the topic. The classifications of whether analogs were presented as advance organisers, embedded activators, or post synthesisers, were often equivocal.

Comments by the teachers about their own thinking and learning suggest that many of the conceptions about abstract chemistry that teachers hold are founded on an assortment of analogical structures. These foundational, analogical structures may be those with which the teachers have learned the concepts or may be modified structures that have gained credibility when they have proven fruitful for the teachers' explanations of the concepts to their students. Indeed, it may be argued that all of our knowledge about abstract chemical concepts – those with which we can have no direct sensory perception – has some analogical basis. In this instance, we settle with the notion that our conception of a chemical concept is an effective reality for us. This type of conception has been described above as a Level Two Alternative Representation (see Figure 5-2). While there is a true analogical aspect to Level Two Alternative Representations, for the purposes of this study, the researcher focussed principally on Level One representations where teachers have clearly drawn an analog from outside of what the students would consider to be 'chemistry'.

Finding schools in which to conduct classroom-based research of this type is often difficult. Invariably, teachers who are selected or willing to be involved in these studies are those having prior contact with either the research centre, the researcher or some professional networks or associations. Hence, these teachers tend to be of the sub-group who are interested in professional development – a sub-group which may not be representative of the wider teaching community. Not only were most of the teachers involved in this study involved in many professional activities, but the schools in which they were based tended to be independent schools that were well resourced. How these teachers' use of analogies differ from those of their colleagues who are less experienced or who teach in government and/or less resourced schools is unclear. Similarly, how novice teachers or teachers lacking good chemistry content knowledge use analogies in their chemistry teaching is not described in this study. While this may be an area for further, fruitful research, the reader needs to be cautious if attempting to generalise these findings to other educational settings or other teachers with less developed analogical knowledge.

Finally, readers should note that this study does not directly investigate whether the analogies used by the teachers resulted in positive outcomes with respect to student learning. It could be inferred, as these experienced teachers were using spontaneous and planned analogies in response to the realisation that an initial explanation had been partially unsuccessful, that the teachers believed that the analogies resulted in positive learning outcomes for the students. As their skills develop, teachers feel able to ascertain student understanding by the glance around the room, the look in the eye, or the shifting of the body and these data, while difficult to document at an appropriate level, are powerful indications to the practitioner whether or not learning has occurred.

Implications for Teaching and Teacher Education

By observing how experienced teachers use analogies as part of their normal teaching repertoire, much information and many ideas can be learned to inform both preservice and in-service teacher education. The utility of this kind of information is currently provided in research reports elsewhere which deal with case studies of teachers in different contexts (see, for example, Carter & Richardson, 1989).

The findings of this research with six experienced teachers of chemistry, each of whom had excellent content knowledge and a broad repertoire of teaching skills, can be used in a similar way to inform preservice and in-service teacher education about the use of analogies in classroom practice. The three implications from this research relate to (a) the need to develop a personal repertoire of useful analogies, (b) the necessity to select analogies which can relate to students' own experiences, and (c) the importance of mapping the attributes in an overt manner and identifying limitations.

The six teachers in this study each used analogies when students were considered not to have understood an initial explanation. In response to this consideration, in most instances the analogies were not pre-planned. However, each teacher had been teaching chemistry for between 5 and 27 years and during that time had used analogies during his or her teaching of the same content, albeit to different groups of students. So, while not strictly pre-planned, the analogies were within the repertoire of the teachers, having been built up over many years experience. The researcher's contention is that analogies have great merit in teaching science, especially in non-observable aspects related to chemistry. Consequently, for chemistry teachers who develop a personal repertoire of useful analogies, it is likely they will attain an increased ability to enable students to understand complex concepts: concepts shown by research to be difficult for students. The development of teachers' analogical repertoires can be promoted with the provision of manuscripts which document useful analogies for a range of chemistry topics. One such example of this is the *Applications and Analogies* section that frequently appears in the *Journal of Chemical Education* (introduced by De Lorenzo, 1980). Alternatively, teachers may find it beneficial to share their own teaching experiences with analogies as a way to further their own repertoires and to have others comment upon the particular analogies presented.

As competent as the six teachers were in developing opportunities for students to understand the chemistry concepts in the curriculum, there were several instances when opportunities for understanding were lost, or at best were limited, because the teacher chose to use an analog from his or her own experience rather than from the experience of the students. During the observed events that unfolded in the classroom with each of the six teachers, the use of an analogy may arise due to puzzled looks from students and so needs to be presented immediately. The implication from these observations is that, without a repertoire of suitable analogies and knowing how to use the analogy or analogies effectively, this opportunity may not be taken appropriately. The researcher's experiences conducting workshops and seminars on the uses of analogies in teaching for both preservice and practising teachers strongly indicate the value of having some kind of teaching model to guide the use of analogies in science teaching. One model under development (Treagust, 1993) by the analogy research group at Curtin University of Technology, takes students' experiences into account in an overt manner and trial evaluations have been well received by teachers. Further, the experiences of that team have led them to encourage teachers wishing to use analogies to select analogs that are well known to their students and to engage their students in some aspect of the analogy formulation or generation where this is feasible. It also will assist students if teachers develop non-threatening classroom environments where students feel free to express dissatisfaction with an alternative explanation that has been proffered for their assistance.

In this chapter, the researcher has described two key competencies that he believes are related to good analogy use: well-founded content knowledge and understanding how students learn. In institutions engaged in preservice science teacher education, competition exists for the allocation of time-table space for different subject areas. For example, should trainee teachers be provided more opportunities to develop their content knowledge to the possible detriment of their knowledge of educational theory? Further, should the content knowledge provided be specific (e.g. chemistry) or general (e.g. multidisciplinary science)? While it is likely that good analogy use is dependent upon teachers' specific content knowledge, it is unlikely that significant increases will be made to the time available for instruction in either subject matter knowledge or pedagogical subject matter knowledge in the short term.

The second competency, however, is more achievable in the short term. Two decades of research into the conceptions that students bring to their science instruction and the conceptions that they adopt as a result of instruction now informs teacher education courses worldwide. 'Methods' textbooks and accompanying volumes encourage preservice and in-service teachers to apply a range of new techniques to discover the nature and extent of learning in science (see, for example, White & Gunstone, 1992). Evaluation of this type enables teachers to monitor the effectiveness of their alternative explanations from the perspective of student learning and efficacy.

In this study, the six teachers varied considerably in the extent to which they mapped the similarities and dissimilarities between the target and the analog. The literature base which informs research into analogies in science teaching argues that analogies that are inappropriate or are inappropriately used may result in the formation of misconceptions in students' understanding. Better mapping of shared analogical attributes can help overcome these hurdles. The impetus for teachers to map analogies better may come from in-service courses employing teaching models that overtly guide teachers towards mapping the similarities and the dissimilarities of the target and the analog, such as the one indicated above (Treagust, 1993).

Summary

This chapter has reported an interpretive study into chemistry teachers' use of analogies. The assertions are useful additions to the corpus of research into teachers' spontaneous use of pedagogical strategies such as analogies. Further, the assertions should guide the implementation of future training programmes for preservice and in-service teacher education.

The following two chapters investigate the third aspect of analogy use examined in this thesis – that of students' use of analogies. Chapter 6 describes the construction of an instrument to investigate how students map textbook analogies and Chapter 7 reports the implementation of that instrument with senior secondary chemistry students.

CHAPTER 6

STUDY FOUR – THE DEVELOPMENT OF AN INSTRUMENT TO MEASURE STUDENTS' ANALOGY MAPPING EFFECTIVENESS

Overview

The past three chapters have described three studies into the use of analogies in chemistry textbooks and by chemistry teachers. These studies have employed an interpretive research style to ascertain how and why analogies were used in the teaching and learning of chemistry. The final stages of this research agenda involve an investigation into students' use of the analogies that they encounter during instruction about chemistry. Previous research studies into students' understanding of analogies in chemical education have tended to employ quantitative methods in non-classroom situations (see, for example, Gabel & Samuel, 1986; Gabel & Sherwood, 1980, 1983, 1984; Friedel, Gabel & Samuel, 1990). This present study differs, however, as it attempts to keep the assessment of students' use of analogies within the naturalistic setting of the chemistry classroom. In this way, the findings should be more readily transferable to other school settings.

This chapter describes the fourth phase of this research programme. Study Four reports the investigation of Research Problem 4: how might an instrument be developed to determine chemistry students' understanding of analogies that they encounter during instruction? The chapter discusses the iterative process used to produce draft versions of an Analogy Map; describes the analogical thought process used by the researcher to form the map; and addresses some of the difficulties that were encountered during the developmental phases. The researcher deemed it important that such an instrument be designed in close association with the teaching-learning setting of the chemistry classroom and, to that end, iterative development trials in school settings were sought to best achieve this goal.

Requirements of an Analogy Mapping Instrument

The researcher considered the broad research questions, and used his knowledge of the research literature and the understandings developed from the previous three studies (see Chapters 3, 4, and 5), to create the following framework of requirements to guide the development of the analogy mapping instrument. From this background, the researcher considered that a suitable analogy mapping instrument should:

4-1. Be able to be used by teachers in classroom settings both as an evaluative tool and as a teaching/learning device;

4-2. Characterise analogy as a process of active comparison between two separate domains;

4-3. Be flexible with respect to content matter so that transferability across the curriculum is high.

This process required several iterations, referred to as *development phases*, which are described as follows:

Development Phase 1: In-class questions for Year 10 Biology students about the brain and the nucleus of a cell.

Development Phase 2: Written questions involving pictorial analogies for senior chemistry students on the topic of Chemical Equilibrium.

Development Phase 3: Interviews with students about an analogy used in their lessons on the topic of Rates of Reaction.

Development Phase 4: Formalisation of draft and modified Analogy Maps.

In each phase, a student testing procedure was invoked as iterations of the instrument were trialled. For the following descriptions of the iterative phases, the student testing procedure is described, after which students' responses are discussed. Following each of these four phases, the semi-developed instrument is analysed for its suitability to attain the three desired attributes for an analogy mapping instrument listed above; recommendations are made following this analysis for implementation in the following phase or phases.

Descriptions of the Developmental Phases

Development Phase 1

In the first phase of development, a series of verbal questions was asked of a class of 25 Year 10 (14-15 year old) Biology students at the conclusion of a lesson in which they had been reading the assigned textbook on the topic of *Cells and Cell Structure* and answering some comprehension questions related to cellular structure and function. Part of the text from the chapter that the students were reading was about the nucleus of a cell. One paragraph contained the sentence: "The cell nucleus may be considered to be like the brain" (Chandran, 1988, p. 24) with no further elaboration on the analogy. Towards the end of the lesson, the teacher asked the following three questions:

1. *The textbook authors have written that the cell nucleus may be considered to be like the brain. Why do you believe this is the case?* (Response time of three minutes.)
2. *Obviously, a cell nucleus and a brain are not the same thing. Provide one difference between a cell nucleus and a brain.* (Response time of three minutes.)
3. *Instead of comparing the cell nucleus to a brain, how else might the author of the textbook have described the nucleus?* (Response time of three minutes.)

The students responded with written answers that were collected without discussion at the end of the lesson.

Student Responses

Question 1.

In this question, the researcher's intention was to ascertain students' ability to correctly attribute functional and structural attributes to an analog/target system. While all students indicated at least one way in which the brain was like the nucleus, some chose to include more than one way. Hence, there were 38 statements recorded by the students as they attempted to compare the two domains. Of these 38 statements, 31 were functional in nature and 8 were structural. Of the functional attributes that were mapped, many students (20) chose to comment on the similarity that the brain and the nucleus have to *control* their domains. Other examples of functional attributes that the students chose to map included the notions that both domains "communicate" (3), are "important" (2), and "can be split in the middle" (2). Hence, most students were able to correctly relate a functional attribute to the two domains in the manner in which the author probably intended, although the eight structural attributes that were mapped may be cause for concern for future learning. Within these student choices, the most popular (6) related to the central location of the nucleus in the cell.

Question 2.

In this question, the researcher intended to ascertain the students' ability to correctly identify functional and structural limitations of an analog/target system. There was a range of student responses to the question of how the analog and target systems differed in this analogy indicating a mixture of structural and functional attributes. The most common responses related to the lack of complexity of the cell nucleus when compared to the brain; no student, however, indicated that the brain comprised many cells whereas the nucleus was part of one cell. Other popular choices related to the nucleus' inability to make informed choices or to have emotions. The researcher had expected that students would take this opportunity to express the structural attributes that clearly did not map correctly in this analogy. This non-dominance of structural attributes may be explained by either of two presumptions. Firstly, students may have considered it to be an overstatement to say that the nucleus and the brain are different sizes. Secondly, as the students were already focusing on the functional attributes of the system in Question 1, this may have guided their thinking for the second question as well.

Question 3.

In this question, the researcher wished to ascertain the students' tendency either to use a context-based description or to use another analogical term to replace the "brain". When asked to replace the term "brain" with another description, 14 of the new descriptions were analogical in nature. These included terms such as *head, control box, battery, heart,* and *life support*. Only seven non-analogical descriptions were ventured by the students – these including *controller, main organ,* and *organiser*. Whether students chose analogical representations or not, the key concept of control was present throughout the descriptions.

Instrument Analysis (Development Phase 1)

From this first development phase, students appeared capable of identifying both structural and functional attributes as well as the limitations of a given analog/target system that they had encountered during their normal class-work. Further, given the opportunity, they offered other analogical expressions that may have been meaningfully used by the textbook authors in place of the chosen "brain" analog. Few students chose spurious attributes for the first question that involved mapping shared attributes.

One of the problems of this question-answer type instrument is that the mapping conducted by the students was not as overt as it may have been. More emphasis on the relationship between the analog and target domains may assist future maps. In addition, following the success of many of these students to identify several matching attributes, there seems to be little requirement for the instrument to provide matching halves. Rather, given some subtle direction, students could determine and match both the analog and target attributes.

Recommendation 1: The analogy mapping instrument should take into account both the analog and target domains and require students to clearly map between domains.

Recommendation 2: The analogy mapping instrument should challenge students to find their own attribute pairs rather than matching given attributes.

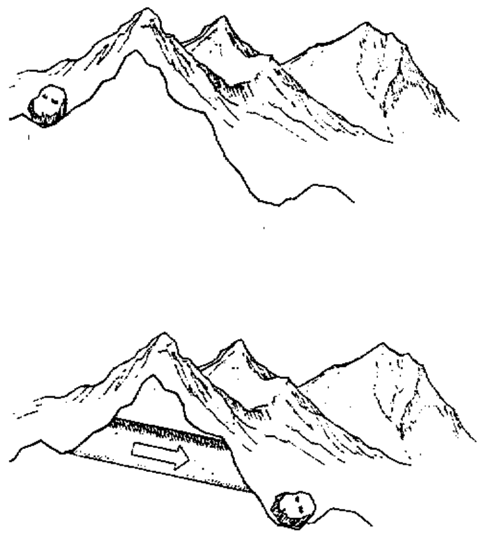
Recommendation 3: The analogy mapping instrument should challenge students to record more than one attribute pair for any given analogy.

Development Phase 2

For this second development phase, the student cohort comprised 16 Year 12 chemistry students who were learning about reaction rates and chemical equilibrium. Students were requested to complete three questions taken from a student reference book (Department of Education, 1982) each of which involved a picture that was analogically related to these topics. The three questions are shown as Figures 6-1a, b, c.

While each of the analogies was pictorial in format, each of them had textual support of some kind. In Question 1, the verbal question directly associated the pictorial analog to the target concept; in Question 2, a complete paragraph with the embedded question supported the picture; and in Question 3, supporting text and chemical symbols incorporated into the diagram focused the students' thinking.

This development phase represented two variations: firstly, it went from general science (lower secondary school biology) into the study context of abstract concepts in senior high school chemistry; secondly, it went into the use of pictorial-verbal analogies rather than purely verbal analogies as used in Development Phase 1.



Discuss this model for the operation of a catalyst.

Figure 6-1a. Question 1 used for Development Phase 2. (From Department of Education, 1982, p. 67.)

Student Responses

Question 1.

This question (see Figure 6-1a) required students to describe how a large rock in a mountain valley may model the concept of catalysis. Of the 16 responses to this question, it was found that 11 students recognised the mountain peak as being analogous to the activation energy required for a successful reaction to occur. In addition, 12 students recognised the tunnel as being analogous to the influence of a catalyst on a reaction in that it provides an alternative reaction mechanism (pathway) that requires less energy for a successful reaction to occur.

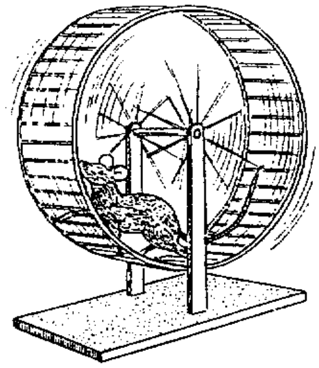
Other mappings were attempted, though far less frequently. Four students focused on the rock itself rather than on the changes it undergoes. For example, some students considered that the rock was analogous to the catalyst or that the rock was analogous to the reactants when it was on the mountain valley and analogous to the products once it had successfully traversed the tunnel route.

Question 2.

In this question (see Figure 6-1b), students were asked to relate the diagram of the dynamic equilibrium of a mouse on a toy treadmill to the concept of chemical equilibrium. Chemical equilibrium is characterised by both constant macroscopic properties, in that no visual, measurable changes occur, and by dynamic microscopic properties as the forward and reverse reactions continue, albeit at the invisible, molecular level. Several students began by remarking that the picture was "a recognisable, visual solution" that "helps us to see" as "it is sometimes hard to picture this." Thirteen students were able to accurately relate aspects of the mouse on the treadmill to chemical equilibrium. Many of these students accurately mapped analog attributes to the dynamic microscopic properties – these students showing clearly how the concept of equal and opposite rates applied in both the analogous and target situations. However, the constant macroscopic properties of a system at equilibrium were not so well mapped. For example, the treadmill system remains unchanged despite the occurrence of the forward and reverse processes.

Several students drew comparisons that were not scientifically valid. Of these, two indicated that the tendency for the mouse to remain at the bottom of the treadmill while it was running related to the fact that, at equilibrium, the amount of product equals the amount of reactant. As discussed with the water transfer analogy for chemical equilibrium (see Evidence of Planning section in Chapter 5), this latter statement is not true for a system at chemical equilibrium that is characterised by equal, yet opposing, *rates*. The belief that the amount of reactant and product are equal at equilibrium is a misconception commonly held by students of this age group (Hackling & Garnett, 1985).

In the second part of Question 2, students were invited to "Discuss information in the passage and diagram that you think might give you the <u>wrong ideas</u> about <u>chemical equilibrium</u>." The negative attribute matches that were found included statements by several students that chemical equilibrium can only occur in a closed system. Other statements indicated that the analog gives no information as to how the equilibrium was first established and that a visual change can be seen in the analog whereas no



Dynamic Equilibrium.

The word **dynamic** is used to describe processes in which **movements** or **actions** are involved. A simple way of representing dynamic equilibrium is by means of a pet mouse on a treadmill. The pet mouse running on the treadmill goes nowhere as time passes. Both the legs of the mouse and the treadmill are moving, yet, in the overall process, the position of the mouse remains essentially the same. The forward motion of the mouse's legs is balanced by the backward motion of the treadmill.

a) Discuss ways in which the diagram and the passage help you understand things about chemical equilibrium.

b) Discuss information in the passage and diagram that you think might give you the wrong ideas about chemical equilibrium.

Figure 6-1b. Question 2 used for Development Phase 2. (From Department of Education, 1982, p. 84.)

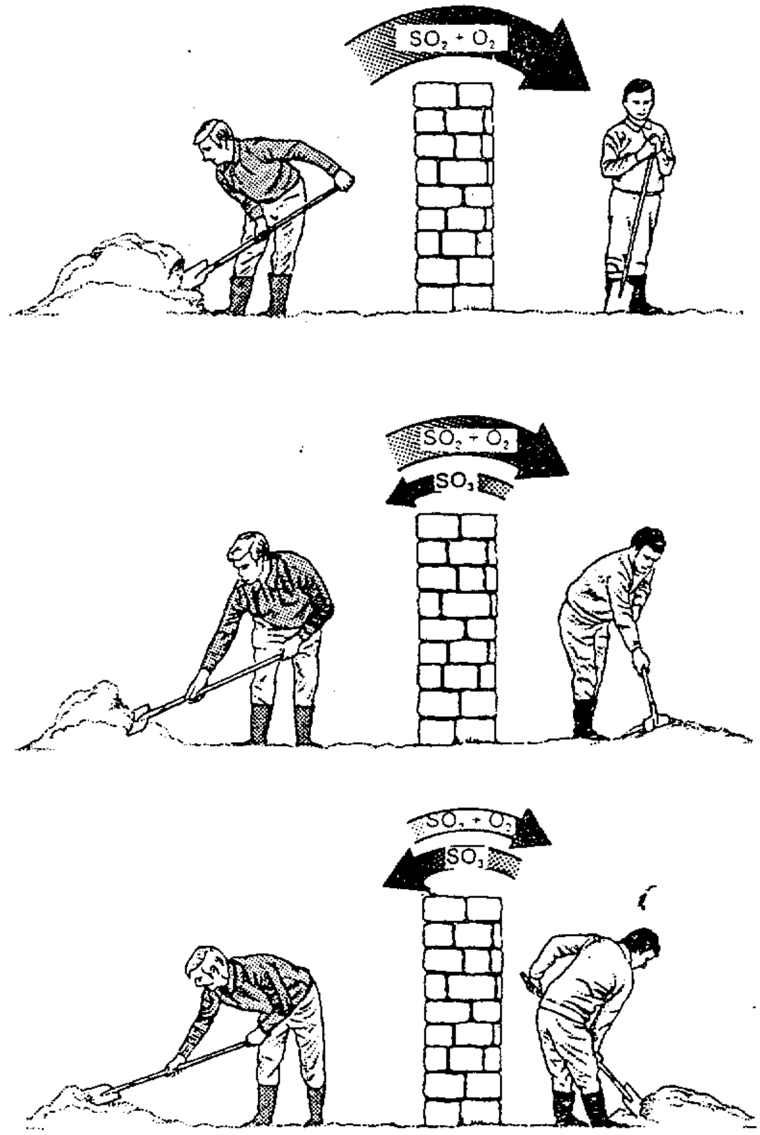
visual changes can be observed during chemical equilibrium. Some students felt uncomfortable with the notion that the wheel was turning only one way – obviously these students placed more emphasis on the rotation of the treadmill than on the motion of the mouse to indicate a reaction. Some students identified also the negative attribute match that the chemical system can continue infinitely whereas the mouse would eventually "run out of energy." Finally, several students subtly considered that the movement in the treadmill was dependent upon movement in the mouse – and indeed was causal. They cleverly argued that this differed from a true chemical equilibrium situation.

Question 3.

In this question (see Figure 6-1c), students were supplied with a series of pictures connected, by the inclusion of some chemical symbols and by the inclusion of a brief statement before the question, to the chemical equilibrium process involving the oxidation of sulfur dioxide by oxygen. This reaction is one of several involved in the commercial production of sulfuric acid – a process later to be known to the students as the Contact Process. In the first part (a) of Question 3, students were invited to comment on how the diagrams communicated things to them about the establishment of chemical equilibrium.

Again, a wide range of attributes was mapped by the students with most readily identifying the size of the sand piles on each side of the wall as being analogous to reactant/product concentrations. Five students commented on the concept that the reverse reaction could not commence until the forward reaction had produced some product. Four students showed that they held the previously mentioned misconception that the amounts of product and reactant are equal at equilibrium. In this analogy, the equal sizes of the two reaction arrows above the wall indicated that the system has reached equilibrium by the third diagram. The misconception may be supported, however, as the diagram shows the levels of sand on both sides of the wall to be approximately equal once "equilibrium" has been reached.

The concept of equal rates was addressed by several students through the concept of equal "work rate" by each of the shovelling men. Several students noted also that the rate of each reaction was proportional to the amount of sand available as a reactant for that reaction (be it forward or reverse) to take place. Only two students commented upon the significance of the two arrows at the top of each diagram; it appears that the analogous component of the pictures was far more capturing of students' attention than the symbolic chemistry text. This is attested to by the many students who referred to the size of the sand piles, rather than the size of the arrows, as the key issue in the determination that a system had reached or was reaching equilibrium.



For the reaction SO_2 (g) + O_2 (g) ⇔ SO_3 (g), equilibrium is established when the reaction occurs in a closed system.

a) Carefully observe this series of pictures and comment upon the ways in which the diagram tells you things about the establishing of chemical equilibrium.

b) Describe what change/s could be made to the diagram to show that the reaction is to be carried out at a lower temperature.

Figure 6-1c. Question 3 used for Development Phase 2. (From Department of Education, 1982, p. 87.)

In the second part of Question 3, students were asked what change/s could be made to the diagram/s to show that the reaction was being carried out at a lower temperature. Although the question did state "the reaction" specifically, many students attributed the lower temperature conditions to the analog domain more so than the target domain. Hence, students' responses included suggestions such as having the men wear winter clothes to keep them warm, having the pictured men shovel snow rather than sand, having clouds in the sky and even a snowman in the background! One student attempted to link the two domains by advising that the addition of thicker clothes would have the effect of slowing down the mens' shovelling motion hence decreasing the rate of reaction. The researcher suspected, however, that other students advocating the thicker, warmer clothes had probably not thought the issue through to the same extent.

A range of changes was recommended for the analog that would represent the target reaction being carried out at a lower temperature. These changes included having older men who are unable to shovel as quickly and having heavier shovels. One student justifiably commented that the arrows would decrease in width. A response that came from several students had particular merit: these students argued that there would be little change in the diagrams themselves, but that the number of diagrams would need to be increased as it would take longer for a state of chemical equilibrium to be reached.

Some suggestions appeared to have merit although they represented an increase rather than a decrease in temperature such as having larger shovels. Other students provided recommendations that would decrease the relative rates of reaction (an outcome of the colder reaction conditions) but better related to other target attributes. For example, a larger brick wall would be better mapped to the removal of a catalyst from the reaction mixture and decreasing the amount of sand would be better mapped to a decrease in initial concentration of a reactant.

Instrument Analysis (Development Phase 2)

In one of the analogies used in this phase, part of the diagram may have supported a common misconception about the nature of a system at chemical equilibrium. The number of students who identified the misconception, presumably prompted by the levels of sand, indicate that analogies such as these may play a significant role in identifying students' misconceptions, either as an evaluative or remedial tool.

In this phase, some of the analogies stretched the conceptual abilities of students and wrong or poor matchings were identified from this pilot sample. This observation indicates that such an instrument may have a place in evaluating chemical conceptions. While some students appeared to recognise the role that analogies play in the visualisation of abstract concepts in chemistry, many appeared to struggle when asked to modify the analog to represent some aspect of the target. The possibility of incorporating modifications to the analog should be further considered in the next development phase.

From this second development phase, it was determined that pictorial-verbal presentations may be suitable analog foundations for the analogy mapping instrument. They could be included with verbal analogies to widen the scope and usage of the instrument.

> Recommendation 4: The analogy mapping instrument should include both pictorial-verbal and verbal analogs.

Development Phase 3

During an observation schedule of the investigation into how teachers use analogies, the researcher observed a chemistry teacher (Lucas) teaching the chemistry topic of Rates of Chemical Reactions. During one of the observed lessons, the teacher was attempting to relate how particulate motion and collision frequency are related to temperature. In doing so, Lucas used the following spontaneous analogy:

L. Think of the dance: it's not that far off. When the music is slow – how I like it – you move around more slowly. If INXS come on . . . the music

Interview Protocol

1. Briefly cue analog
2. Does student remember it?

Yes (Student describes) | No (Interviewer reads analog transcript)

3. What topic was analog used to describe

Correct | Incorrect
Interviewer relates analog to reaction rates

4. What are some important aspects of the [dance] that may help you understand [reaction rates]?
5. When the teacher tells a story like this about something else, do you think it helps you? (If so how/why; if not why not).
6. When the teacher tells a story like this about something else, do you think it hinders you? (If so how/why; if not why not).
7. What are some of the aspects of the [dance] that you think don't fit the [reaction rates] very well?
8. Do you think you might get confused by these?
9. If you wanted to describe how [the pressure of a gas can be increased] to a Year 10 student by talking about [the dance], could you tell me what you would say?

Figure 6-2. Interview protocol for Development Phase 3.

gets louder and the people move faster. Then they are more likely to . . . [in a tone such as to invite a response from the students]

S. Collide.

L. Right!

At the conclusion of the observation schedule, the researcher arranged for himself and a colleague to interview the Year 12 chemistry students (all male) on a one-to-one basis over the following several days at times convenient to the teacher and students. To assist with these interviews, and to facilitate agreement between the interviewers, an interview protocol was prepared (see Figure 6-2).

One of the objectives of the interview was to determine the status that the analogy had in the students' conceptual understanding of the target. Hence, the "lead-in" to the analogy was kept to a minimum. The main area of interest was the ease with which the students identified analog/target attribute matches and the notions that arose from the interview with respect to the development of an instrument to determine students' analogy mapping effectiveness.

Each of the 11 interviews lasted between five and ten minutes and was audio-taped with the student's permission. Full transcripts of the interviews were prepared and the transcripts examined. After the interviewers had conducted four interviews, they held discussions concerning the usefulness of the protocol. Following these discussions, the researcher instituted an additional interview tool that was expected to aid discussion when dealing with Questions 4, 7 and 9 on the interview protocol. This addition required the interviewer to sketch a two-column table once Question 4 had been reached. Of the columns, one was headed by the term *Dance* and the other with the term *Chemistry*. As the students described their mappings (Question 4) of the analog and target domains, these mappings were recorded in the columns – analog attributes under the heading of *Dance* and target attributes under the heading of *Chemistry* as shown in Figure 6-3.

Dance	*Chemistry*

Figure 6-3. Key word columns used in interviews.

This mapping was openly done in full view of the student and it appeared to prompt a more structured response by each of the remaining students and acted also as an instrument of review. At the completion of Question 4, a line was ruled under the mappings and the same columns were used to record parts of the analogy that students felt were confusing at Question 7. In Question 9, students were required to further extend the analogy to explain (to a fictitious, younger student) another facet of the concept of reaction rates. As each student responded to this question, the interviewer drew another line under the attempts at Questions 4 and 7 and added the new Question 9 attributes in the lower half of the table as they were proposed by the student. This two column format proved fruitful for the interviewers and was considered to be useful for an analogy mapping instrument. Figure 6-4 shows a (typed) representation of one of the completed key word column maps from an interview with a Year 12 student, Jason. The numbers at the left of the Dance column indicate the protocol questions, 4, 7 and 9.

	Dance	*Chemistry*
4	People	Molecules/ions in solution/atoms/particles
4	Collide	Collisions/bounce/join/possibility of reaction
4	Music louder	increased energy/increased temperature
7	INXS	
9	Add people	Increase concentration
9	Smaller room	Increase concentration

Figure 6-4. Jason's mapping attempts from his interview.

Student Responses/Instrument Analysis (Development Phase 3)

While some questions in the interview protocol addressed general issues about the teachers' and students' use of analogies, for the purpose of this chapter only responses related to analogy mapping were considered. Of these analogy mappings, the students freely proffered functional attributes of the analog and target that they believed were important in this analogy. The more frequently mapped attributes were volume of music to temperature (6), dancers' collisions with molecular collisions (6), and dancers as molecules (5). Less frequently mapped attributes included type of musical band to the kinetic energy of molecules (3), dance speed with molecular speed (1), and music speed with temperature (1). The willingness of some students to offer several suitable matchings underlies the ease with which they found this task. There were a few students, however, who attempted to describe comparisons that the researcher considered to be invalid from a scientific perspective. These incorrect or negative analogies included attempts to compare "lights and all that" [*sic*] with heat (1) and the rock band *INXS* with a chemical catalyst (1). The student who offered the latter mapping commented that, when it comes to analogy, "I only understand about 40% of it but once [the teacher] goes into the actual thing [the chemical explanation], then I understand it." This student was a non-native to Australia – one for whom English was not his first language. The difficulty that he encountered may have been related either to his lack of experience with the cultural setting in which the analog was framed or with his lack of proficiency with the English language.

The inclusion of negative mappings such as the two referred to above, caused the researcher to consider how mappings in a suitable instrument could be rated for the purposes of research. At the time of the data collection of this study, the researcher was also a participant in a study that involved rating concept maps drawn by Year 10 physics students (Shymansky, Treagust, Thiele, Harrison, Waldrip, Stöcklmayer, & Venville, 1993). Subsequently, a rating system for the analogy mapping instrument was produced that would enable researchers to evaluate analogy mapping in an analogous manner to the rating schemes employed to evaluate students' conceptions from concept maps. Such an analogy mapping instrument could be referred to simply as an *analogy map*.

When asked to extend the analogy to explain another way of increasing the pressure of a gas rather than by increasing its temperature, students appeared to have little difficulty. Common positive mappings included making the dance floor smaller and adding more dancers. These mappings closely resemble the general teachings on factors that affect the pressure of a gas (temperature, volume, and number of gaseous particles). Hence, it may be that these students drew their conclusions about the analog based on their target knowledge rather than the reverse process. This duality of analogy has been documented in the past (see, for example, Duit, 1991). For the purposes of this study, it was not considered that this was an adverse outcome of the question; rather, it illustrates the manner in which learning may take place by active comparison between two domains. Any active comparison between domains requires self-evaluation of a student's conceptions about the chemistry target and would, therefore, be considered educationally advantageous. The proposed instrument should be able to cater for either cognitive process – that is, going from analog to target or transferring in the opposite direction. It should be noted, however, that this ability to transfer from the chemistry domain to the analog domain depends upon the students' successful understanding of the target concept. In this instance, students had briefly covered the same topic in the previous year and this most likely aided their understanding of reaction rates and their transference skills.

> Recommendation 5: The instrument should be presented with two distinct columns for the target and analog domains. Further, some row by row development of multiple matchings should be available.
>
> Recommendation 6: A system should be developed for rating the mappings provided by students on the analogy mapping instrument.
>
> Recommendation 7: Such an instrument should be referred to as an analogy map.
>
> Recommendation 8: The mapping instrument should be non-specific in the order in which domain attributes are ascribed by the student.

Development Phase 4

The fourth development phase involved the formalisation of the draft analogy map. In the first instance, ten draft maps were prepared based on the recommendations and findings of the first three phases. The topics for these ten draft analogy maps are shown in Figure 6-5.

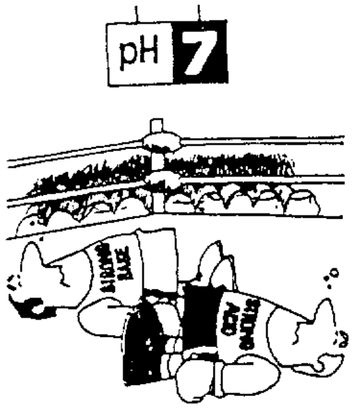
Map Number	Analog	Target	Format
A	Two boxers	Acid/base reaction	Pict-verbal
B	Layers of an onion	Electron arrangement	Verbal
C	Football spectators	Spectator ions	Verbal
D	Reams of paper	Counting in moles	Verbal
E	Marble on sports oval	Nucleus of an atom	Pict-verbal
F	Bees to a beehive	Chemical equilibrium	Pict-verbal
G	Bridge over gully	Catalysis	Pict-verbal
H	Rotating fan	Electron properties	Pict-verbal
I	Waterfall	Chemical stability	Verbal
J	Oiling a door	Chemical equilibrium	Verbal

Figure 6-5. The ten draft analogy maps prepared for formalisation.

As seen in Figure 6-6 (a sample of draft analogy map A), each analogy map begins with a segment extracted from a Year 12 chemistry textbook that had an analogical component – in some cases the analogical component was pictorial. Under the analogy, that was presented to the students as an *Insert*, the terms *Common World* and *Chemistry* were used to describe the analog and target domains respectively. Under these two headings students were provided with key words for the analog and target domains (for example, *Boxers* and *Acids & Bases* respectively). They were required to identify up to three matching attributes (*characteristics*) for each and to include a comment as to *why* the analog was like the target. On the *sample* maps (see Figures 6-6 and 6-7), possible responses were typed in to guide students as they attempted the non-sample maps; in the latter instances they have to complete all nine boxes (six boxes for Figure 6-7) which were void. Further, students were asked to identify if they recalled seeing the analogy elsewhere and to comment on whether they found the comparison helpful for their understanding of the chemistry concept.

For this pilot study, five of the analogy maps (A-E) were chosen as providing sufficient variety in style. Map A was used as a worked example to indicate to the students what was expected. Four Year 12 Chemistry students were permitted 30 minutes to complete the four maps and, for the purpose of the pilot trial, they discussed the analogy map as a group with the researcher at the conclusion of the allocated time. The purpose of the discussion was to collate comments related to the difficulty of the task, time allocation for task completion, and structure of the table. Findings of the mapping and discussion are included below.

INSERT A



COMMON WORLD Boxers	CHEMISTRY Acids & bases	WHY	Office Use
1. "Acid" and "Base" in the same rink will fight.	An acid and a base in the same vessel will react.	On contact, in solution, H^+ will react with OH^- to produce water: $H^+ + OH^- \rightarrow H_2O$	
2. "Acid" and "Base" are the same size.	The acid and base are same strength.	Equal strengths of acid and base can cause neutralisation.	
3. "Acid" and "Base" were both knocked out.	The final solution is neutral; i.e. pH = 7	Complete neutralisation will result in a solution that is neither acid nor base but is neutral; pH = 7.	

Complete the following sentences:

4. Do you recall ever seeing *boxers* being compared to *acids and bases* before? Yes/No*
5. I find that comparing *boxers* to *acids and bases* is/isn't* helpful for me in chemistry because ....

*Cross out the part that does not apply

6. Office use only

Figure 6-6. The completed Sample Analogy Map A in draft format.

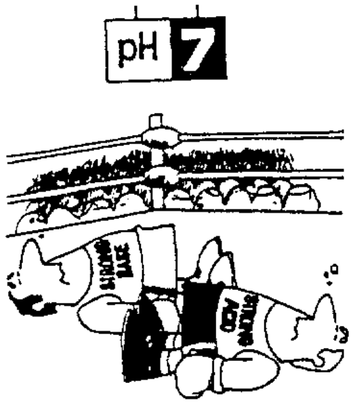
Student Responses

As a result of the students' work and from the following group discussion, it became evident that several modifications were necessary for the analogy mapping instrument. The first required change was due to the problems that the students encountered as they attempted to complete the "Why" column on the maps. The students agreed that the contents of this column invariably duplicated, or at least overlapped, the contents of the analog/target (Common World/Chemistry) columns. If this is the case, sufficient information would be gleaned by expanding the space in the attribute columns and removing the "Why" column. This change would have the added advantage of not leaving the students with the negative feeling that they had inadequately completed the task. Further, the students reported that much of their unproductive thinking time was expended on this column. The removal of this column would decrease the time required without losing important data.

These students were willing to communicate that they felt some analogies were unhelpful for them. This provided no further information for this pilot study, however, it does indicate that Question 5 on the map should provide useful supporting data for the studies. In these pilot instruments, there was space for three matched attribute pairs and a statement on the instruction sheet directed students to "please try and fill in every space." 37% of the analogies had three mappings attempted; 25% two mappings; 25% one mapping and 13% with no mapping. Three attribute spaces were considered appropriate to encourage multiple mappings without being excessive. It may be, however, that the wording of the survey instructions with regard to the completion of each space needs to be less emphatic.

The students believed that Map A was useful, not only as an advance organiser but also as a ready reference once they had begun working on Maps B through E, and they encouraged its inclusion in future trials. They found the actual process of mapping the shared attributes to be interesting and of educational benefit. Although two students found two analogies each which they did not believe were helpful to their understanding, no student reported undue difficulty finding suitable attribute matches.

INSERT A



COMMON WORLD Boxers	CHEMISTRY Acids & bases	Office Use
1. "Acid" and "Base" in the same rink will fight.	An acid and a base in the same vessel will react.	
2. "Acid" and "Base" are the same size.	The acid and base are of the same strength.	
3. "Acid" and "Base" were both knocked out.	The final solution is neutral; i.e. pH = 7	

Complete the following sentences:

4. Do you recall ever seeing *boxers* being compared to *acids and bases* before? Yes/No*
5. I find that comparing *boxers* to *acids and bases* is/isn't* helpful for me in chemistry because

   ....

   ....

   *Cross out the part that does not apply

6. Office use only

Figure 6-7. The completed Sample Analogy Map A in modified format.

Recommendation 9: The "Why" column should be removed in favour of expanded columns for analog/target attribute matches.

Recommendation 10: The instruction sheet should be revised to remove the imperative for completion of every space.

The draft analogy maps were then modified to take these recommendations into account. The removal of the "Why" column enabled the analog and target columns to be substantially enlarged offering abundant space for students who wished to map extensively. A modified analogy map is shown as Figure 6-7. In addition, the instructions were modified to read "Please try to fill in as many spaces as possible" rather than "Please try to fill in every space."

The spaces on the right hand side (Office Use) were used for the analogy ratings that were done using the scale shown in Figure 6-8. Each map for each student was rated. The notion that analogy, or more specifically individual attributes, can be rated as positive, neutral, or negative has been adapted from early work by Hesse (1967). The researcher has used the terms "positive" and "negative" analogy in much the same way as Hesse, however, there is a difference in the use of the term "neutral" analogy. Hesse's concept was that neutral analogy is the part of an analogy that is yet unexplored – it has yet to be determined whether it is negative or positive. The researcher has used this term to describe those comparisons that, while being seemingly logical, have no explanatory power towards the target conception being described. For example, consider a student attempting the Boxer analogy for acid-base neutralisation (see Figure 6-6). If the student related the fact that some acids can be diprotic (contain two removable hydrogen ions) to the fact that each boxer wears two gloves, this would be rated as a neutral mapping. While some shallow relationship exists, no further conceptual understanding can be reached.

While it should be noted that these ratings are nominal representations only, effort was taken to have a consistent approach through the rating profile. A rating of '0' was allocated whenever no response was offered by the student. Ratings of '1' and '2' were used to designate negative and positive responses respectively. As it was

Analogy Map Rating Profile

A. Mapping for each of the three *attribute spaces*:

Neutral mapping – of little use for understanding yet unlikely to create misconceptions	Rate *3*
Positive mapping – scientifically valid	Rate *2*
Negative mapping – attributes mapped either to give incorrect meaning of target or indicating misunderstanding of analog	Rate *1*
No mapping – did not attempt mapping for the attribute	Rate *0*

B. Each analogy was classified using to the Analogy Classification Framework (see Figure 3-2)

C. Students' recognition of analogy from elsewhere:

Analogy had been seen before	Rate *2*
Analogy had not been seen before	Rate *1*
No response	Rate *0*

D. Students' belief that the analogy was helpful:

Analogy helpful	Rate *2*
Analogy not helpful	Rate *1*
No response	Rate *0*

Figure 6-8. Analogy map rating profile.

possible for students to respond in section 'A' with a neutral mapping, an extra rating of '3' was used for this section.

Summary

Having determined factors related to the use of analogies by teachers and in textbooks, this part of the research began to address research questions related to how students use analogies that are presented as part of their chemistry instruction. This chapter has described the process by which the researcher developed a suitable instrument to determine the effectiveness with which students map given analogies for chemistry concepts. The iterative process has engaged classroom-based research methods in an attempt to develop an instrument that is of value in a school-related research study. The inclusion of a rating system should allow the researcher to compare students' effectiveness at mapping chemistry analogies with the type of analogies (using the Analogy Classification Framework) and students' academic performance.

At each phase of the development of the analogy maps, the researcher was conscious to develop a system appropriate with the three stated requirements of an analogy mapping instrument (see points 4-1 through 4-3 above). In addressing 4-1, the analogy maps could be used both as a tool for further research and still be transferable to the classroom setting where teachers could sketch a rough map on the black/white board when enriched or extended analogies are being used. In this classroom setting, the active mapping process would become more overt. Further, students would become more aware of the process of analogical comparison and would be more likely to have opportunity to express their conceptions about the analogy. These are issues that research reports identify as being important in the classroom setting (Licata, 1989; Thiele, 1994; Webb, 1985).

Point 4-2 required the instrument to characterise analogy as a process of active comparison between two separate domains. This criterion is met by the structure of each map comprising clear separation between the analog (*common world*) and target (*chemistry*) domains. Further, point 4-3 required flexibility with respect to content matter so that transferability across the curriculum is high. The structure of the maps enables any choice of analogy to be put into the insert. In the analogy maps used in this thesis, a short phrase (such as *acids and bases*) or a single term (*boxers*) heads each of the domain columns. Once students had become more familiar with the meaning of *common world* and *chemistry*, however, the inclusion of these terms – and their repetition in the attendant questions under the map columns – would no longer be required. This would simplify the transferability of the map profile.

The following chapter of this thesis describes Studies Five and Six. These are studies in which the analogy maps developed herein were used with groups of senior high school chemistry students.

CHAPTER 7

STUDIES FIVE AND SIX – CHEMISTRY STUDENTS' ABILITY TO IDENTIFY MAPPABLE ATTRIBUTES IN COMMON ANALOGIES

Overview

The previous chapter of this thesis described the evolution of an instrument that is designed to be used both as a research tool to diagnose students' ability to draw suitable comparisons in a chemistry analogy and as a teaching/learning device to encourage a more structured approach for developing analogy-inclusive curriculum. In the two studies described in this chapter, the analogy maps were used with two groups of Year 11 students in Western Australia with the intention of documenting the types of mappings drawn, the ease with which they were drawn by students of different abilities, and the way in which different types of analogies influenced the students' learning of chemistry concepts and students' mapping attempts.

Research Questions

With these two studies, the researcher endeavoured to address the research questions indicated below. While Studies Five and Six have been treated separately for reporting purposes, they are contained here in the same chapter due to the similarity of the research questions and of the research design. Following a Discussion section for each of the studies, a joint Conclusions section considers the findings of the studies with respect to the research questions below:

5-1. How was the ability of students to suitably map an analogy affected by the analogy factors of (a) Presentational format and (b) Level of enrichment?

5-2. Was there evidence that analogy maps can assist in the identification of, and challenge to, students' alternative conceptions?

5-3. What evidence existed to show that analogies contribute to the formation of alternative conceptions?

5-4. Did students who performed better at chemistry perform better in the analogy mapping tasks?

STUDY FIVE: STUDENT' USE OF ANALOGY MAPS

The purpose of Study Five was to investigate the use of the analogy maps by interviewing eight Year 11 Chemistry students who had completed analogy mapping exercises.

Method

This section of the chapter begins with a description of the student group chosen for Study Five. This is followed by a discussion related to the chemical concepts supported by each of the four analogy maps and an investigation into the historical development of the analogies and/or the teaching points that the analogies may be designed to address. A description of the procedures for the administration of the testing procedure and interviews concludes the section.

Description of the Student Group

Eight Year 11 students were selected to complete a set of analogy maps. This number of students was small enough that the students could complete their mapping exercise and be interviewed over a two day period. The students were from a chemistry class that was taught by a colleague of the researcher and was in a school in which the researcher taught on a part-time basis at the time of the study. However, none of the students was known to the researcher prior to the study. The school was a co-educational independent school drawing students from middle class suburbs south of the city of Perth, Western Australia.

These eight students volunteered to come back to school for several hours during their extended summer holiday period following the conclusion of their final Year 11 examination period. Each responded to a request by the researcher for assistance from the 23 students in the chemistry class. Nine students responded positively to the request although one student was unable to attend on a suitable day. For the purposes of this study, the final eight students have been referred to as Len, Jon, Tina, Anthony, Paul, Chris, David, and James.

Given the manner of selection, these eight students tended to represent the more academically able sub-group of the cohort – those who were willing to submit themselves to an alternative chemistry "test" procedure as well as the scrutiny of a follow-up interview. In return for their assistance it was advertised that, at the conclusion of the interview phase, each participating student would be provided with a luncheon supplied by the researcher.

Documentary Resources

In a manner similar to that described and used in Study Four (see Chapter 6), the eight Year 11 students were provided with the set of analogy maps. The map set comprised instructions to candidates, a sample map (A) with possible solutions already entered in, and four unworked, modified analogy maps (B, C, D, and E) as listed in Figure 7-1. Consequently, data sources for this study consisted of analogy maps completed by students and interview transcripts. The entire map set with instructions to candidates is presented in Appendix 2.

Map	Analog	Target
A. Sample	Two boxers	Acid/base reaction
B.	Marble on M. C. G. [a] oval	Nucleus of an atom
C.	Rotating fan	Electron properties
D.	Reams of paper	Counting in moles
E.	Bridge over gully	Catalysis

[a] The Melbourne Cricket Ground (M. C. G.) is a large oval shaped playing arena surrounded by seating for 90,000 spectators. It is used for cricket matches and for Australian Rules Football.

Figure 7-1. The five modified analogy maps used in Study Five.

Three of the four maps were pictorial-verbal in presentational format. Of these, Map E was distinctly reliant upon the students' transference of mappable attributes from the pictorial component to the target. Map B contained little text although most of the mapping could have been effected with a suitable understanding of that text. Map C, however, had a considerable amount of textual information (11 lines) as well as two small diagrams that students were directed to during their reading of the text. The other map (D) was purely verbal with 14 lines of text which began with a contextual situation and ended with the analogy followed by a one sentence chemical definition of the target concept. The analogs in these maps were classified according to the Analogy Classification Framework and pertinent characteristics are shown in Figure 7-2.

Map	Presentational Format	Analog Explanation	Level of Enrichment	Analogical Relationship
A. Sample	Pictorial-verbal	No	Enriched	Functional
B. M. C. G.	Pictorial-verbal	Yes	Extended	Structural
C. Rotating fan	Verbal	No	Simple	Structural-functional
D. Reams of paper	Pictorial-verbal	No	Enriched	Functional
E. Bridge over gully	Pictorial-verbal	No	Enriched	Structural-functional

Figure 7-2. Pertinent criteria from the Analogy Classification Framework for the five maps used in Study Five.

Description of the Items

Map B: Marble on M. C. G. analogy for atomic structure.

Early in the development of their chemical conceptions, students are introduced to models of atoms that are space filling and often rigid and spherical in shape. For example, the billiard ball model of the atom that is used in the early years of high school to develop concepts of the kinetic theory of matter, atomic packing, and crystalline structures, represents an atom as having an even mass distribution throughout and a rigid shape. A more complex conceptual understanding of the atom would, however, involve one that has the nucleus, containing almost all of the mass of the atom and yet almost none of the volume of the atom, at the centre of a charged region in which electrons move with high speed or wave-like properties. This region, often referred to as an electron cloud, is predominantly empty space. In a hydrogen atom, the ratio between the diameter of the nucleus and the diameter of the atom is about $1:10^5$, a ratio that troubles many students. Hence, when students progress to these more complex chemical concepts, maintenance of the earlier models such as the billiard ball model may cause limitations to their new understanding. A chief function of this analogy was to address the change to the more complex conception.

This analogy was predominantly pictorial in presentation, with a short sentence after the pictorial component. The picture is a photograph showing the Melbourne Cricket Ground full of spectators watching a game of Australian Rules Football. The details of the players or any on-field identities are not readily observable from the picture. The text below the photograph relates this picture to a marble: "If this football field represents an atom, the nucleus would occupy a region the size of a marble in the centre." To a limited extent, the first phrase in the sentence provides some mapping to the enrichment level although there is no analog explanation, strategy identification, or expression of limitations present in the analogy. The key aspects of the analogy relate to the sharing of structural rather than functional attributes and the concrete analog attempts to describe an abstract target concept.

Map C: Rotating fan analogy for electron properties.

As mentioned above, a more complex conceptual understanding of the atom would involve one that has a nucleus at the centre of a charged region in which electrons move with high speed or wave-like properties. This region is predominantly empty space. Students often see this situation as somewhat paradoxical. The *single* electron of a hydrogen atom, as a result of these high speed or wave-like properties, causes chemists not to consider the electron as an entity but as a region or space in which it can reasonably be expected that the electron could be present. The electron's properties are manifest throughout the region and yet it is not scientifically valid to identify the electron as being in any specific location at any one instant in time. The analogy attempts to describe a quantum mechanical phenomenon in terms of a Newtonian mechanical analog. The analogy, while still being pictorial-verbal, contains significantly more text than the Melbourne Cricket Ground analogy. Similarly, the two pictures that accompany the text in this analogy have much less detail than the picture of the M. C. G. Comparison of the two adjacent diagrams, however, powerfully communicates the key functional attribute of the analogy – that a small number of blades can appear to take up a large space if travelling fast enough.

As alluded to above, the conceptually concrete analog shares functional attributes with the abstract target concept. Considerable analog explanation has been provided by the authors and despite there being no strategy identification with respect to the use of the terms "analog" or "model," in the text students were specifically directed to actively compare the two diagrams in the light of the concept being discussed. The extended mapping that is present in the last paragraph of the text is distinctly parallel with two repetitious, matched phrases. The first of these phases maps the inability to detect the blades or electrons in that "we cannot say where the blade is" and "we cannot say exactly where the electron is." The second attribute pair maps the presence or influence of the blade or electron throughout the entire region: "Some evidence of the blade can be seen at every point in the volume of space through which it moves" and "some influence of the electron exists at every point in the spherical volume of the hydrogen atom." These parallel statements provide a clear, structured mapping. The "rapid rotation of the fan" is subtly linked to the "tiny particles which move at very high velocities" although this was not considered to be a further extension of the analogy's mapping. The authors have provided no statements of limitations for this analogy.

Map D: Reams of paper analogy for counting in moles.

The reams of paper analogy addressed the concept of the mole – the unit that chemists use to quantify amount of substance – a concept that has been a chronic cause of confusion for many chemistry students. The sources of difficulty with the concept of mole are several. Firstly, the numbers involved (6.02×10^{23}) are beyond the comprehension of all but the most gifted mind; secondly, the definition stated in many textbooks is long and often confusing, with reference to comparisons of masses of carbon and hydrogen isotopes. Often, the simplicity that the mole is a counting device developed for ease of use is lost by students. While other abstract measures such as the coulomb and farad are encountered in senior high school chemistry, they do not appear to cause the same degree of confusion. The cause of this may be that the mole is a concept that becomes foundational to all quantitative work in the subject. In addition, the mole concept frequently is introduced to students while they are still in lower school science, possibly at a stage when too few students have developed the necessary abstraction skills to adequately process the information.

In the first study (see Chapter 3), the researcher identified 6.4% of the textbook analogies to be related to stoichiometry – of these most described the mole concept. Analogs include truckloads of sand, dozens of eggs, and bank rolls of coins. In the verbal analogy contained in Analogy Map D, reams of paper have been chosen as an analog for the mole. The textbook author has provided some analog explanation by advising students that each ream contains 500 sheets of paper and that schools would normally order their paper in reams. While some subtle comparisons were provided, the author has provided no clear mapping for the many mappable attributes of this analogy. The analogy maps the concrete notion of the ream, with which most students should have had some experience, to the abstract target. The author has not provided any limitations or strategy identification with this analogy which comes as a post-synthesiser at the end of a paragraph introducing the mole through the context of the composition of 1 g of iron and sulfur.

Map E: Bridge over gully analogy for catalysis.

In the first study of this thesis, it was reported that 15% of the 93 textbook analogies came under the loose headings of "energy" or "reaction rates." The bridge over the gully analogy for catalysis was one of the analogies classified under the "energy" heading; it addressed the effect of a catalyst on the rate of a chemical reaction. One facet of the normal teaching approach is an analysis of a series of diagrams that are enthalpy/extent of reaction diagrams. These diagrams show the changes in enthalpy as the reaction progresses, indicating the original enthalpy of reactants, final enthalpy of products, activation energy required to be supplied for bond breakage, and the net

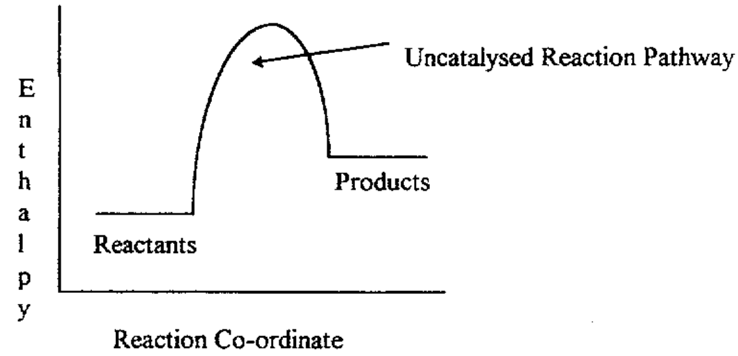


Figure 7-3. An enthalpy/extent of reaction diagram commonly used at Year 11 and 12 levels.

release or absorption of heat energy as a result of the reaction. An example of such a diagram is shown in Figure 7-3.

Once catalysts are introduced to the teaching sequence, it is usual for teachers and textbook authors to show a modified enthalpy/extent of reaction diagram with a "catalysed pathway" – having a lower activation energy positioned under the normal "uncatalysed" reaction pathway (see Figure 7-4). The terms "path," "pathway," and energy "barrier" have analogical components that may be described as Level Two Alternative Representations (see Figure 5-2). While the terms may have analogical roots, it has been assumed that students process these terms as chemical rather than analogical terminology.

The diagrams presented in this analogy (see Appendix 2) are Newtonian mechanical representations analogous to the enthalpy/extent of reaction diagrams. These diagrams often are developed from analogies used to describe activation energy where some object, such as a bus, must have sufficient initial kinetic energy to successfully traverse the hill or "energy barrier". This analogy offers students a pictorial representation to explain a concept that is peculiarly abstract due both to the submicroscopic size of the particles and to the abstraction of the concepts of stored molecular energy and bond energy.

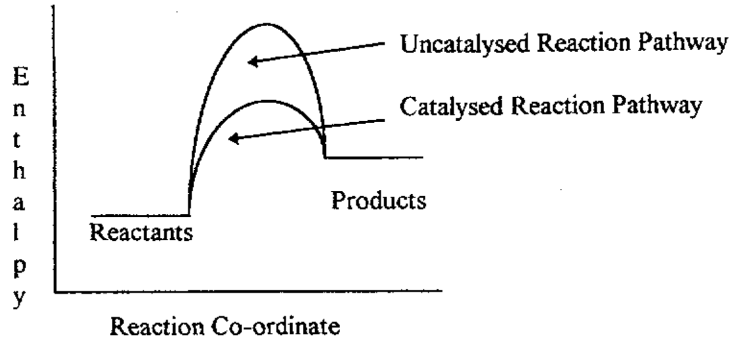


Figure 7-4. An enthalpy/extent of reaction diagram modified to take into account the influence of a catalyst.

In a manner similar to the Melbourne Cricket Ground analogy, there is a small amount of text accompanying the analog, but in this case the text describes only the target concept. There is no strategy identification, analogical explanation, or expression of limitations. The only subtle, verbal enrichment is the name *Catalysts Ltd,* on the side of the truck.

Administration of the Test

The set of maps and instructions may be found in Appendix 2. Students were permitted 30 minutes to complete the mappings. While most did the activity in silence, several asked questions of the researcher during the task to clarify a detail. Later, all 32 (4 x 8) analogy maps were rated using the rating profile shown in the previous chapter (see Figure 6-8).

Upon completion of the analogy mapping exercise, each student was interviewed. An interview protocol (see Figure 7-6), focussing particularly on the students' mappings for the M. C. G. and reams of paper analogies (B and D respectively), was prepared to address the research questions indicated above. The researcher was careful to conduct the interviews immediately after each student had finished his/her map. For this reason, students commenced the mapping exercise at staggered times during the data collection days.

INTERVIEW PROTOCOL

The interviews based on 2 maps only: B (marble on M. C. G. oval analogy for atomic structure) and D (reams of paper analogy for the mole concept).

1. General feelings with mapping process: ease, difficulty, easiest and most difficult maps, confusions, etc.
2. Consider mappings of B: check student's conceptions of electrons and nucleus. Have any new conceptions arisen as a result of the analogy?
3. Any ways in which the M. C. G. analogy may give the student wrong ideas about atomic structure [negative mappings]?
4. Do the spectators represent anything to the student?
5. Do the players represent anything to the student?
6. Does the grass represent anything to the student?
7. Consider mappings of D: check student's conceptions of mole concept. Have any new conceptions arisen as a result of the analogy?
8. Any ways in which the reams of paper analogy may give a student the wrong ideas about mole concept [negative mappings]?
9. What does each individual sheet represent to the student?
10. Maps C and E? Any other arising issues?

Figure 7-5. The protocol for post-mapping interview.

Analysis of the Data

Each interview was audio-taped and full transcripts were prepared. The interview transcripts were analysed in conjunction with any handwritten notes made by the researcher during the interview. These data were assembled and, along with the analogy maps, were analysed on a map-by-map basis. Conclusions were drawn and assertions formed in accordance with the interpretive method chosen (Erickson, 1986). These conclusions and assertions are presented as part of the Conclusions section of this chapter which follows the reporting of Study Six.

Results

Prior to an examination of the students' mappings and their interview responses, it is useful to consider two preliminary issues that arose from the interviews. The first of these relates to the structure of the analogy maps and their perceived level of difficulty and the second to the popularity of the pictorial analogies. Following discussion of these two points, relevant data for each of the four analogy maps are presented by focussing principally upon the interview transcripts and using the student responses to the maps as an auxiliary source. The Discussion section of

Study Five provides an analysis of students' mappings from the perspective of analogy criteria including presentational format and analog explanation.

Preliminary Issues

The Perceived Difficulty of the Analogy Maps

Most of the students were comfortable with the mapping exercise although two students indicated how the maps were problematic for them. Tina (T) told the researcher (R) that she found the maps for the M. C. G. analogy [B] and the rotating fan analogy [C] to be "easy" and the maps for the reams of paper analogy [D] and the bridge over the gully analogy [E] to be "hard:"

T. Some are easy and there are some that I couldn't do [that] were hard.

R. Which ones did you find easiest?

T. The first two [B and C] but for these two [D and E] I couldn't think of any more reasons. [Tina had only one mapping for each of D and E.]

R. Why do you think you had trouble finding reasons? I'm not suggesting that is a bad thing.

T. Because there only seemed to be one comparison, no more. (nsi01)

Hence, the difficulty that Tina perceived with the task was not related to her understanding either of the mapping process or of the analog and target domains. Rather, it was the strong desire to have a completed survey to return that had produced her misgivings. Indeed, as both of Tina's mappings for Maps D and E were positive mappings, and as she felt that there seemed to be only one comparison, it was appropriate that she cease the mapping procedure when she did. Anthony's concern was of a similar nature; he believed that each map lacked space in which he could write his feelings about the analogy. He solved his problem, however, by managing to "squeeze it into [his] answer for the last question" (asi01). No other student, however, gave any indication that they were under pressure to complete every box on the analogy maps or that they required more space in which to adequately complete the mapping exercise and its associated questions.

Preference for Pictorial-verbal Analogies

The second preliminary issue relates to the students' argued preference for analogy Maps B and E – the two that had clear pictures and the least amount of text. David showed his preference for these two analogies by arguing: "A few things I don't think were too useful – the fan one and the reams of paper. I don't think they gave a good visual account of the electrons and the atoms" (nhi02). He argued that the analogy maps were "useful to use, especially when there is a diagram available" (nhi02). Other students' statements were similarly clear in their preference towards the pictorial analogs. James (Js) believed that the ease of use of the pictorial analogies was related to how people process information:

Js. I think it looks easier if you have got pictures more than words as a general thing. Like you have got some things there with pictures and other things with wording. I think it is even easier if you have got pictures there, like this one on the back [E] there with the comic strip. It is a lot easier for someone to look at and actually understand it than actually read through it.

R. Why do you think that is, James?

Js. I think that people can just generally relate to pictures and put them in the sense of relating things to what they are used to. And look at a picture and think about what it is doing rather than reading just what is written there and trying to understand it. People just generally try to understand pictures a bit easier.

R. When you read through one like D, do you form in your mind a picture of a ream of paper or do you think of it as words.

Js. I just think of it as words straight off and think what it is trying to say. Sometimes, if there are too many words, you just skim read it and try to work out what is going on. Like the one with the fan, that was sort of half-half [pictorial-verbal with 11 lines of text]. With the picture I could understand it. Otherwise, it would be a lot harder to understand what was going on. (jpi02)

Paul, too felt the tension between deriving meaning by looking at pictures compared with reading text. He commented that he "found the pictures were most useful because you can relate them to what you see rather than reading something. You may not understand a couple of words or the English involved and how they worded it and it is much more difficult" (pwi02). As Len ranked the maps from easiest to hardest, he showed his clear preference for the pictorial-verbal maps by suggesting that E was the easiest, followed by B, and that D was more difficult as "the ones with the writing on were the hardest" (lti03).

Not all of the students attributed the degree of difficulty of the analogies to their pictorial content. As mentioned above, Tina attributed the difficulty to the number of mappable attributes. Jon, who did report that "there were some that were clearer than others, like B and E and the example one [A]" (jii02), believed that it was purely coincidental that these were the analogies that contained more picture than text. Anthony, who was asked whether he found it an advantage to have an explanation or a diagram only as the analog, remarked that "sometimes a diagram can be misleading and sometimes an explanation can be misleading" (asi03). It would appear that he was more interested in the content of the analogy rather than its mode of presentation.

Student Responses to Analogy Map B (M. C. G.)

For this analogy, four students attempted three attribute mappings and the other four attempted only two mappings. Of the 20 attempted mappings, ten (50%) were rated as positive, three (15%) as negative, and seven (35%) as neutral mappings. Six of the students believed that the analogy was helpful for their understanding of the concept and five of them recalled having seen a similar analogy in the past. Of this latter group, Anthony's (A) response to the researcher, who had questioned him about his familiarity with the analog, provides a useful summary:

A. The one about the football field and the marble is quite a common comparison.

R. You had heard of that before?

A. Indeed, and it's fairly important to realise the size of the atom and the size of the nucleus and also about the space within the atom.

R. So, you see that as being the key part of the analogy?

A. Yes, I think that is quite a good analogy. (asi04)

A closer examination of the completed positive mappings revealed that four students chose to map the comparison of relations of size represented by the analogy statement:

stadium : marble :: atom : nucleus

while three students mapped the concept of the empty "space" on the football field and in the atom. Other mappings, each made only once, related the marble directly to the nucleus, the large football stadium to the (relatively) large atom, and the position of both nucleus and marble at the "centre". Hence, most of the positive mappings addressed directly the key issues presumably intended by the author.

While no mention of the spectators or players appeared in the text supporting the pictorial-verbal analogy, there was a number of mappings that focussed on the presence or activities of the players and spectators, mapping these persons to electrons; students like James being attracted to the "living" aspect to the analog. Some of these mappings were rated as being neutral with two students pursuing the reasoning that there were many spectators and these represented the electron fields/clouds. For example, David (D) saw this relationship as being particularly tenable:

R. What did you see as the most important factor that the author is trying to communicate there?

D. How small the nucleus is compared to how large the cricket ground is – just how small it is compared to the rest. And how the spectators represent the electron fields and orbitals.

R. What about the lawn area – does that represent anything to you?

D. Yes, the football field with grass has the wide open space – the space between the nucleus and the electron field. (nhi05)

Other similar mappings were made on one occasion only: the spectators are seated in sections and the electrons are found in orbitals; as the footballers are encouraged by the audience, so electrons are affected by external influences; spectators are distant from the centre while electrons are distant from the nucleus; and the players are more concentrated near the centre of the ground as the electrons are denser towards the nucleus. The researcher did not consider that any of these mappings would act negatively to hinder the development of later concepts or propagate misconceptions, however, neither do they assist students' understanding of the relationship between atomic size compared to nuclear size.

Both Anthony and Len inferred a caution at mapping spectators or players to electrons. Anthony commented that, while the people "could be used to represent electrons, to keep the analogy simple, I would not have mentioned it. But if later you wanted to build on it, you would say there are people on the outside and all that" (asi04). Len's caution arose from the numerical differences that existed between the number of spectators and the number of electrons (lti07). He showed his cognisance of the difficulties that others may have with this analogy by commenting that these other students "would think that the people are the electrons and that they are only found in a thin area around the outside and this [the oval part] is just nothing" (lti07).

Three other mappings that related spectators or players to electrons were rated as negative. Two of these argued that the amount of motion of the players and spectators could represent the level of energy of the relative electrons – near and far from the nucleus respectively. These, however, deny the chemical convention that more energetic electrons tend to be those furthest, rather than closest, to the nucleus. Jon's (Jn) confusion with this issue becomes evident by examination of the following excerpt:

R. You have written down some things that compare the chemistry and the football oval. Do you see anything in there that does not compare and may give you the wrong idea?

Jn. Um, the fans [supporters]. Because the electrons, . . . they are more dense towards the centre. And when you see this, it gives the impression that they are more denser on the outside. So, I have basically looked at the layout itself and not the stacking.

R. The lawn area or grass area —what does that mean to you?

Jn. Well, that is what is the electron cloud and that.

R. I'm not too sure whether you are saying that the electrons are the . . .

Jn. [interrupting] The players.

R. I see, so not the spectators?

Jn. No.

R. I see. So this [lawn area] is the region in which they would go.

Jn. And I feel it is really not very dense there.

R. So, to you, what is the most important thing that this is trying to communicate?

Jn. Um, the size with the marble and the size. And also how they are spread out – the electrons. So with the players, there are more in the centre and less on the outside. (jii04)

While acknowledging a degree of inconsistency, Jon retained the attributes as matched with some unclear qualifications. Paul's (P) arguments were similarly self-diagnosed as being flawed:

R. So, you are matching up spectators and electrons, is that correct?

P. No, spectators and players on the field. Some of the players would be the electrons that are moving around really fast and the spectators would be the electrons that are moving around slower.

R. I see, so all the people there are electrons.

P. Yes, but they have got a lower kinetic energy than the other ones. (pwi06)

and later:

R. Are there some things in there that you think may be misleading for students who might get the wrong ideas about atomic structure given that common world idea?

P. Yes, maybe, because the spectators on the outside aren't moving which may suggest that some electrons on the outside don't move at all and electrons closer have a higher kinetic energy which may be wrong because they have got less of a space to travel in.

R. So, you would prefer a situation where they were swapped . . .

P. [interrupting] Swapped around. (pwi06)

The third mapping related the motion of the players relative to the "central mark" as being analogous to electrons moving faster than the nucleus. This could be misleading in that it infers a lack of motion of the nucleus that is contrary to the kinetic theory. One other mapping argued that the two football teams were analogous to the two different particles – protons and neutrons. This student conveyed a lack of understanding of the analogy in that the nucleus, allegedly containing the protons and neutrons, was the size of a marble. Given that the only positive mapping this student made related to the empty "space" of most of the atom, it is probable that the key issue was not attained.

A significant limitation that should have acted against students making analogical relations between spectators and electrons was the flat terrain of the playing fields and stands. Several of the students who had made the person/electron links provided limitations when speaking in the interviews. For example, the following comment recounts Chris's (C) response when asked about the significance of the grassed/lawn area:

R. And what about the grassed/lawn area – did that mean anything to you?

C. [pause] Well, that is a sort of a negative thing because it only makes it into a 2-D thing.

R. Rather than?

C. The real three dimensional. (mci05)

Similarly James, who related the electrons to players, identified this limitation when asked:

R. If somebody like you was to read this, do you think they could get some wrong ideas about atomic structure based from that picture?

Js. It depends how far they are actually looking into it. Like if you are looking more into the electrons themselves, obviously you would have people scattered around. In a lot of cases you would not have as many electrons as what you would have in a footy game – like it is in really random order where they are. Because the electrons can be there but if you have got your *x*, *y*, and *z* planes [*p*-subshell electrons], then it doesn't seem to be anything like that. It seems to be almost a 2-D structure instead of a 3-D. (jpi06)

As mentioned above, six of the students believed that the analogy was useful for them. Of these, Paul commented that it was useful as he enjoyed cricket and found it easy to relate to. Others argued that it made it "easy to understand" (David) and "put the size of the nucleus [versus] the atom into perspective" (Tina). Anthony, having identified that it helped him "appreciate how small a nucleus is, and how much 'space' there is in an atom," went on to identify a limitation of the analogy. On the map, he argued that it did not "explain the mass ratio which is also an important concept." In the interview, he emphasised his point:

R. Are there things that you see in here that may give a student or give perhaps yourself, the wrong idea.

A. Well, the football stadium looks like it is full of people and that would have a mass of many millions of tons where the marble would only weight 20 grams or whatever and that would give the wrong impression because it is actually the other way around.

R. I see

A. That's what I wanted to put in [at the bottom of the map].

R. Anything else?

A. I don't know. If they said that the marble weighed a few million tonnes but as it is an analogy to explain the size, I think it is fine. (asi04)

Anthony was correctly arguing that most of the mass of the atom is located in the nucleus and this does not fit with the chosen analog. His attempts to alter the analog to better fit his understanding of the target had merit.

Two students did not believe that the analogy was useful. James commented that the analogy didn't provide sufficient information about the numbers of protons, neutrons, and electrons. He had mapped the two different football teams to protons and neutrons. Chris, committed to the analogical relationship between electrons and players, commented that "electrons are much smaller compared to the nucleus than footballers [are] to the centre."

Student Responses to Analogy Map C (Rotating Fan)

For this analogy, four students attempted three attribute mappings and the other four attempted only two mappings. Of the 20 attempted mappings, thirteen (65%) were rated as positive, four (20%) as negative, and three (15%) as neutral mappings. None of the students recalled having seen a similar analogy in the past and six of them believed that the analogy was helpful for their understanding of the concept.

From the examination of the positive mappings it was found that the two mappings provided in the text were both recorded by four students: the blades and electrons cannot be precisely detected at a given instant, and both blades and electrons seem to be everywhere in the region at once. The more subtle "rapid rotation" mapping was identified by four students and one student compared the shaft to a nucleus. Hence, all except one of the positive mappings were drawn from the text itself and related directly to the key concept described earlier in this chapter.

Other mappings were attempted that were rated as neutral or negative by the researcher. Neutral mappings included comparisons between: the "circular" shape of the fan and electron clouds; the motion of the fan blades and the kinetic energy of the electrons; and the attachment of the blades to the shaft as electrons are attracted to the nucleus. Four different negative mappings were identified. James made two negative mappings. In the first of these, he argued that the three blades on the fan could relate to the x, y, and z orbitals of the p-subshell. The text, however, identifies the comparative atom as the more simple hydrogen atom comprising a spherical electron region for which the x, y, and z notation has little meaning. James also argued that the shaft and nucleus both have a "fixed position," a notion that contradicts principles of the Kinetic Theory of Motion. While this description may prove fruitful for this particular analogy, it would be problematic if transferred into students' understanding of other chemistry concepts.

Chris identified the electrons as having "relatively fixed positions" around the nucleus in much the same way as the fan blades are fixed to the shaft. This student attempted to map what is clearly a limitation of the analogy. David succumbed to a second limitation of the analogy, that the fan travels only in a two dimensional region whereas electrons exist in three-dimensional orbitals. This limitation was identified by Anthony who commented in the interview:

A. The fan/electron analogy? I thought that was a good one, and I hadn't seen that one before, but it did help to explain it. . . . But also the fact that the fan is pretty much two dimensional whereas spherical is pretty much the shape of electrons. But, apart from that, it did explain it and because it is moving so fast, it pretty much is a sphere.

R. So, you felt this one was helpful?

A. Yes, it was. [pause] I did say that as a comparison that fan blades move at a high speed you can only detect them with precise equipment and yet electrons move so fast that you can't freeze them. (asi09)

He supported this with a note in parenthesis following his response to the question about the analogy's usefulness: "However: fan is 2-D, electron shell 3-D."

As mentioned above, six students considered the analogy to be helpful for their understanding of electron location. Of these, four students made simple comments to the effect that the analogy made the concept easier to understand. There were two more noteworthy contributions, however. Tina remarked, "I never knew electrons are a cloud of negative charge filling all of the volume of the hydrogen atom." This indicated that the analogy mapping exercise may have resulted in some further conceptual growth of the target concept. Chris extended the analogy by noting, "the blades can deflect objects like electrons in an atom." His comments may reflect an awareness of Rutherford's experiments in nuclear physics in which the scientist observed the effects of firing alpha particles at gold foil. Deflections in the path of the alpha particles that passed through the foil were attributed to the influence of the positively charged nucleus, however, rather than the electrons. Neither Paul nor David found the analogy useful, both of them arguing a lack of visualisation. Paul would have preferred some representation that had "easily distinguishable things like [a] central nucleus" and David suggested that the analog "did not give a very visual account of an electron cloud."

Student Responses to Analogy Map D (Reams of Paper)

For this analogy, three students attempted three attribute mappings, two attempted two mappings, and the other three attempted only one mapping. Of the 15 attempted mappings, 14 (93%) were rated as positive, none as negative, and one (7%) as a neutral mapping. None of the students recalled having seen a similar analogy in the past and only two of them believed that the analogy was helpful for their understanding of the concept.

From the examination of the positive mappings it was found that the most frequently mapped attribute was the practicality or ease of use of the mole and ream (six mappings). Several other mappings were recorded by two students; the large number of sheets related to a large number of atoms, and an analogy that could be expressed as ream : sheet :: mole : atom. Other attributes mapped by only one student included: one ream of a given type of paper has a set mass, so too, one mole of a species has a fixed mass (molar mass); it makes counting easier; and as there are a fixed number of sheets in a ream, so too with atoms in a mole. The difference in ratio (500 : 6.02×10^{23}) of the numbers of sheets to atoms was identified by several students as a limitation to the analogy. Chris quickly realised that Avogadro's number of sheets of paper would make a very great amount of paper:

R. I'm not too sure what you mean here by "Atoms compared to moles are much smaller than sheet compared to a ream" [R. reads aloud Chris' mapping on Analogy Map D].

C. Well, you have got a sheet of paper which is about that [gesticulates A4 paper sheet] size and a ream is probably about that [gesticulates ream size] large. Well, if you had an atom that was the size of a sheet of paper, you would have a ream that would be [laugh] very big. (mci16)

Similarly, Anthony said that his "only qualm [was] that the ream is only 500 and if there was something with a much larger number, then it would be a more direct explanation" (asi10). David, while not particularly appreciating the ream as a suitable choice of analog, admitted that "it was probably the easiest thing to use:"

R. You have written that it is not useful because it "doesn't give a clear picture of how small an electron is."

D. Because [the analog] is 500 and [the target] is $6x10^{23}$, so it is quite different.

R. Do you see a big problem in the difference between the two numbers?

D. Yes.

R. Why do you think then, if there is this big difference in the numbers, that the author has bothered to put that in?

D. Because it is probably the easiest thing to use.

R. But what would be the main reason for using it?

D. The impracticability of using individual ones instead of using a package. (nhi11)

While it may have been an "easy" choice, the difference in number will continue to be a limitation that cannot be avoided although students could be warned about it. Paul summed up this continual limitation by accurately describing the need for an analogical representation in the first instance:

R. Do you think the difference in number would be a problem to students – the 500 as against the '*x*' by ten to the twenty odd?

P. Um, yes, because we can't relate to it. We never have it in real life situations, hardly ever. (pwi12)

Despite these students' concern over the ratio discrepancy, it did not appear to hinder their ability to map the attributes.

One student (Paul) recorded a different limitation for this analogy. He identified that, although it is quite easy to take one sheet from a ream, it is not at all easy to remove one atom from a mole of atoms. This student's ability to identify accurately one of the limitations of this analogy indicates his awareness that the analogy is not a perfect match. Indeed, during the completion of the analogy map, Paul asked of the researcher, "What is a ream?" Hence, while the term was unfamiliar to the student, the satisfactory understanding of the concept developed from the researcher's response, was sufficient for him to conduct the necessary analogical reasoning. In his neutral mapping, Chris related the mixing of different coloured paper to the formation of compounds. While this indicates an understanding of the combinatorial nature of the species, it contributes little to the understanding of the mole concept.

While all eight students recorded that they had not seen the analogy before, two students identified similar analogs that could be used to describe the same target. Jon, when asked about his knowledge of other analogies for the mole concept, indicated that he had seen the mole concept described in terms of grains of rice:

Jn. Yeah, because I know that this is a fairly common one. It's not normally in sheets of paper. I know in *Foundations of Chemistry* [the students' textbook], it is rice and another one I saw [pause], I can't remember what it was.

R. What do you see as the advantage of grains of rice over this?

Jn. They are just smaller. (jii10)

Tina spoke of "the dozen" analog that one of her teachers had used when she had first encountered the mole concept during lower secondary science lessons and indicated that her familiarity with this analog meant that she did not find the ratio $500 : 6.02x10^{23}$ troublesome. While it was not established which forms the earlier "rice" and "dozen" analogies had taken, these instances support the argument that students may revisit foundational analogies when reconsidering the target concept.

As mentioned above, six students recorded that they did not find the analogy helpful for their understanding of the target concept. Tina seemed put off by the "ordering" of the paper as she wrote that she "wouldn't know how to go about ordering paper" and Len was confused by the "many figures" in the text prior to the analogy and he considered that the "example [was] not really extensive enough." Indeed, while acknowledging a role for analogy, Len sought a more familiar analog:

R. Now, the word ream is obviously one that you are very familiar with. If you were the author, would you bother to put something in here about trying to make some comparison.

L. I'd maybe make it a bit more of a common one that I know.

R. Could you give me an example – I know it is hard to think on the spot.

L. [pause] No.

R. What would it need to better it?

L. Just something that is clear and as the mole contains many things this [new analog] contains many things as well but it has to be an obvious one, it must be a common one. (lti12)

David argued that the analogy was "unclear" in a number of ways. James remained unconvinced of the need for the analogy, arguing that a straight explanation and definition approach was less confusing:

R. [Reading mapping] "It is harder to understand the idea behind the mole." What do you mean by this?

Js. I've seen just straight out approaches – instead of using different things to relate moles to other things. Like if you just went straight out and said, "This is what a mole is and this is how you use it," instead of trying to relate it to normal things, that may have made it a bit easier to understand than that [the analogy]. I think the [reams of] papers confuse the idea a little bit. I think when I did it [was introduced to the concept], I just said "This is what a mole is, deal with it," you know.

R. For students who do have problems understanding the idea of why we use the mole, and some do, can you think of another way rather than talking about reams of paper that you could use or would you rather say, "no, let's just stick with the mole explanation?"

Js. Takes a while to think of something, I think. You would have to have something in bulk and paper seems like a good bulk idea but it does seem to confuse the idea. So you would have to go just straight for what the mole is. That seems to be easier than trying to use another example.(jpi11)

Clearly, the analogy proved fruitless for James as, later in the interview, he provided evidence that he had maintained an incorrect chemical conception that should have been challenged by the analogy:

R. Do you think there are any wrong ideas that students can get out of the reams of paper compared to the mole?

Js. You are just getting the main idea that you are getting a lot of paper and therefore you are getting a lot of atoms in one mole but it is not really giving the representation that one mole consists of different numbers of atoms for different things [note incorrect conception]. When you buy 500 sheets, you get 500 sheets, no matter what it weighs or anything else. There is no comparison between the two there. (jwi11)

James' maintenance of the tenet that a mole of different chemical entities contains different numbers of that entity indicates that the analogy had little effect. It is unclear as to how students process new analogies when they hold a conception that should be challenged although it is possible that they attempt to reconstruct the analog so that it fits their conception of the target. Duit (1991) has described this reversible analogical process in more detail.

Chris was unhappy with the limitation of "atoms compared to moles are much smaller than sheet compared to a ream [*sic*]" while Paul complained that a "picture, which would have helped [him] to understand more easily," was missing. These students' difficulties appear to have stemmed from difficulties with the structure of the text in the analogy, or lack of an adequate conception of the analog, more than the conceptual relations between the analog and target domain.

Student Responses to Analogy Map E (Bridge Over Gully)

For this analogy, five students attempted three attribute mappings, two attempted two, and one student made only one mapping. Of the 20 mappings made, 17 (85%) were positive and three (15%) were neutral. Once again, no negative mappings were recorded for this analogy. While no student recorded having seen the analogy before, Chris made an interesting observation:

> C. You do see these things, you just don't remember them. You see the pictures but I don't remember them. I remember concepts best. (mci06)

Despite the finding that Chris believed the analogy to be useful for his understanding of catalysis, he was willing to encounter analogically-inclusive instruction with the intention that it be mentally discarded once the target concept was attained.

Five positive mappings focussed on the lower energy/power/fuel/petrol requirement for the bus to get over the gap with the "catalyst." Similarly popular were four mappings describing how the bus travels quicker with the bridge as a reaction occurs quicker with a catalyst, and three arguing that a catalyst provides a second possible route regardless of its energy requirements. Chris added that the bridge enables the bus to travel well in the reverse direction as a catalyst speeds both forward and reverse reactions. Jon mapped the "space between where the bus was and where it needed to be," as the activation energy. Anthony commented that, just as the bridge is still there after the traverse, so too does the catalyst remain unconsumed at the end of a reaction. He believed that the lack of some comment to the effect that the catalyst remained unconsumed at the end of the reaction was an important deficiency of this analogy.

Two of the mappings that were rated as neutral conveyed some essence of correctness about the target chemistry concept although they were not presented logically with respect to the mapping. Anthony argued that, as the bus "uses less energy because of the shorter distance," then the "reaction is less violent because less energy is required." Chris proposed that, as the "bridge allows [the] bus to go over [the] river without having to climb a hill," the "catalyst allows reactions to occur at lower temperatures." While this mapping shows understanding of the chemistry involved, the two statements are not logically linked. The third neutral mapping was linked to the provision of an alternative path for the bus and mechanism for the reaction, except in this case David described the bus and the reaction as having the opportunity to now make a choice whether to go via the easy or the more difficult route. Not only was the anthropomorphism unsuited to this situation, the key aspect of one path being more energetically favourable was absent. The mapping was not, however, likely to lead to the formation of alternative conceptions.

According to the students' responses, the strength of this analogy lies in the ease of visualisation provided by the pictures. Following their positive responses to the usefulness of the analogy, the students made many comments such as "it is graphic and easy to understand" (Len) and "the diagram is easy to understand and easy to relate to as you don't [*sic*] get confused with lots of reading" (James). These comments provide a useful contrast to the previous analogy that contained several paragraphs of verbal text only – an analogy which most students believed did not help their understanding.

Appendages were found on several students' maps. Tina commented that, "although I know a catalyst provides a path with lower [activation] energy, I still do not know how it does it." Clearly, in a search for a more conceptual understanding, possibly at a molecular level, Tina has found this analogy lacking conceptual depth. In an attempt to deal with what Anthony saw as a limitation of this analogy – it "doesn't explain that [the] catalyst is not consumed" – he proposed what he called a "better analogy: building a bridge as opposed to filling in the valley." He also, was showing evidence of a conceptual understanding beyond the level provided by this analogy. There is no evidence, however, that these students are in any way hindered by this lower level description. On the contrary, analysis of an analogy's depth and identifying its limitations should further develop these students' chemistry conceptions.

Discussion

The results of this investigation provide useful insights both into how students extract attributes from analogies and how effective the analogy maps are as a research tool to record and rate the mappings students attempt. Table 7-1 provides a useful summary of the quantitative aspects of the eight students' mappings. Using this table and the description of this study's qualitative findings reported above, a brief analysis of each map precedes the general discussion.

Table 7-1

Summary Table for the Quantitative Aspects of the Eight Students' Mappings

Map	Present. Format [a]	Analog Explan.	Level of Enrich.	No. of Mappings	Pos %	Neg %	Neut %	Helpful	Recog-nition
B	PV	No	Enrich	20	50	15	35	6	5
C	PV	Yes	Extend	20	65	20	15	6	0
D	V	No	Simple	16	93	0	7	2	0
E	PV	No	Enrich	20	85	0	15	7	0

[a] V = Verbal, PV = Pictorial-verbal

Analogy Map Analyses

Analogy Map B (M. C. G.) Analysis

Analogy Map B is noteworthy for having the lowest proportion (50%) of positive mappings. Surprisingly, this is despite the evidence that more than half of the students had some recollection of a similar analogy prior to this – something that was not identified for the other three analogies in that mapping series. The low proportion of positive mappings appears to be due principally to the high proportion of neutral mapping that the students attempted.

Most of these neutral mappings involved an incorporation of the role of spectators and players into the analog domain which was then mapped to the structure or function of electrons around the nucleus. Examination of the analog shows that the spectators represent a significant proportion of the more visible components of the analog. It could be argued that a better analog would have shown a picture of an empty M. C. G., although it would be true that, in any choice of analog, there is a natural tendency for students to approach the analog from their own experience. The normal experience that students have with a venue such as the Melbourne Cricket Ground is as a spectator, or participator, in a sporting event. Hence, it is to be expected that students focus upon functional and living structural attributes of the analog rather than impersonal structural attributes such as size. An interesting later study could investigate the influence of changing the content of a pictorial component on students' mapping selections.

Analogy Map C (Rotating Fan) Analysis

Analogy C, while being pictorial-verbal in its presentational format, included a considerable amount of text. In this text, several mappings were provided by the textbook authors, sufficient that the analogy was classified as *extended* according to the Analogy Classification Framework. Despite the provision of three mapped attributes in the text, student mapping of the analogy's positive attributes was still low. Unlike analogy B, where the shortfall could be accounted for by a high proportion of neutral mappings, in this case students frequently made negative mappings. The students' inability to transfer the positive mappings from the text to the analogy map is cause for concern. In this analogy mapping exercise, students were focussed specifically upon the task of reading the analogy and extracting mappable comparisons. It was reasonable to propose that, in the normal setting of classroom work or home study, students reading their textbook would be less focussed on the extraction task. Hence, the efficacy of the analogy to engender the construction of a correct concept, or to challenge that status of an alternative conception, would be decreased.

It is possible that the students' inability to record these previously mapped attributes may have been related to the manner in which they appeared in the text. Rather than identifying openly that "as the blades travel around the shaft, so too do electrons travel around the nucleus," the mappings were provided in parallel, yet separate sentences. For example, parts of the third sentence (*tiny particles which move at very* *high velocities*) map vaguely to the first clause of the fifth sentence (*during rapid rotation of the fan*); the latter part of sentence six (*we cannot say where the blade is*) is parallel to the end of sentence eight (*we cannot say exactly where the electron is*); and sentence seven (*some evidence of the blade can be seen at every point in the volume of space through which it moves*) maps strongly to the first part of sentence eight (*some influence of the electron exists at every point in the spherical volume of the hydrogen atom*). While it does appear a simple task, students were either reluctant or unable to record these same mappings on their analogy maps. It is, however, speculative to suggest that this inability to transfer the positive mappings was due to the structure of the analogy as presented in this particular textbook.

Analogy Map D (Reams of Paper) Analysis

Map D was described as being difficult by several of the students for a variety of reasons, most of which could be attributed to the nature and extent of the text. Similarly, it was perceived as the least helpful analogy and was mapped less extensively than the other three analogies with only 16 mappings compared to the 20 mappings found in each of the other maps. Despite these three factors, however, this map had the highest proportion of positively mapped attributes (93%). This outcome could indicate that students were able to readily identify suitable attributes and were not willing to attempt extension of the analogy beyond an apparent comfort level. Tina's notion of difficulty, an inability to find three mappable attributes, may well have underpinned the negative feelings of other students who were less able to elucidate their feelings of unease.

Another feature of Map D is noteworthy; this was the only analogy to be classified as having a *simple* level of enrichment. In this instance at least, the absence of mapping provided by the textbook authors did not appear to have restricted the students' ability to identify and record mappable attributes. This contradicts the tentative statements about the rotating fan analogy suggesting that the way in which the textbook authors arrange the analogy mapping in the text may advantage, or otherwise, students' ability to draw mappable attributes.

Analogy Map E (Bridge Over Gully) Analysis

Despite not being one of the analogy maps investigated intensively in the interviews due to time constraints, several of the students ventured the comment that Analogy Map E was the easiest of the four mapping tasks. This was reflected in the absence of any negative mappings and the 20 mapping attempts. As the students were familiar with the function of the catalyst and also familiar with the energy/extent of reaction diagrams referred to above, they appeared to have little difficulty matching a wide range of positive attributes.

The similarity between the structural and functional attributes of this concept to the structural and functional attributes of the analog, enlarge the range of mappable attributes. In this case, the transference of the structural components (a high hill and a bridge over a gully) to the functional attributes (the bridge path is energetically more favourable than the hill path) appears relatively straight forward. It should be expected that, if students can make this transference correctly, it should assist transference of the target's structural attributes (the shape of the energy graph) to its functional attributes (an energetically more favourable reaction mechanism when a catalyst is present). Further, in this analogy, the analog becomes a suitable vehicle for description of the abstract concept – evidence of this being the maintenance among chemists of the Level Two Alternative Representation (see Figure 5-2) language such as "path", "pathway", and "barrier" described above.

In mapping the shared attributes for this analogy, students had a choice of mapping the structural attributes to the shape of the energy curve, or the functional attributes to either molecular behaviour or reaction rates. Some students focused only on the structural similarities between the analog and the energy/extent of reaction diagrams. For example, as mentioned above, Jon mapped the "space" between where the bus was and where it needed to be as the activation energy. None of his three mappings addressed the molecular level – the other two mappings dealt with the changes to the "path" of the reaction with respect to the energy diagrams. Such mappings by students indicate that they are unlikely to have a clear understanding of the meaning of the energy terms measured on the vertical axis of the diagram and would be unlikely to describe these processes at the molecular level. Albeit at the macro level, their understanding allows them to accurately describe and deal with the relationship between rate of reaction and reactant energy and describe the notion of a transition state. This level of understanding is sufficient for students to answer most of the questions they are proffered in class time, tests, and examinations; for these students, transfer of the analogs' structural attributes to the target is sufficient to meet their assessment needs.

For the other group of students – who feel comfortable to describe these energetic processes in terms of bond breaking and bond forming – the functional attributes of this analogy have mappable content also. These students too can use the analogy as good grounding for the development of their conceptual understanding. For these students, however, the useful life of the analogy may be decreased; subtle limitations that will become evident with more complex levels of treatment may render it less useful than the continuing development of their understanding at the molecular level.

For this analogy, the broader "superordinate concept" (Glynn, 1991) of *energy requirement* agrees well with both the analog and the target. Important in the consistency of these analogies is the relationship between successful collisions and kinetic energy prior to the interaction. In this instance, the ability of the bus to negotiate the original hill depends upon its initial velocity. Many similar analogies, such as the pole vaulter analogy from the *Chem Study* materials, are based upon the same principle. Tacit in the workings of these analogies, is maintenance of the notion that bond breaking occurs as a result of a mechanical collision rather than electron delocalisation. At this stage of chemical education, however, this level of understanding is usually acceptable and is unlikely to cause significant limitations to the development of higher concepts related to kinetics should the student pursue chemistry beyond high school level.

Summary

Study Five has produced some useful findings that, while lacking generalizability, provide a good grounding for Study Six. These students felt generally comfortable with the analogy mapping tasks although several would have preferred the descriptions of the chemical content to be free of analogical explanations.

In these analogy mapping tasks, the students were revisiting chemical concepts that they had encountered during their last eight months of instruction. Hence, the mapping exercise was limited in its ability to determine whether chemical concepts were understood as a result of the mappings attempted. There were only a few instances, such as that of Tina documented above, in which the researcher recognised new concepts being correctly attained as a result of the exercise. Similarly, there was little evidence that these analogies contributed to the formation of misconceptions in the students' understandings of the chemical concepts. There were, however, instances in which the analogy failed to adequately challenge an alternative conception that was held by a student. In at least one of these instances, the student ignored the mapping provided by the textbook author and altered the analog to suit his incorrect conception of the mole concept. Here, support for enriched analogies with structured mapping is advocated although, just as a normal textual description of some chemistry concept will not cause all students to change their conceptions, so too a well-structured, enriched or extended analogy may similarly "fail" due to reasons outlined in previous chapters.

Several of the more academically-able students, such as Tina and Anthony, were able to identify limitations of the analogies and to describe how they could be modified to better map the target concept. This was possible due to their strong content knowledge – often at a molecular level. Further, Anthony displayed an understanding that, while an analog may be limited, it is often included to describe a particular concept at a particular level and, therefore, he felt that some of the limitations that he had identified could be overlooked (see asi04 above in *Student Responses to Analogy Map B* section).

It is interesting that the mapping exercise and interviews produced data revealing where students held alternative conceptions about the chemistry topics addressed. While this adds credence to the use of an analogy mapping exercise to identify these alternative conceptions, it would appear that the analogy's ability to *challenge* these conceptions is not automatic.

For the four maps considered in this study, those that were pictorial-verbal were preferred by the students and were also mapped more extensively although this mapping was not necessarily more accurate. Study Six should address more fully the relationship between mapping and presentational format by altering the analogs and by increasing the number of students.

While a majority of the students in this study recalled having seen an analogy similar to the M. C. G. analogy for atomic structure, this previous exposure did not appear to substantially influence their ease with the mapping process. With the reams of paper analog (D) for the mole concept, several students demonstrated their cognisance of alternative analogs for the same target concept and it was apparent that there was some transfer between analogs to support the mole concept.

Evidence gained from the M. C. G. analogy causes the researcher to suggest that, despite the presence of a picture or enriched text, students constructed their own conceptions of the analog domain based upon their prior experiences with the analog and their partial understanding of the target. While this is to be expected, it does provide a need for caution when writing analogically-inclusive material for textbooks where there is little opportunity for discussion or redress.

The general level of agreement between the students' recorded mapping attempts and their responses during the interview sessions indicate the strength of the analogy mapping instruments to document the students' perceptions of mappable attributes. Study Six engages a different group of students on a similar mapping process without the cross validation of the interviews. This allows more data of a quantitative nature to be collected so that students' mapping performances can be compared for analogies of different structures and formats.

STUDY SIX – RELATIONSHIPS BETWEEN VARIABLES INVOLVED IN ANALOGY MAPPING

The purpose of this study was to use analogy maps to determine the nature and extent of the relationship between students' mapping performance, their chemistry performance (a grade based on test and examination results and classwork), and the format and style of the textbook analogies.

Method

This section of the chapter begins with a description of the student group chosen for Study Six. This is followed by a discussion related to the four analogy maps with an emphasis on those maps that differ from the ones used in Study Five. A description of the procedures for the administration of the testing procedure concludes the section which is followed by a presentation of the results obtained.

Description of the Student Group

One class, comprising 19 Year 11 chemistry students, was selected for Study Six due to the collegiate nature of the relationship shared between the researcher and the classroom teacher. Some students in the class were known to the researcher as he had taught in that school several years prior to the commencement of the study. The school was a co-educational government operated school drawing students from middle and working class suburbs in the hills district east of the city of Perth. Unlike students in Study Five, these were not volunteers and it was expected that, on the teacher's request, all students would complete the task to the best of their ability in the allocated time.

In the previous study, the eight students surveyed were aware of the researcher's intent to interview each of them at the conclusion of their mapping session and that the interviews would focus on the attempts that each student had made. It was anticipated that this would have provided added motivation, enhancing students' diligence at the task. The students in Study Six, however, were not to be interviewed and were not advised that any follow-up interactions would occur. Further, they were afforded the privilege of anonymity with an initialled code only being written on each survey sheet for the purpose of matching students' mapping ability to their chemistry performance. These factors would be expected to have influenced the amount of effort that the two student groups put into the tasks and caution should be exercised when drawing comparisons between Studies Five and Six.

Documentary Resources

For Study Six, five modified analogy maps were prepared as shown in Figure 7-6. Full copies of the analogy maps are provided in Appendix 3. The analogs in these maps were classified according to the Analogy Classification Framework and the pertinent characteristics are shown in Figure 7-7.

Map	Analog	Target
A (sample)	Two boxers	Acid/base reaction
B	Marble on M. C. G. oval	Nucleus of an atom
D	Reams of paper	Counting in moles
F	Football spectators	Spectator ions
G	Onion skin layers	Electron shells

Figure 7-6. The five modified analogy maps used in Study Six.

Map	Presentational Format	Analog Explanation	Level of Enrichment	Analogical Relationship
B. M. C. G.	Pictorial-verbal	No	Enriched	Structural
D. Reams of paper	Verbal	No	Simple	Functional
F. Football spectators	Verbal	No	Enriched	Structural-functional
G. Onion skin layers	Verbal	No	Simple	Structural

Figure 7-7. Pertinent criteria from the Analogy Classification Framework for the four maps used in Study Six.

In a manner similar to that described in Study Five, the 19 Year 11 students were provided with the set of analogy maps. The map set comprised instructions to candidates, a sample map (A) with possible solutions already entered in, and four unworked analogy maps (B, D, F, and G) as shown in Appendix 3. Maps B and D were the same as those used in Study Five which were reported with interview data as well as with the mapping results. Maps F and G were substituted into the map set to widen the scope of the data with respect to verbal (only) analogies.

Map F (the spectator ions analogy) used an analog of spectators at a football match to help define the term "spectator ions". There are two key aspects to the target concept, firstly that spectator ions do not take part in the reaction, and secondly, because of their lack of participation, they are not shown in the final, net ionic equation. This duality made it difficult to classify the analogical relationship: if the target concept of the role of the spectator is being addressed, then the analogy exhibits functional relations; if the omission of the spectator ions' formulae from the final equation is being mapped, however, the analogy may be considered structural. For these reasons, the analogy was classified as having a structural-functional analogical relationship.

The spectator ions analogy is presented in a verbal format with 12 lines of text and a chemical equation. It is introduced in the latter half of the insert as an embedded activator to the concept of a spectator ion. No analog explanation, strategy identification, or limitations were present with this analogy although the textbook author provided some mapping. This mapping occurred at the start of the sentence (from Ainley, Lazonby, & Masson, 1981, pp. 111-112) reading:

> Just as the names of the spectators are not included in the press report of a football match, so the formulae of the spectator ions are not included in our report of the reaction, which is the equation, and so the equation for neutralisation in aqueous solution is:
>
> $$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

Evidently, the language of "spectator ion" is rooted in a Level Two Analogical Representation as discussed in Chapter 5. This, no doubt, inspired the selection of the analog domain, the authors strengthening the analog/target relationship by the word association. Although the concept of *an ion* is somewhat abstract, the decision not to record the name of that ion in the equation was not considered abstract; hence the analogy was rated as concrete/concrete.

Map G (the onion skin analogy) uses an analog of layers of onion skin to illustrate consecutive "shells" of electrons around a Bohr atom. In this analogy, structural attributes only are transferable from the concrete analog domain to the abstract target domain. The analogy has no mapping accompanying it, is presented as an embedded activator, and has no analog explanation, strategy identification or expression of limitations. The onion layers analogy is presented in a verbal format with 12 lines of text and the analog is less obvious than others used in the maps to date, comprising only six words at the end of a sentence.

The origin of the analogy is not particularly clear from reading the text as there appears to be little in the way of surface similarity or common phraseology that often characterises more popular analogies such as the "solar system" analogy for the Bohr model of the atom, in which planets represent electrons. As an analog, the "solar system" appears to have many more mappable attributes – both functional and structural – than the "layers of the onion" analog provides. Glynn et al. (1989) have produced a useful analysis of mappable attributes for the solar system analogy and, while many teachers distance themselves from the Bohr model of the atom because of the difficulties that arise when more abstract conceptions of the atom are being taught, the Bohr model remains part of many high school chemistry curriculum packages.

Administration of the Test

The 19 students were permitted 30 minutes to complete the mapping exercise which was done as a whole class exercise during a normal chemistry lesson. While most did the activity in silence, two students asked questions of the researcher during the task to clarify details. Later, all 76 (4 x 19) analogy maps were rated using the rating profile shown in the previous chapter (see Figure 6-8). In addition, the teacher provided the researcher with a list of the students' grades and examination marks for chemistry, each matched to the code identifying the analogy maps.

Results

Following the ratings of the maps, the numerical data were assembled on a summary table as shown in Table 7-2. Each map was considered individually before the relationship between mapping ability and chemistry achievement was investigated. In completing the task, some students appeared to require several more minutes to complete the tasks although the majority had time to spare. Nevertheless, many students were unable or unwilling to attempt two or three mappings for each analogy.

Table 7-2

The Summary Table for the 19 Students' Mappings

Map	No. of Mappings	Positive %	Neutral %	Negative %	Helpful %	Recog-nition %
B. M. C. G.	31	42	42	16	82	11
D. Ream	26	58	27	15	47	11
F. Spectators	35	80	20	0	82	29
G. Onion layers	35	40	29	31	47	20
Totals/Averages	127	55	29	16	-	-

Indeed, given that each of the 76 maps had three spaces available for mapping, the total possible number of mappings was 228. Only 127 mappings were attempted, however, and the proportion of mappings on the whole was therefore reasonably low (56%). Of this low proportion of attempted mappings, only 55% were rated as being positive. These figures were lower than the attempt rate for students in Study Five and may reflect the method of (self) selection and the ability of the student cohorts. While the students in Study Six attempted fewer mappings, it was not expected that the process of making choices about the mappings and the type of mappings made would substantially vary between the first group (Study Five) and this study.

Analogy Map Analyses

The M. C. G. Analogy (Map B)

While a reasonable number of mappings (31 of a possible 57) were made for this analogy, the proportion of mappings that were rated as positive was again low (42%) as shown on Table 7-2. The lack of mapping in the analogy text appeared to cause difficulties for some. Student 106 wrote, "it is simple but not enough information has been supplied to understand or identify any more similarities." Analysis of the maps revealed that four students failed to attempt any mappings for this analogy, accounting for 12 of the 24 (57 - 31) mapping spaces that were not completed. Of these four students, Student 115 made no marks at all on the page and Student 118 only circled the "No" response in Question 4 to indicate that s/he did not recall the analogy. Student 102 responded with "No" on Question 4, but responded also that the comparison was not useful because, "I don't get chemistry or atoms," indicating some alienation from either the task or the subject matter. Further investigation revealed that this student had mapped only one attribute for the whole of the exercise – a positive mapping for the spectator ions analogy. For the verbal onion skin analogy, Student 102 had written that "diagrams and pictures [are] easier for me to understand – less words [the] better." For the reams of paper analogy, s/he wrote "I don't get it! I need it explained to me in simple [student's emphasis] terms." Although this student had been awarded a grade of C, it is possible that s/he relied principally on rote techniques rather than a sound conceptual understanding. Alternatively, evidence of chemical ability is not reliant on analogical reasoning such as was required for these tasks. An analysis of students' mapping ability compared to their chemistry achievement is reported in detail later in this chapter.

Of the other mappings, a considerable proportion was rated neutral (42%) and there were an acceptably low number of negative mappings (16%). Once again, students who correctly identified positive mappings centred their mappings around the structural attributes of the analog. Many mapped the nucleus to the centre of a large atom and many mapped sizes of the marble in the M. C. G. to the comparative proportion of nuclear to atomic sizes. One student wrote, "I thought that the nucleus of an atom was much larger," showing that, for this student at least, the analogy appeared to challenge his/her prior conceptions about the structure of the atom. Lower achieving chemistry students (those with grades of C or D) often mapped the smallness of the marble to the smallness of the atom, yet appeared to overlook the power of the analogy to map the ratio of comparative sizes of atomic and nuclear size. Several students mapped the circular or oval shape of the oval area to the spherical shape of an atom. While this concept is inconsistent with higher treatments of atomic structure, it is consistent with many students' instruction at this stage of their chemical education and, hence, was rated positively.

Once again, the many neutral mappings arose from the students' willingness to map the spectators' and players' structure and function to the electrons in the target concept. Just as this analog attribute transfers functional attributes to what is a structural analogy, many of the negative mappings had similar faults. The importance of the centre of the ground as the hub of game play was noted by several students although chemists, other than nuclear chemists, generally view electrons as being responsible for most of the (chemical) activity of the atom rather than the nucleus. Another functional attribute that was rated negatively was made by a student who argued that the analog "indicates energy requirement to split an atom." The chemical principles underpinning this argument were not evident to the researcher. Similarly, mappings of a football to the nucleus, while they may be consistent in their own right, contradict the analogy that refers expressly to a marble, and, hence, these mappings also were rated negatively.

The Reams of Paper Analogy (Map D)

As was the case in Study Five, students found fewer mappable attributes for the reams of paper analogy although those attributes that were mapped comprised a reasonable proportion (58%) of positive mappings (see Table 7-2). Analysis of the mapping attempts indicates a high proportion of empty mapping boxes for students awarded a C or D chemistry grade. Of the seven students awarded a C grade, two attempted no mappings, two others had one mapping, two students attempted two mappings and the other had three mappings. Of the three students graded with a D, two attempted no mappings and the other recorded three mappings, only one of which was rated positively. Hence, while the proportion of all students' mappings for this analogy was 45% (26 mapping attempts of 57 possible), the mapping proportion for C students was only 38% (8 of 21) and for D students 33% (3 of 9) indicating that the analogy was markedly more difficult to map for lower achieving chemistry students. Further, from the returns of all students, it was found that this analogy had the lowest – shared with the onion layers analogy – proportion of students who thought it helpful. Similarly, it had the lowest proportion of students who believed they had seen a similar representation in the past, shared with the M. C. G. analogy.

The students recorded a range of positive mappings, all of which shared only functional attributes. Common mappings related to the set number of units and the convenience of counting and use of the mole and the ream. The negative mappings, which also identified only functional attributes, tended to confuse "the mole" with the other amounts mentioned in the analogous passage; 1.4×10^{22} and "1 g of a mixture of iron and sulphur." One other negative mapping warrants discussion. Student 115 recorded that, "certain reams of paper contain different amounts of sheets" [as the analog] and "moles contain different amounts of atoms in certain elements" [the target]. It is possible that this student previously held the naive conception that one mole of X can have a different number of atoms than a mole of Y. Had the student been confident that any ream of any paper contains exactly 500 sheets, it is improbable that the mapping would have been attempted. Hence, it is likely that analog uncertainty hindered the challenge of the analog to the target. An alternative explanation, however, is that this student did generate the target description based upon his/her conception of the analog. If this was the case, then analog unfamiliarity has resulted in the transfer of an alternative conception from the analog to the student's conceptual framework of the target.

The Spectator Ions Analogy (Map F)

By a substantial margin, this analogy produced the greatest proportion of positive mappings (see Table 7-2) and it was characteristic in that it had a low proportion of neutral mappings and no student recorded a negative mapping. Further evidence of these students' confidence with the analogy was gained from the survey questions under the analogy maps. The students considered this to be one of the most helpful analogies and also the one they found most familiar. The helpfulness of the analogy may also have been an indication that the students found the analogy easy to map. The higher level of familiarity with the analogy may well have stemmed from the Level Two Alternative Representation in that the basis of this analogy shares the foundation of the analogical root of the term "spectator ion".

The students frequently mapped functional attributes for this analogy. For example, several students mapped the unchanging nature of the spectator ion, before and after a chemical reaction has taken place. Others recounted that as a spectator takes no part in the game, so too the spectator ion takes no part in the reaction. Both of these mappings required little more than extraction of the suitable target phrases from the analogous text provided and, with a suitable understanding of the concept, mappings could be drawn without a great deal of further interpretation on the part of the student. Another mapping that was frequently found in the second or third mapping position, had a structural-functional attribute. In this case, the students mapped the actual recording of the name of the ion to the recording of the names of the spectators. This mapping was the one provided by the textbook authors in the analogous text supplied.

Hence, with this analogy, the students appeared to have little trouble extracting suitable mappable attributes from the text. As the analogy contained only verbal information – most of which related to the target concept – little further interpretation was required. The analog of spectators at a football match was sufficiently familiar to the students and the term "spectator ions" had been encountered as part of their normal chemistry lessons. It is unclear, however, if the students' ability to correctly map this analogy was related more to (a) the style of analogy presentation, (b) the ease of the concept itself, or (c) the prior familiarity with the term "spectator ion" and its analogically grounded meaning.

The Onion Layers Analogy (Map G)

This analogy map had a high number of mappings attempted but it had the lowest proportion of positive mappings (40%) with much of the deficit being taken up by the high proportion of negative mappings (31%). While several students recognised the analogy, fewer than half of the students felt it helpful for their understanding of the concept of atomic structure.

The students were able to map positively a range of structural attributes. Of these attributes, many identified the progression of size of an onion layer as being analogous to the increasing numbers of electrons in each successive energy level in the Bohr atom. Another popular mapping related the near spherical shape of the onion to a spherical Bohr atom. With this Year 11 class, most students' conceptions of an atom were still a Bohr type – having not progressed to orbital notation. For B graded student 105, however, this may not have been the instance. S/he commented that, "I didn't know the electrons were in layers. [This has] successfully managed to confuse my idea of an atom." This student may have already progressed beyond the Bohr spherical atom and may have been cognisant of the issue that, while energy levels are often referred to, they do not represent physical, Newtonian orbits in which electrons can be found. Student 103 mapped positively the spherical nature of analog and target and, like several others, commented that the analogy was helpful and that it enabled him/her to "picture the shape of the atom, and . . . relate to the 'layers' or 'shells' made of electrons." However, s/he went on to comment that "this example isn't wonderful."

The source of negative mappings appeared to be confusion between onion *layers* and onion *skin*. Several students clearly regarded the onion as a large sphere surrounded by several layers of brown skin that are removed prior to cooking. This misconstruction of the analog, which should have conveyed a layered composition of almost the entire onion, may have arisen as students considered the analog in the light of their conception of atomic structure. In this conception – albeit a naive one – most of the bulk of the atom is taken up by the nucleus and the "shells" of electrons occupy only a thin, surrounding layer. Alternatively, the students' experiences preparing onions and removing the outer layer to get to the onion flesh may have reinforced this two-partedness to the analog that was not anticipated by the textbook authors. A cross-sectional diagram of the onion presented as a support to the verbal analog would have challenged this naive conception. Instead, these students have been able to maintain their prior conception that does not agree with the textbook paragraph's opening phrase that "an atom consists of a *small*, *dense* [italics added], positively charged nucleus, surrounded by negatively charged electrons."

A related negative mapping occurred when student 107 argued that the thickness of the onion layers was directly analogous to the number of electrons in a layer and, hence, the outer "shell" contained the least number of electrons. This conclusion is contrary to the intent of the analog. Several other students attempted to ascribe negative functional attributes to the analogy. One such example described the purpose of the electrons as providing a protection for the nucleus in the same way as the outer layers of an onion protect its flesh. Another example argued the aroma of an onion to be in some manner analogous to an atom's chemical activity.

A significant problem with the onion analog is that it has no attribute to which an atomic nucleus can be suitably mapped as the onion has no distinct centre – a limitation not evident with the solar system analog. Student 117 identified the limitation in his/her mapping by arguing that, while "in the middle [of the atom] there is a nucleus," "the centre of the onion has no shells. Just a circle (pip type of thing)." Similarly, Student 108 proposed that "the comparison between each [analog and target] isn't a very strong one." While some students reinterpreted their conception of an onion's centre to fit their conceptions of a central nucleus, this was done crudely at best. Perhaps their thoughts about the similarities contained in the analogy were best captured by Student 106 who wrote that s/he didn't find the analogy helpful because, "they do not compare correctly. The electrons have no real substitute with the onion layers – and the electron arrangement is too technical and complicated to be compared to an onion." Further support for this criticism came from Student 101 who argued that "using the layers of an onion is very generalised whereas the structure of electron fields around a nucleus follow strict rules and complex patterns and using an onion won't explain this so you won't learn very much."

Chemistry Performance and Analogy Mapping

The students' mapping performances were analysed with respect to their chemistry performance as measured by their semester grade: A, B, C, or D. While a failing grade of F was also possible, no student in the class had been awarded that grade. Of the 19 students, one was awarded an A grade, eight students had a B grade, seven had C grades, and the remaining three students had a D grade. Tables 7-3 and 7-4 indicate the mapping performances for each of the grade levels.

Table 7-3

Proportion of Positive, Negative, and Neutral Mappings Achieved for Each Grade of Chemistry Performance Based upon Total Number of Possible Mappings

Grade	No. of Students	Positive Maps (%)	Neutral Maps (%)	Negative Maps (%)	Totals Mapped (%)	Non Map (%)
A	1	6 (50%)	3 (25%)	0 (0%)	9 (75%)	3 (25%)
B	8	41 (42%)	12 (13%)	5 (5%)	58 (60%)	38 (40%)
C	7	16 (19%)	17 (20%)	10 (12%)	43 (51%)	41 (49%)
D	3	8 (22%)	5 (14%)	5 (14%)	18 (50%)	18 (50%)
Totals	19	71 (31%)	37 (16%)	20 (9%)	128 (56%)	100 (44%)

Table 7-3 includes information relating to the number (and proportion) of attempted maps for each of the grade levels. For C and D grade students, the percentage of unmapped (Non Map) spaces were similarly high underlying the difficulty that they had with the mapping exercise. The sole A student left only three spaces while the eight B students mapped 60% of their possible spaces. If these "non map" spaces are ignored, a more-useful picture of the mapping performances can be created. This is presented in Table 7-4 where the frequency of each mapping is based on the number of attempted mappings rather than of the total possible number of mappings.

Table 7-4

Proportion of Positive, Negative, and Neutral Mappings Achieved for Each Grade of Chemistry Performance Based upon Total Number of Attempted Mappings

Grade	n	Positive (%)	Neutral (%)	Negative (%)
A	1	6 (67%)	3 (33%)	0 (0%)
B	8	41 (70%)	12 (21%)	5 (9%)
C	7	16 (37%)	17 (40%)	10 (23%)
D	3	8 (44%)	5 (28%)	5 (28%)
Totals	19	71 (55%)	37 (29%)	20 (16%)

Students with grades of A and B have substantially greater proportions of positive mappings and substantially smaller proportions of negative mappings. The chi square test for multiple independent samples (Siegel, 1956, p. 175) indicates the significance of these variations ($\chi^2 = 15.2$, $p < 0.02$) in mapping ability. The trends in grade performance may best be viewed on a graph as portrayed in Figure 7-8. On the graph, the numbers of mappings can be followed for a particular grade. In the case of the A and B grade students, the graph reflects the lesser tendency to attempt negative or neutral mappings; a trend less observable in the case of C and D grade students.

A concerning feature of this tendency is that it is these grade C and D students who more frequently require additional visualisation to understand abstract chemical concepts; they are the chief target audience for the textbook analogies. These data, however, indicate that these students are less able to process this information and to draw suitable comparisons even after they have had prior exposure to the content knowledge. Further, the graph shows that D grade students have a tendency to attempt negative mappings which is more likely to result in the formation of chemical misconceptions.

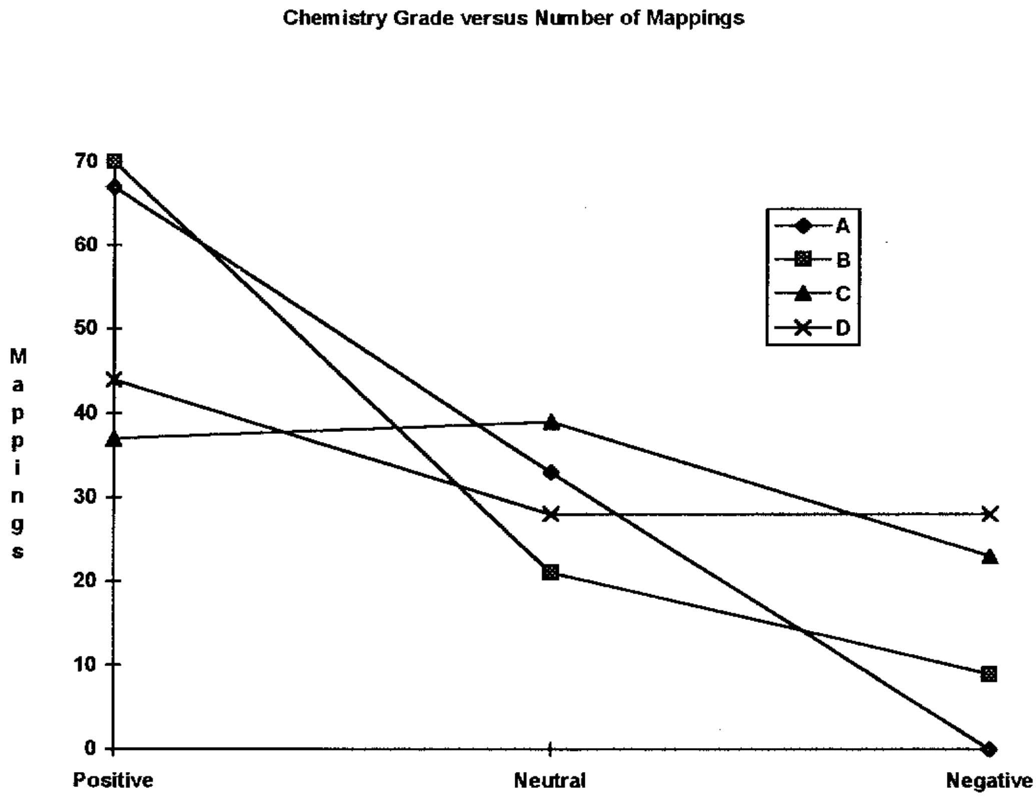


Figure 7-8. Trends in mapping performance based on chemistry grade.

Discussion

The low number of positive mappings for the M. C. G. analogy (42%, see Table 7-2), coupled with the continued attraction of students to map the function of players and spectators to electronic behaviour, reflects their willingness to construct their own understandings of the analog based upon the visual presentation rather than following the supplied mapping in the brief text. This finding indicates that caution is needed when using pictorial-verbal analogies in textbooks and in teaching. In Study Five, students indicated their preference for pictorial analogies due to the visualisation gained. Evidence was gathered to support the tentative assertion that the visualisation gained from the pictorial component was more powerful when constructing concepts than that obtained from verbal sources. In Study Two (see Chapter 4), one of the textbook authors commented that students often focus on parts of diagrams that were not considered by the textbook authors to be of significance.

The pictorial analogy of the bus going over the bridge (in Study Five) did not appear to suffer the same limitations as the M. C. G. analogy. This may have been due to its presentation as a stylised, hand-drawn diagram rather than a photograph of an actual entity. The advantage of the stylised, hand-drawn diagram is that only relevant attributes need to be included. This limits the opportunity for students to bring to bear their own conception of the analog as freely as was done in the case of the M. C. G. analogy.

As in Study Five, this study showed that some analogies, possibly due to a lack of analog explanation or structured enrichment, are unable to successfully challenge and decrease the status of students' alternative conceptions. In several instances, the reverse appeared to happen where the alternative conception was strong enough to permit students to view, and modify, the analog in the light of their chemical understandings. This raises interesting questions related to the construction of analogically supported knowledge that are dealt with in the following chapter.

Conclusions (Studies 5 and 6)

This study concludes a series of studies that have focussed on the use of analogies in textbooks, by teachers, and by students. In this chapter, the use of analogies by senior high school students has been investigated through the analogy maps designed by the researcher. The two studies (Five and Six) provide a useful blend of rich qualitative data from the interviews and the quantitative data from the maps and auxiliary questions. While the settings for the two studies differed, along with the method of selection of the student groups, enough similarity existed between the data collection methods that the research questions can adequately be addressed for both studies together. In this section of the chapter, the research questions are addressed in the light of the assembled data and assertions are presented in response to these research questions.

Research Question 5-1a: How is the Students' Ability to Map Affected by Presentational Format?

The first research question considered how the presentational format of an analogy influenced the students' ability on the mapping task. Analogies in the presentational format of pictorial-verbal were those that students believed they were most able to map. Despite the difficulties that both student groups encountered with the M. C. G. analogy for atomic structure, many students argued that they were able to have greater visualisation with pictorial-verbal analogies. It should be noted that, while the students *believed* they were more able to map these analogies, they were not necessarily able to map them better than verbal (only) analogies. Indeed, while pictorial-verbal analogies tended to be mapped more frequently, these mappings were generally less accurate (see Tables 7-1 and 7-2).

As mentioned above, the type of picture incorporated into a pictorial-verbal analogy may influence how students interact with the analog. If it is a photograph of a familiar entity, it may provide more opportunity for students to bring to bear their own conceptions of the analog rather than to carefully observe the diagram with reference to any supporting textual information. One student discussed the relationship between the size of the football in the middle of the M. C. G. rather than the marble described in the supporting text. How students process information in pictorial-verbal analogs that are familiar to them is an area that warrants further investigation.

> Assertion 5-1a: Students felt more able to map pictorial-verbal analogies although they were not necessarily able to map these analogies more accurately than verbal (only) analogies.

Research Question 5-1b: How is Students' Ability to Map Affected by Level of Enrichment?

While the presentational format did appear to influence the confidence with which students approached analogy mapping tasks, the level of enrichment did not appear to have the same influence. It was surprising to the researcher that students frequently ignored the mappings that were present in some of the analogies. Whether this was because students overlooked them, felt that they were too trivial to map, or did not understand the supporting text in which the enrichment was embedded is not clear. However, had the latter two alternatives been true, this should have been identified in the student interviews during Study Five. Evidently, it was rare for students to draw all of their mapping attempts from the supplied enrichment even for the more extended analogies. Further, the provision of enrichment did not appear to affect the proportion of mappings that were rated positively (see Table 7-2).

> Assertion 5-1b: Students' ability to map appeared not to depend upon the level of enrichment supplied with an analogy.

Research Question 5-2: Was there Evidence that Analogy Maps can Assist in the Identification of, and Challenge to, Students' Alternative Conceptions?

This question sought evidence that analogy maps could assist in the identification of, and challenge to, students' alternative conceptions. Related to this is the question of whether the maps could be used to ascertain a correct understanding by a student. The researcher identified several instances where students attempted to modify the analog to fit their conception of the target concept. In these instances, it became clearly evident that a wrong conception was held by the student. When the students have to compare their own conception of the chemistry content against the introduced analog, there is some clash of concepts if mapping is attempted. Regardless of the fit of an analogy, this clash eventuates as a result of the limitations of the analogy. These limitations may be evident at a cursory glance or may require in-depth analysis. The process of sorting through the attributes to find matches and limitations provides a vehicle through which the students can examine target concepts and even express them in a way other than in the original language of the teacher or textbook. As mentioned in Chapter 5, a Study Three teacher (Julie) encouraged her students to convert new chemical knowledge into an analogical "story" format and to describe that new "story" to her. This gave her an evaluative tool that she found fruitful to determine if the correct understandings had been gained. In Chapter 4, Lewis described how he found it useful to build up analogies with his students and then to see where they break down. Again, the learning that arises can be assessed by an examination of how students interact with this comparative process.

Without the aid of the interview data, the ability to ascertain the presence of alternative conceptions was not as straightforward. The maps are suitable to determine some of the more common alternative conceptions, however. For example, Student 115's persistence that "moles contain different amounts of atoms in certain elements" highlights the type of misconception that may be readily identified. Other alternative conceptions were also identified as students attempt the analogy maps. For the M. C. G. analogy, one student wrote, "I thought that the nucleus of an atom was much larger," indicating that they had held the conception that the nucleus was larger – possibly holding to the spherical "billiard-ball" model of the atom. While the presence of an alternative conception may have been identified, there was little information received to propose that the analogy had sufficiently challenged the status of the old conception. This appeared to be a problem in several instances. As noted earlier for the onion layer analogy, some students held tenaciously to alternative conceptions and, rather than having the status of that conception reduced by the introduction of the analog, mentally processed the analog in an alternative format so that it fitted their construct of the chemical target. Given, however, that the alternative conception was able to be identified by the active comparisons of the analogy map, other remedial work or teacher assistance may need to take place if the alternative conception is to be replaced by a more appropriate conception.

> Assertion 5-2: The analogy maps were useful as a means to identify alternative conceptions although there was evidence that the analogies contained therein did not sufficiently challenge the status of these alternative conceptions so as to result in their replacement with more scientifically valid conceptions.

Research Question 5-3: What Evidence Existed to Show that Analogies Contribute to the Formation of Alternative Conceptions?

This fourth question sought evidence that the analogies contributed to the formation of alternative conceptions. This is a problem that has been documented in some of the research reports discussed in Chapter 2. From this study, however, few instances of this were documented. In one of those instances, Student 105 commented that "I didn't know the electrons were in layers. [This has] successfully managed to confuse my idea of an atom." As mentioned in the Study Six Results section, it is unknown what conception this student had of electron arrangements prior to attempting the mapping process. While the student had obviously gone through some personal challenges of conceptual understandings, at the end of the process, the student was left unsure and confused which may serve as fertile ground for the formation of alternative conceptions.

Given that each analogy is not a perfect fit, and that the limitations may result in the formation of alternative conceptions, it was interesting to recall that Tina and Anthony were able to detect the limitations of the analogy and to have a sense of the extent to which they could be mapped and where that mapping process should cease. If more academically able students can display that ability, and the less-academic students are capable of extracting the essential mappings from the analogy – possibly with the assistance of some structured mapping in the text – then the analogy's outcomes are satisfactory.

> Assertion 5-3: There was little evidence that the analogy maps contributed to the formation of alternative conceptions in the learners. More capable chemistry students, who may be tempted to map beyond the obvious mappable attributes of an analogy, are often capable of recognising the analogy's limitations.

Research Question 5-4: Did Students who Performed Better at Chemistry Perform Better in the Analogy Mapping Tasks?

This question sought to investigate the relationship between chemistry performance and performance on the analogy mapping tasks. From the data assembled above, including the graphical analysis, it was concluded that a relationship existed between performance on the tasks and performance in chemistry as measured by examination and test results (indicated by a semester grade).

Students receiving grades of A and B attempted a higher proportion of the mapping spaces (75% and 59% respectively) than students with C and D grades (49% and 50% respectively). Further, of the mappings attempted, students with A and B grades had a substantially higher proportion of positive mappings (67% and 70%) and a substantially lower proportion of negative mappings (0% and 9% respectively) than their C and D graded peers (positive: 37% and 44%; negative: 23% and 25% respectively). The finding that lower achieving students obtained a substantially lower proportion of positive mappings is of concern to the researcher as authors include analogies for students who require extra visualisation and these students are more likely to be from the lower performing cohort.

> Assertion 5-4: Students who performed better at chemistry, as measured by normal assessment tasks, were able to map the analogies more fully and more accurately than their lower performing peers.

Limitations

There are several factors that limit the interpretation and generalisability of the findings of these two studies. The first of these relates to the number of analogy maps used in each student survey. While the researcher attempted to analyse a range of criteria including: simple, enriched, and extended; verbal and pictorial-verbal; with and without analog explanation; and with a variety of structural, functional, and structural-functional attributes, the provision of more analogy maps to each student would have unduly increased the students' time commitment. With the researcher's background in school science teaching, he was conscious that those who volunteered their time gave freely for little personal return, while the Study Six students had no choice but to accommodate the interruption to their learning sequence. In both cases, the researcher was grateful for this limited time access to these students. Therefore, the decision to limit the number of analogy maps was based on the researcher's desire to keep the mapping exercise to a single period, whole class activity (hence, the small numbers of students), and to maintain the good relationship that existed between the researcher and the contact teachers.

A second limitation relates to the apparent inequity in the interview programme. Interviews were conducted with students in study Five yet not in Study Six. In the fifth study, the research focussed on the process of mapping and the quality of maps drawn. Hence, triangulation by interview was seen as an important step to probe more carefully *how* students conduct the mapping activities (Yin, 1989). In the sixth study, the outcomes of mapping were under more careful scrutiny and these were best analysed by more quantitative methods.

Further research is required if analogy maps are to be used most effectively as a learning and research tool. As a starting point, research should determine if, for example, students better map the reams of paper analogy when provided with a picture of a ream compared to one without a picture. That is, the same analogies need to be destructured and presented, with and without specific analogy criteria, to large numbers of students if more useful comparisons within each analogy are to be determined. From research such as this, it will be possible to assert more confidently how students' understanding of an analogy is influenced by criteria such as those listed in the Analogy Classification Framework (see Chapter 3, Method section).

While female students comprised slightly less than half of the population surveyed in Study Six, only two of the eight Study Five students were females. It has not been a focus of these studies to consider the influence of gender upon mapping or analogy use although it may be that boys and girls perform differently at these tasks. Hence, care needs to be taken when considering the results of these studies – especially those of Study Five – as this factor has not been taken into account.

Summary

The empirical studies in this thesis have investigated analogy use in secondary chemistry education from three perspectives – textbooks and authors (Chapters 3 and 4), teachers (Chapter 5), and students (Chapters 6 and 7). The last chapter has reported several investigations into how students use analogies to improve their understanding of abstract chemical concepts. The research questions have been addressed by five assertion statements and several limitations of the studies have been addressed. Studies Five and Six are the last of the empirical studies reported in this thesis.

The following chapter draws together and discusses the assertions made in all of the previous studies before considering the contribution of the thesis to theory building. The implications of the research are then discussed and suggestions made for future research on analogies in chemistry education. The chapter concludes with a section that outlines how the findings of the research have begun to be disseminated.

CHAPTER 8

RESEARCH OVERVIEW, CONTRIBUTIONS TO THEORY BUILDING, IMPLICATIONS, FUTURE RESEARCH, AND RESEARCH CONTRIBUTIONS

Introduction

This chapter draws together the findings of Studies One through Six in a Research Overview where assertions made in the previous chapters are discussed in an integrated manner. The chapter then focuses on several of the thesis' findings by considering Contributions to Theory Building. In this section, the relationship between the analog and target concept is examined and discussion is made of the relationship between analogy structure and the nature of scientific 'reality'.

The Implications of the Research section outlines three areas in which further developments can now be made in teaching practice and research methods. These areas investigate the use of analogy maps as tools for research and teaching, the requirement of guides for teachers and authors who use analogies, and alternatives for suitable professional development programmes for chemistry teachers. The Future Research on Analogies in Chemistry Education section describes four main areas in which fruitful research questions have been identified. The areas include textbook analogies and analogy types, authors' use of analogies, teachers' use of analogies, and analogy maps and students' use of analogies.

The Contributions from this Research section of this chapter outlines the manner in which the findings of this research have begun to be disseminated. The section directs the reader to an appended list of dissemination activities relating to professional development workshops and in-service courses for teachers, conferences and seminars for science education researchers, and contributions in published materials for interested practitioners.

Research Overview

This thesis has described a series of six studies relating to authors', teachers' and students' use of analogies in senior high school chemistry. Each study has included its own Discussion and/or Conclusions section/s and, where appropriate, findings from earlier studies were used to inform later ones in terms of how the studies were conducted, how instruments were developed or utilised, and how data were analysed.

The research problems addressed in the thesis were as follows:

1. What was the nature and extent of the use of analogies in textbooks used by senior secondary chemistry students in Australia?
2. What were the views of textbook authors and editors concerning analogies and their use in textbooks for secondary chemistry students ?
3. How, when and why were analogies used by experienced chemistry teachers in normal classroom instruction for secondary students?
4. How might an instrument be developed to determine chemistry students' understanding of analogies that they encounter during instruction?
5. How did chemistry students use the analogies presented to them in textual information and what types of analogies did students of different abilities find easiest to understand?

Study One was designed to answer Research Problem 1, Study Two to answer Problem 2, Study Three to answer Problem 3, and Study Four to answer Problem 4. Research Problem 5 was addressed jointly in Studies Five and Six.

Study One reported the further development of the Analogy Classification Framework. Using that framework, 93 analogies from ten chemistry textbooks were analysed with respect to their structure and presentation. From the study, four assertions were drawn, summarising the findings of the four research questions directing the focus of the study (see Chapter 3).

It was found that analogies were used sparingly in the ten chemistry textbooks: five of the textbooks had fewer than six analogies while the other five textbooks had between 12 and 18 analogies. The analogies were more frequently employed in content areas characterised by non-observable processes and structures such as atomic structure, chemical bonding, and energy. It was found also, that analogies were more frequently positioned towards the beginning of textbooks; this could indicate the positioning of topics such as atomic structure, chemical bonding, and energy throughout the syllabi in accordance with common practice.

There was considerable use of pictorial-verbal and concrete/abstract analogies as authors attempted to enhance students' visual constructs concerning the target concept. It was found, however, that simple analogies comprised a substantial proportion of the total; authors decided frequently – possibly due to a variety of constraints – to allow students no assistance with the construction of comparisons between analog and target domains. Further, stated limitations or warnings by the authors were infrequently identified, a finding that highlights the need for improvements to be made in the dissemination of research findings for the benefit of chemistry textbook authors.

When confronted with a range of constraints – including the practicalities of textbook publication – it may be difficult for textbook authors to apply the findings of research into analogy use that promotes particular styles of analogical presentation. If this is the case, then the findings of research such as those from Study One will lack credence and applicability. For these reasons, it was appropriate that Study Two – the investigation of chemistry textbook authors' perspectives on analogies – followed the study of textbook analogies. The findings of Study Two were reported as six assertions, drawn to summarise the findings of the five research questions directing the focus of the study (see Chapter 4).

Study Two identified that the eight authors predominantly held one of two perspectives on what was the more important aspect of the teaching-learning process. Textbook authors who put more emphasis on the depth and correctness of the teachers' content knowledge used analogies less frequently in their textbooks. Authors who used analogies more frequently viewed relationships with students, communication, and motivation to be more important.

The eight authors viewed analogies as pedagogical tools that require flexibility in their use. For this reason, they viewed unfavourably the frequent inclusion of analogies in textbooks and the use of analogy teaching models that were overly prescriptive with respect to the order of presentation for analogy components. For the most part, this stemmed from their belief that students' requirements for, and ability to use, analogies varied greatly and that instructional devices should tolerate this variance.

Where due regard was given to flexibility in different teaching settings, however, the authors' indicated general acceptance for the concept of a model to guide textbook authors and teachers in the use of analogies. Further, several authors expressed appeal for the inclusion of analogies in teachers' guide materials or analogy resource books. This was seen as a way in which teachers' analogy repertoires might be improved. When these authors discussed their recollections of personal analogy use, however, most described interactions with other teachers, textbooks, and resources such as audio-visual materials and laboratory activities; these interactions apparently provided a fertile basis for the development of useful repertoires of chemistry analogies.

In an activity to determine preference for analogy placement, most authors favoured analogy placement as an embedded activator although some support was shown for both marginalised and advance organiser analogies. No author proposed that an analogy be placed as a post synthesiser. These findings reflected those of Study One with respect to the analog position when compared to the target concept in the text. Study One (see Table 3-5) showed post synthesiser to be the least used position for analogies (4.3%) after embedded activator (56%), marginalised (32%), and advance organiser (7.5%).

The importance of the classroom teacher in the investigation of analogy use in chemistry was paramount and, for this reason, Study Three contributes a major proportion of the volume of this work. Chapter 5 reported Study Three – the interpretive investigation of six chemistry teachers' use of analogies. From the study, 16 assertions were drawn, summarising the findings of the four emergent research questions guiding the study (see Chapter 5). The high number of assertions reflects the attempts of the researcher to match eight assertions (Assertions 3-3a through 3-3h) directly to components of the Analogy Classification Framework.

These experienced teachers rarely planned to use analogies; rather they tended to use them spontaneously when they believed their students had not understood an initial explanation. The sources of analogy repertoires included the teachers' personal experiences and professional reading.

When presenting analogies on a whole class basis, the teachers tended to adopt a less formal manner, frequently devaluing the content of the analog domain. Further, the teachers had different expectations of how students should treat the analog at the conclusion of the explanation. Several of the teachers guided the students away from any long-term attachment to the analog, seeing it as a means to an end only. Others saw a more lasting role for the analogy and hoped that the students would recall the analog when later revising the target concept for study purposes.

With regard to the structure of analogies used by these six teachers, concrete analog domains were used to describe abstract target domains where the two domains shared predominantly functional rather than structural attributes. The teachers varied the extent of mapping depending upon perceived needs of the students and they used both verbal and pictorial-verbal analogies in the lessons. In a similar manner to the textbook authors interviewed in Study Two, these teachers used analogies most frequently as embedded activators rather than as advance organisers or post synthesisers.

Analog explanation was frequently employed by the teachers although they rarely used pure strategy identification to explain the process of analogy use. Similarly, the inclusion of clear statements of analogical limitations were rare, although more frequent than in the Study One textbook analogies. As Study Three observed teachers during the presentation of selected topics, however, caution is needed when drawing generalisations from these findings.

The assertions provided in Chapter 5 should be seen as useful additions to the corpus of research into teachers' spontaneous use of pedagogical strategies such as analogies (Dagher & Cossman, 1992; Treagust, Duit, Joslin, & Lindauer, 1992) and the findings could guide the implementation of future programmes for preservice and in-service teacher education.

Having determined factors related to the use of analogies by teachers and in textbooks, Studies Four through Six began to address research problems related to how students use the analogies that are presented to them as part of their chemistry instruction. The studies described in those chapters outline the development (Chapter 6) and implementation and evaluation (Chapter 7) of an instrument – analogy maps – to determine the effectiveness with which students map analogies.

The assessment using the analogy maps found that students' ability to map analogies correctly appeared not to depend upon the level of enrichment supplied with an analogy. This finding appears somewhat illogical and could indicate that the students were more willing to follow their own mental constructs of the analog and target attributes than to restate those mapped attributes that may have been provided with the analogy text. Further, with respect to different analogy types, the students felt more able to map pictorial-verbal analogies although they were not necessarily able to map these analogies more accurately than verbal (only) analogies.

It was tentatively asserted that the analogy maps may be useful for identifying alternative conceptions although there was evidence that the analogies contained therein did not sufficiently challenge the status of these alternative conceptions for them to be replaced by more scientifically valid conceptions. Further, there was little evidence that the analogy maps contributed to the formation of alternative conceptions in the learners.

With regard to the relationship between chemistry performance and students' mapping ability, it was found that students who performed better at chemistry were able to map the analogies more fully and more accurately than their lower performing peers. More capable chemistry students, who may be tempted to map beyond the obvious mappable attributes of analogies, were often capable of recognising analogy limitations also.

Contributions to Theory Building

The Relationship Between Analog and Target Knowledge

In Chapter 2 (see Figure 2-1), several models describing the relationship between an analog and new target knowledge were discussed. These models were informed principally by literature identifying *incorrect* use of analogies by students – the evidence of which was incorporation of parts of the analogy in answers to test and examination questions (see, for example, Webb, 1985). However, the second and third Preliminary Issues discussed in Chapter 5 outlined several ancillary findings that caused the researcher to reconsider the status of a model in which there remains a separation between the analog and the newly constructed target knowledge.

The second Preliminary Issue considered those terms such as *buffer* and energy *barrier* that have analogical roots yet were not considered to be instructional analogies for the purposes of this research. Terms such as these have long been part of the established language of chemistry providing evidence that the language 'baggage' of many analogies remains with the science conception beyond the period of instruction and the period within which overt mapping might be conducted. While evidence of this can be found in time-honoured examples such as those indicated above, a more modern example is the description of the carbon allotrope Buckminsterfullerene (C_{60}) as *Buckyball* due to its soccer ball-like structure (Thiele, 1994). Indeed, its formal name is analogically derived from the name of Buckminster Fuller, an architect famous for the design of dome-shaped buildings in the United States!

The third Preliminary Issue discussed the notion that it is rare for a chosen analog to describe directly a chemistry target considered to be a chemistry 'reality'. More likely is the scenario in which the chosen analog can be used to describe a target that is further analogous to a described 'reality'. Figure 5-2 used the terms Level One and Level Two Alternative Representations respectively to account for these two sets of analogous relations. This provides further evidence that the analog and target are not clearly separated in the way suggested by Figure 2-1.

Newly informed by the findings of this research; discussions within the Analogy Research Group based at the Science and Mathematics Education Centre, Curtin University of Technology; and literature related to conceptual change (Hewson & Hewson, 1992), constructivist views on learning science with analogies (Duit, 1990), and the language of science (Sutton, 1992); a revised model of analogically-inclusive learning (see Figure 8-1) – that the researcher considers more useful – is proposed.

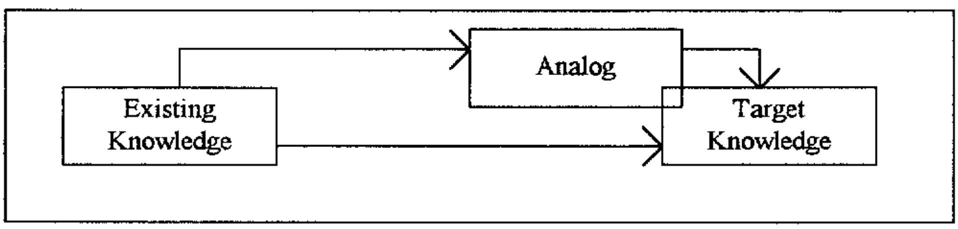


Figure 8-1. A revised model of the process of knowledge transfer with analogy.

In this revised model, the final target knowledge remains integrated with and supported by learners' conceptions of the analog employed. To some extent, each informs the other as learners' conceptions of the analog become altered by their relationship with the target. For example, Warren (a teacher observed in Study Three, see Chapter 5) discussed how he frequently used the analog of magnetism when he taught the concept of electrostatics. His rationale was that the students had already attained hands-on experience with magnets, a factor that Warren believed made an "important difference" (see Assertion 3-3c). In this analogy, there are many positive functional attributes mappable between the domains and as students developed their conceptions of electrostatics they also could have furthered their conceptions of magnetism beyond the "hands-on" level.

The revised model has several advantages over the earlier model with regard to its ability to inform our view of how analogy assists students to understand chemical concepts. In addition to its agreement with the Preliminary Issues described above, it is better suited to a constructivist perspective on learning (see Duit, 1990) where new knowledge is viewed as being constructed upon students' prior experiences. It is unlikely that this new knowledge is readily separable from the prior experience. Further, if the new target conception can be shown to be inter-related with and supported by a student's prior conception – in this instance an analogical prior conception – then that student should be more readily able to embrace the new conception. Adoption of the revised model would result in teachers encouraging students to recall analogs when revising target concepts, as to encourage students to "forget the analogy" would be illogical.

The Scientific 'Reality' of Target Concepts

As mentioned above, the research findings from Study Three (see Chapter 5) encouraged the researcher to reconsider the status of target chemical subject matter. In that study, issues arose suggesting that many of the chemistry targets we teach are alternative representations in their own right. It has been argued (see Figure 5-2) that there are two levels of alternative representations present frequently when teaching science using analogies. The first of these levels of alternative representation (Level One) covers the relationship between the traditional analog and the target. The Level Two Alternative Representation concept views the constructed target as a model in itself – capable of analogically representing or describing some sense of 'reality'.

Consideration of this as a view of the nature of science and appropriate science pedagogy can help inform the manner in which teachers approach their subject matter. Rather than viewing science as a fixed body of objective knowledge, it could be viewed as a process of more accurately describing a series of observed scientific phenomena. This perspective has the advantage that it more closely approximates the process by which students themselves learn science, with continual knowledge growth – or construction – as they attempt to make sense of their experiences.

As a practicing chemistry teacher, the researcher has found that he has become more tentative when approaching science as the 'truth', and is more likely to use phrases such as "which we describe as . . ." following the activities of this research. Whether the significance of the subtle turn of phrase is captured by many of the students, however, is not yet known.

Implications of the Research

There are implications of the findings of the studies that warrant discussion. These include:

1. The use of analogy maps as tools for both research and teaching. Such uses include charting the development of students' conceptual growth longitudinally and structuring the process through which analogies are used in the teaching-learning setting.
2. The use of guides for chemistry teachers and textbook authors. Such guides would inform practitioners of better practice with analogically-inclusive curricula, would enable teachers to extend their repertoire of appropriate analogies for use in their teaching, and would encourage textbook authors to use flexible models that encourage overt mapping between domains.
3. The implementation of professional development programmes for in-service teachers. These programmes aim both to assist teachers with the manner in which they introduce abstract chemistry concepts using analogies and to increase teachers' awareness of their own practices.

Analogy Maps as Tools for Research and Teaching

In this thesis, analogy maps have been used to rate students' ability to draw correspondences between analog and target domains. There are several other possible uses of the maps, however. One use in a research setting is to have students make analogy maps over a longitudinal study to identify and chart the development of their conceptions over time. Secondly, researchers interested in alternative conceptions held by science students could use analogy maps as a survey instrument. These uses are consistent with other determinants of students' conceptual growth and understandings such as those described in *Probing Understanding* (White & Gunstone, 1992).

Alternatively, analogy maps of a less formal structure could be used by teachers in whole class settings to elicit appropriate and inappropriate relations between analog and target attributes. For this purpose, the key word columns used in the interview phases of Study Six (Development Phase 3, see Figure 6-3) would be appropriate. With respect to using the maps in a teaching setting, however, it is important that the tool of instruction does not become the dominating factor of the classroom experiences. As with any educational research, there is a tendency for the researcher to view the outcome of his or her research as being paramount to the learning experience. Caution needs to be maintained so that analogy maps are used as teaching/learning instruments and do not provide hindrance to students' attempts to understand basic chemical concepts. Similarly, it is important that the analogy map does not introduce an unwelcome time-wasting obstacle for those students who master these more abstract concepts easily.

Use of Guides for Teachers and Authors

From discussions with textbook authors, it became evident that there was a need for analogies to be provided in teachers' guides to textbooks rather than including analogies more frequently in the textbooks themselves. Unfortunately, due principally to economic considerations related to small populations, teachers' guides do not often accompany Australian chemistry textbooks. For this reason, an alternative approach was considered; the publication of a book of analogies – each formatted in the style of a suitable approach such as the T-W-A Model (Glynn, 1991) or the FAR Guide (Treagust, 1993) – is to be made available for sale in Australia. From the study of chemistry teachers in England, it became evident that the analogies used and the content covered by these teachers was very similar to those of their Australian colleagues. There would be a reasonable demand for such a publication in much of the western, English-speaking science education community. The Analogy Research Group at Curtin University of Technology has commenced plans for such a publication that encompasses the major scientific disciplines of biology, chemistry and physics. Its publication would represent an important phase of the dissemination of the research activities of the Group and, more specifically, the research described in this thesis.

All of the eight authors interviewed for Study Two of this thesis were themselves chemistry teachers at either the secondary or tertiary level. Indeed, it is reasonable to expect that the majority of authors have had this relevant teaching experience. For these authors, access to a publication on teaching with analogies would be sufficient to provide appropriate guidelines for the use of analogies in textbooks. Indeed, such a publication would be a useful addition to the analogy repertoire available to a writing or editorial team.

Professional Development Programmes for Teachers

At an international level, there is a growing demand by teachers for access to professional development programmes related to teaching and learning with alternative representations. In England and Wales, this demand is a result of the National Curriculum that has been legislatively imposed through the *Education Reform Act 1988* (see National Curriculum Council, 1992). That curriculum includes a section on "Models and Modelling in Science". In response to the paucity of resources for teachers when considering this aspect of the curriculum, the Association for Science Education has published a handbook to assist teachers (Gilbert, 1994). While the researcher was living in the U. K., he noted the considerable interest in professional development related to analogies when he offered a session on that topic at the 1993 Annual Meeting of the Association for Science Education. Cursory inspection of the programme literature revealed that the bulk of offered sessions focused on subject matter knowledge rather than pedagogical knowledge.

In the Australian state of Victoria, curriculum changes in 1990 have resulted in the inclusion of "the use of a scientific model" to the senior chemistry syllabus for the new Victorian Certificate of Education (V. C. E.). The researcher is, as yet, unaware of any teacher professional development programmes or resource materials that have been provided specifically to facilitate implementation of this inclusion. Hence, there is an increased demand for programmes and literature which similarly inform Australian teachers.

While the provision of teacher professional development programmes are more costly than printed literature, the implementation of large scale in-service activities related to teaching with analogies is likely to be more effective in enabling teachers to introduce new abstract chemistry concepts with analogies and to increase teachers' awareness of their own practices. As outlined in more detail in the final section of this chapter, the researcher has been involved with the Analogy Research Group at Curtin University of Technology, where several models of teacher professional development already have been trialled. (In Appendix 4, see Thiele, 1993, 1994; Treagust, Thiele, Stocklmayer, Harrison, & Venville, 1993; Treagust, Venville, Harrison, Stocklmayer, & Thiele, 1993.) These activities have ranged in scale from intensive work with a small number of teachers through to sessions with up to 100 teachers in which video excerpts of teaching instances have been shown and debate initiated after discussion about the advantages and constraints of analogy use. The outcomes of the programmes with respect to either the teaching-learning process or the teachers' self awareness of their use of analogies has yet to be evaluated formally.

The manner in which the researcher's own teaching has altered as a result of conducting research into teachers' and students' use of analogies may reflect the outcomes of other teachers who experience professional development activities related to this teaching and learning instrument. One of the advantages of observing teachers in classrooms over many hours is that my own repertoire of analogies – and other teaching techniques – has been extended and refined. Subsequently, when I feel the need to respond to a classroom situation with analogy, the selection of a suitable analog has become easier. Teacher observation schedules – where the teacher undergoing the development programme observes a series of lessons from expert or peer teachers – could well be integrated into larger teacher development programmes.

Further, I have become much more aware of when I use analogies and I have become more cautious about their use in a whole-class setting. Frequently, I have noted myself making the decision *not* to use an analogy in the whole class setting and to search for an alternative explanation within the field of the target domain in response to "puzzled looks on students' faces" (see Assertion 3-1a). In the instances that I do use analogy on a whole class basis, procedural mapping now seems second nature. Students are often invited to draw comparisons between the selected analog and the target although I am yet to employ the approaches of either Chris – where students are invited to proffer analogies for the whole class – or Lucas – where the key factor is in destruction of the analogy to illustrate where it broke down (see Chapter 4, data for Assertion 2-2a).

I also have become more aware that some students prefer not to be exposed to analogically-inclusive explanations. This is the case especially with students for whom English is their second language (see Chapter 6, Development Phase 3). As Australia is a migrant country, this issue is important for science teachers to be aware of because these students represent a substantial proportion of some school populations. Any teacher professional development programme would need to take this into account.

Future Research on Analogies in Chemistry Education

Several aspects of this thesis warrant further investigation; questions have arisen that could be addressed by future research into the use of analogies in chemistry education. Following the progress of the studies in this thesis, these questions can be identified in the areas of textbook analogies and analogy types, authors' use of analogies, teachers' use of analogies, and analogy maps and students' use of analogies.

Textbook Analogies and Analogy Types

Study One identified a range of different analogy types used in Australian chemistry textbooks. Studies Five and Six used survey instruments with small sample sizes to answer the question "what types of analogies did students of different abilities find easiest to understand?" Further research of a more systematic manner is required to investigate what analogy structures students find easiest to use to construct appropriate chemical conceptions. Research in this field should employ quantitative analysis with large scale survey instruments – analogy maps or their kind – to determine how different analogy structures influence student learning. Suitable analogy maps may use a series of the same analogy with slight modifications. For example, structural variations could include analogies that were pictorial-verbal and verbal only; simple, enriched, and extended; with and without analog explanation, etc. Large student sample sizes with a broad range of analogies for a range of topics would allow suitable analysis to identify analogy factors important to students' ability to effect positive attribute mapping and possibly influence student learning.

The researcher is hesitant to suggest that research of this nature would show clearly what types of analogy structures improve learning outcomes. One of the difficulties of Studies Five and Six, and larger studies adopting similar approaches, is that the research is difficult to conduct at the time when students are being instructed about a specific target concept. This is because many classes of students would need to be surveyed at an exact time if the research is to be integrated into the intended learning programme. An alternative approach would be to conduct the research prior to the students encountering the chemical concepts used for the target domains. While this is not without difficulty, the alternative approach may be less problematic.

A second related area that may be fruitful for further research relates to gender variances in students' requirement for and use of analogies. The research on students' use of analogies in this thesis (Studies Five and Six) used samples that had low proportions of females. Due to this factor, and the small sample sizes, no attempt was made to analyse possible gender differences in the way analogies were mapped. It is possible that different types and structures of analogies (e.g., verbal compared to pictorial-verbal) may be preferred by one gender and these research outcomes may be a useful by-product of the large scale survey research suggested above. The findings of research into the differences in how male and female students use and require analogies would be useful for instructional designers. This is the case especially where efforts are being made to write chemistry textbooks and other curriculum materials that are more appealing to female students in an attempt to encourage them to adopt the study of chemistry at the senior high school level and beyond.

Authors' Use of Analogies

Where due regard was given for flexibility in different settings, the chemistry textbook authors interviewed in Study Two accepted the concept of a model to guide authors in the use of analogies in textbooks. This thesis has described (see Figure 2-2) the Teaching-with-Analogies model (Glynn, 1991), a model based upon instructional design characteristics of textbooks. Three other models, which focus primarily on teaching and yet may have some applicability in textbook settings, were also discussed. These were the General Model of Analogy Teaching (Zeitoun, 1984), the Focus-Action-Reflection (FAR) Guide for Teaching and Learning Science with Analogies (Treagust, 1993), and the Modeling Analogies (Dupin & Johsua, 1989) guidelines (see Figures 2-3, 2-4, and 2-5 respectively). However, no research has been published to date describing the process that authors might apply as they employ a model approach for including analogies in new textbooks. A suitable study would involve in-depth case analyses of a small number of authors writing chemistry textbooks. The authors should first have been made aware of these models and been given opportunity to consider carefully their efficacies. Research outcomes of such a study would determine what modifications are needed to these models if they are able to be used readily.

Teachers' Use of Analogies

The Implications section of this chapter has described suitable characteristics of professional development activities for teachers to improve their use of analogies. Research is needed, however, to investigate the outcomes of such programmes with respect to either the teaching-learning process or the teachers' self awareness of their analogy use. With these as research foci, researchers could use classroom observation techniques that investigate teachers' behaviour in a similar manner to Study Three. An appropriate observation schedule would involve analysis before, during, and after teachers' involvement in the professional development programme.

One of the difficulties with this research design is that in-serviced teachers would be aware that their use of analogies was being observed by the researcher. Their behaviour in this respect may therefore change due to the researcher's presence in the classroom. In Study Three of this thesis, the four Australian teachers were aware of the researcher's interest in analogies and the two English teachers were not. In Study Three, however, it was not apparent that the teachers' knowledge of the researcher's interests contributed a considerable limitation to the findings.

Another implication discussed above related to the use of analogy maps as a tool for teaching. As yet, the maps have not been used in the uncertain context of the classroom but only in a controlled environment under the research conditions described in Studies Five and Six. How teachers might use the maps in their normal classroom routines is a matter that warrants further investigation. The development of a suitable tuition programme for the implementation of analogy maps by teachers would be a suitable precursor to such an investigation.

As mentioned above, changes to curricula in England, Wales and Victoria, Australia, have resulted in the inclusion of the requirement to teach a process of scientific models and modelling. Commentators have identified analogies as playing a role within these new topics (see, for example, Gilbert, 1993). The trend to include aspects of the curriculum such as these may continue. Hence, there is a need for longitudinal studies to investigate the manner in which teachers in the U. K. and Victoria implement the curriculum initiatives with regard to teachers' use of analogies.

Analogy Maps and Students' Use of Analogies

Several possible areas for further research related to analogy maps and students' use of analogies have already been addressed in the section Textbook Analogies and Analogy Types. In addition, the researcher acknowledges the need for empirical research that examines further the manner in which analogy-inclusive instruction challenges naive chemical conceptions and enables students to construct scientifically valid conceptions upon the framework of the analog employed. From this perspective, recent research (Treagust, Harrison, & Venville, 1993) encouraging teachers to use analogical teaching approaches to aid changes in students' conceptions, provides a useful start. Given the importance of analogy in how we learn science and describe its processes, further research of this nature should command a high priority.

This chapter has examined the relationship between an analog and the target knowledge constructed with the aid of that analog (see Figure 8-2). The researcher has contended that the two domains remain inseparable and this is an area that warrants further investigation. One way the research may be approached is to examine spontaneous analogy use when students are asked to describe abstract chemistry concepts to a peer or younger student. Appropriate methods for such a study would involve observation sessions and post-observation interviews. An alternative method may use interviews only to probe students' conceptions. These studies would address questions related to how students' content knowledge remained linked to analogies that they may have experienced, knowingly or otherwise, as part of their chemistry instruction.

Contributions from this Research

Over the past four years, the researcher has had frequent opportunity to present the findings of these studies to members both of the science education research community and the science teaching community nationally and internationally. Generally, much interest has been derived from these sessions as practitioners from Australia, the United Kingdom and the United States have sought a better understanding of how to improve analogy-inclusive instruction. As mentioned above, teachers in England seemed especially interested in professional development that improved their ability to communicate abstract concepts more than to improve their subject matter knowledge.

The appended list (see Appendix 4) documents activities and publications designed to (a) heighten researchers' and teachers' awareness of how analogies may be better used; (b) encourage practitioners to view analogy as a structured – rather than cursory – teaching method; and (c) contribute to the body of available research through contributions in science education journals and books. The appended list shows 45 dissemination attempts to date including chapters in books (2); journal articles and conference proceedings (11); conference presentations (17); seminars (5), workshops (6), and in-service courses (2) for teachers and teacher educators; and radio interviews (2).

REFERENCES

Ainley, D., Lazonby, J. N., & Masson, A. J. (1981). *Chemistry in today's world.* London: Bell & Hyman.

Alexander, P. A., Schallert, D. L., & Hare, V. C. (1991). Coming to terms: How researchers in learning and literacy talk about knowledge. *Review of Educational Research, 61*, 315-343.

Alexander, P. A., White, C. S., Haensly, P. A., & Crimmins-Jeans, M. (1987). Training in analogical reasoning. *American Educational Research Journal, 24*, 387-404.

Andersson, B. (1986). Pupils' explanations of some chemical reactions. *Science Education, 70*, 549-563.

Arber, A. (1964). The biologist's use of analogy. In A. Arber (Ed.), *The mind and the eye: A study of the biologist's standpoint.* Cambridge: Cambridge University Press.

Arnold, M., & Millar, R. (in press). Childrens' and lay adults' views about thermal equilibrium. *International Journal of Science Education.*

Bailey, P. S., & Bailey, C. A. (1989). *Organic chemistry: A brief survey of concepts and applications* (4th ed.). Boston: Allyn and Bacon.

Bean, T. W., Searles, D., Singer, H., & Cowan, S. (1990). Learning concepts from biology text through pictorial analogies and an analogical study guide. *Journal of Educational Research, 83*, 233-237.

Brown, D. E. (1992). Using examples and analogies to remediate misconceptions in physics: Factors influencing conceptual change. *Journal of Research in Science Teaching, 29*, 17-34.

Brown, D. E. (1993). Refocussing core intuitions: A concretizing role for analogy in conceptual change. *Journal of Research in Science Teaching, 30*, 1273-1290.

Brown, D. E. (1994). Facilitating conceptual change using analogies and explanatory models. *International Journal of Science Education, 16*, 201-214.

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science, 18*, 237-261.

Bullock, B. (1979). The use of models to teach elementary physics. *Physics Education, 14*, 312-317.

Campbell, N. R. (1957). *Foundations of science: The philosophy of theory and experiment.* New York: Dover.

Carter, K., & Richardson, V. (1989). A curriculum for an initial-year-of-teaching program. *The Elementary School Journal, 89*, 405-419.

Chandran, S. (1988). *Biological change*. Perth, Australia: Bookland.

Clement, J. (1987). Overcoming misconceptions in physics: The role of anchoring intuition and analogical validity. In J. Novak (Ed.), *Proceedings of the 2nd International Seminar on Misconceptions and Educational Strategies in Science and Mathematics* (Vol. 3, pp. 84-97). Ithaca: Cornell University.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching, 30*, 1241-1258.

Curtis, R. V. (1988). When is a science analogy like a social studies analogy? A comparison of text analogies across two disciplines. *Instructional Science, 17*, 169-177.

Curtis, R. V., & Reigeluth, C. M. (1983). *The effects of analogies on student motivation and performance in an eighth grade science context.* (I. D. D. & E. Working Paper No. 9, March 1983. (ERIC Document Reproduction Services ED 288 519)).

Curtis, R. V., & Reigeluth, C. M. (1984). The use of analogies in written text. *Instructional Science, 13*, 99-117.

Dagher, Z., & Cossman, G. (1992). Verbal explanations given by science teachers: their nature and implications. *Journal of Research in Science Teaching, 29*, 361-374.

Dagher, Z. R., Thiele, R. B., Treagust, D. F., & Duit, R. (1993). Comment on "Analogy, Explanation, and Education". *Journal of Research in Science Teaching, 30*, 615-617.

De Jong, O., & Acampo, J. (1992, September). *Translating textbook content into classroom practice: chemistry teachers' actions and reflections*. Paper presented at the 17th annual conference of the Association for Teacher Education in Europe, Lahti, Finland.

De Lorenzo, R. (1980). Introducing: Applications and analogies. *Journal of Chemical Education, 57*, 601.

Department of Education. (1982). *Change and Interaction*. Perth: Curriculum Programmes Branch, Department of Education.

Dreistadt, R. (1969). The use of analogies and incubation in obtaining insights into creative problem solving. *The Journal of Psychology, 71*, 159-175.

Duit, R. (1990, May). *Analogies and learning science: Remarks from a constructivist perspective*. Paper presented to the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education, 75*, 649-672.

Dupin, J., & Johsua, S. (1989). Analogies and "modeling analogies" in teaching: Some examples in basic electricity. *Science Education, 73*, 207-224.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed., pp. 119-161). New York: Macmillan.

Finley, F. N., Stewart, J., & Yarroch, W. L. (1982). Teachers' perceptions of important and difficult science content. *Science Education, 66*, 531-538.

Flick, L. (1991). Where concepts meet precepts: Stimulating analogical thought in children. *Science Education, 75*, 215-230.

Friedel, A. W., Gabel, D. L., & Samuel, J. (1990). Using analogs for chemistry problem solving: Does it increase understanding? *School Science and Mathematics, 90*, 674-682.

Gabel, D. L., & Samuel, K. V. (1986). High school students' ability to solve molarity problems and their analog counterparts. *Journal of Research in Science Teaching, 23*, 165-176.

Gabel, D. L., & Sherwood, R. D. (1980). Effect of using analogies on chemistry achievement according to Piagetian level. *Science Education, 64*, 709-716.

Gabel, D. L., & Sherwood, R. D. (1983). Facilitating problem solving in high school chemistry. *Journal of Research in Science Teaching, 20*, 163-177.

Gabel, D. L., & Sherwood, R. D. (1984). Analyzing difficulties with mole-concept tasks by using familiar analog tasks. *Journal of Research in Science Teaching, 21*, 843-851.

Gabel, D., Sherwood, R. D., & Enochs, L. (1984). Problem-solving skills of high school chemistry students. *Journal of Research in Science Teaching, 21*, 221-233.

Garnett, P. J., & Tobin, K. (1989). Teaching for understanding: Exemplary practice in high school chemistry teaching. *Journal of Research in Science Teaching, 26*, 1-14.

Gentner, D. (1980). *The structure of analogical models in science*. Cambridge, MA: Bolt, Beranek & Newman.

Gentner, D. (1983). Structure mapping: A theoretical framework for analogy. *Cognitive Science, 7*, 155-170.

Gentner, D. (1988). Analogical inference and analogical access. In A. Prieditis (Ed.), *Analogica* (pp. 63-88). Los Altos, CA: Morgan Kaufmann.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem-solving. *Cognitive Psychology, 12*, 306-355.

Gick, M. L., & Holyoak, K. L. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15*, 1-38.

Gilbert, J. K. (1993, April). *Models and modelling in science education*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Gilbert, J. K. (1994). *Models and modelling in science education*. London: Association for Science Education.

Gilbert, J. K., & Osborne, R. J. (1980). The use of models in science and science teaching. *European Journal of Science Education, 2*, 3-13.

Gilbert, S. W. (1989). An evaluation of the use of analogy, simile, and metaphor in science texts. *Journal of Research in Science Teaching, 26*, 315-327.

Glynn, S. M. (1989). The teaching with analogies (T-W-A.) model: Explaining concepts in expository text. In K. D. Muth (Ed.), *Children's comprehension of narrative and expository text: Research into practice* (pp. 185-204). Newark, DE: International Reading Association.

Glynn, S. M. (1991). Explaining science concepts: A Teaching-with-Analogies model. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The psychology of learning science* (pp. 219- 240). Hillsdale, NJ: Erlbaum.

Glynn, S. M. (1992). *Teaching science with models: Going beyond the book.* [Video cassette recording]. Athens, GA: University of Georgia.

Glynn, S. M., Britton, B. K., Semrud-Clikeman, M., & Muth, K. D. (1989). Analogical reasoning and problem solving in textbooks. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity: Assessment, theory and research* (pp. 383-398). New York: Plenum.

Glynn, S., & Duit, R. (1993, April). *Conceptual bridges for understanding science: A teaching-with-analogies model.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Goetz, J. P., & LeCompte, M. D. (1984). *Ethnography and qualitative design in educational research.* Orlando, FL: Academic Press.

Gould, S. J. (1983). *The panda's thumb – more reflections in natural history.* London: Pelican.

Hackling, M. W., & Garnett, P. J. (1985). Misconceptions of chemical equilibrium. *European Journal of Science Education, 7*, 205-214.

Harrison, A. G., & Treagust, D. F. (1993). Teaching with analogies: A case study with Grade-10 optics. *Journal of Research in Science Teaching, 30*, 1291-1308.

Harrison, A. G., & Treagust, D. F. (1994). Science analogies: Avoid misconceptions with this systematic approach. *The Science Teacher, 61*(4), 41-43.

Hesse, M. B. (1967). Models and analogies in science. In P. Edwards (Ed.), *The encyclopedia of philosophy* (pp. 354-359). New York: Free Press.

Hewitt, P. G. (1987). *Conceptual physics.* Menlo Park, CA: Addison-Wesley.

Hewson, P. W., & Hewson, M. G. A'B. (1992). The status of students' conceptions. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 59-73). Kiel, Germany: Institute for Science Education.

Holyoak, K. J. (1985). The pragmatics of analogy transfer. *The Psychology of Learning and Motivation, 19*, 59-87.

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory & Cognition, 15*, 332-340.

Imperial Chemical Industries Ltd. (1963). *Catalysis* [Video cassette recording]. London: Imperial Chemical Industries.

Johnstone, A. H., & Al-Naeme, F. F. (1991). Room for scientific thought. *International Journal of Science Education, 13*, 187-192.

Keane, M. (1987). Cognitive theory of analogy. In J. Richardson, M. Eysenk, & D. Piper (Eds.), *Student learning* (pp. 66-72). Milton Keynes: SHRE and Open University Press.

Klauer, K. F. (1989). Teaching for analogical transfer as a means of improving problem solving. *Instructional Science, 18*, 179-192.

Leatherdale, W. H. (1974). *The role of analogy, model and metaphor in science.* Amsterdam: North Holland.

Licata, K. P. (1988). Chemistry is like a . . . *The Science Teacher, 55*(8), 41-43.

Marshall, J. K. (1984). Classroom potpourri. *Journal of Chemical Education, 61*, 425-427.

Mathison, S. (1988). Why triangulate? *Educational Researcher, 17*(2), 13-17.

McCorcle, M. D. (1984). Stories in context: Characteristics of useful case studies in planning and evaluation. *Evaluation and Program Planning, 7*, 205-208.

Merriam, S. B. (1988). *Case study research in education.* San Francisco: Jossey-Bass.

Merrill, R. J., & Ridgway, D. W. (1969). *The CHEM Study Story.* San Fansisco: W. H. Freeman and Company.

Miller, G. A. (1979). Images and models, similes and metaphors. In A. Ortony (Ed.), *Metaphor and thought* (pp. 202-250). Cambridge: Cambridge University Press.

National Curriculum Council. (1992). *Starting out with the National Curriculum.* York, England: Author.

Nickerson, R. S. (1985). Understanding understanding. *American Journal of Education, 93,* 201-239.

Ramsden, J. (1992). Going in both ears and staying there: The Salter's approach to science. *The Australian Science Teachers Journal, 38*(2), 13-18.

Reigeluth, C. M. (1983). Meaningfulness and instruction: Relating what is being learned to what a student knows. *Instructional Science, 12,* 197-218.

Shapiro, M. A. (1985, May). *Analogies, visualisation and mental processing of science stories.* Paper presented to the Information Systems Division of the International Communication Association, Honolulu, HI.

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shymansky, J. A., Treagust, D. F., Thiele, R. B., Harrison, A. G., Waldrip, B. G., Stocklmayer, S. M., & Venville, G. J. (1993, April). *A study of changes in student understanding of force, motion, work, and energy.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Siegel, S. (1956). *Nonparametric statistics for the behavioral sciences.* New York: McGraw-Hill Book Company.

Simons, P. R. J. (1984). Instructing with analogies. *Journal of Educational Psychology, 76,* 513-527.

Sutton, C. (1992). *Words, science, and learning.* Buckingham, England: Open University Press.

Tenney, Y. J., & Gentner, D. (1985). What makes analogies accessible? Experiments on the water-flow analogy for electricity. In R. Duit, W. Jung, & C. v. Rhoneck (Eds.), *Aspects of understanding electricity: Proceedings of an international workshop* (pp. 311-318). Kiel, Germany: Institute for Science Education.

Thagard, P. (1992). Analogy, explanation, and education. *Journal of Research in Science Teaching, 29,* 537-544.

Thiele, R. B. (1990). *A review of literature and text materials to examine the extent and nature of the use of analogies in high school chemistry education.* Unpublished manuscript, Curtin University of Technology, Science and Mathematics Education Centre, Perth, Australia.

Thiele, R. B. (1992, July). *Teaching science with analogy.* Workshop presented at the 41st Annual Conference of the Australian Science Teachers Association, Perth.

Thiele, R. B. (1994). Teaching by analogy. *Education in Chemistry, 31*, 17-18.

Thiele, R. B., & Treagust, D. F. (1991a). Using analogies in science education. *SCIOS, 26*(2), 17-21.

Thiele, R. B., & Treagust, D. F. (1991b). Using analogies in secondary chemistry teaching. *Australian Science Teachers Journal, 37*(2), 10-14.

Thiele, R. B., & Treagust, D. F. (1992). Analogies in senior high school chemistry textbooks: A critical analysis. In H-J. Schmidt (Ed.), *Proceedings of the International Symposium on Empirical Research in Chemistry and Physics Education* (pp. 175-192). Hong Kong: ICASE.

Tierney, D. S. (1988, April). *How teachers explain things: metaphoric representation of social studies concepts.* Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Tobin, K., Deacon, J., & Fraser, B. J. (1989). An investigation of exemplary physics teaching. *The Physics Teacher, 27*, 144-150.

Treagust, D. F. (1991). A case study of two exemplary biology teachers. *Journal of Research in Science Teaching, 28*, 329-342.

Treagust, D. F. (1993). The evolution of an approach for using analogies in teaching and learning science. *Research in Science Education, 23*, 293-301.

Treagust, D. F., Duit, R., Joslin, P., & Lindauer, I. (1992). Science teachers' use of analogies: observations from classroom practice. *International Journal of Science Education, 14*, 413-422.

Treagust, D. F., Duit, R., Lindauer, I., & Joslin, P. (1989). Teachers' use of analogies in their regular teaching routines. *Research in Science Education, 19*, 291-299.

Treagust, D. F., Venville, G., Harrison, A., Stocklmayer, S., & Thiele, R. B. (1993, July). *The FAR Guide for Teaching and Learning Science with Analogies*. Perth: Curtin University of Technology.

Webb, M. J. (1985). Analogies and their limitations. *School Science and Mathematics, 85*, 645-650.

White, R. T., & Gunstone, R. (1992). *Probing understanding*. London: The Falmer Press.

Wong, E. D. (1993a). Self-generated analogies as a tool for constructing and evaluating explanations of scientific phenomena. *Journal of Research in Science Teaching, 30*, 367-380.

Wong, E. D. (1993b). Understanding the generative capacity of analogies as a tool for explanation. *Journal of Research in Science Teaching, 30*, 1259-1272.

Yin, R. K. (1989). *Case study research: design and methods* (2nd ed.). Beverly Hills, CA: Sage.

Zeitoun, H. H. (1984). Teaching scientific analogies: a proposed model. *Research in Science and Technological Education, 2*(2), 107-125.

Zietsman, A., & Clement, J. (1990, April). *Using anchoring conceptions and analogies to teach about levers*. Paper presented at the annual meeting of the American Educational Research Association, Boston, MA.

APPENDICES

APPENDIX 1

TEXTBOOKS ANALYSED IN STUDY ONE

Ainley, D., Lazonby, J. N., & Masson, A. J. (1981). *Chemistry in today's world.* London: Bell & Hyman Limited.

Boden, A. (1986). *Chemtext.* Marrickville, Australia: Science Press.

Bucat, R. J. (Ed.). (1983). *Elements of chemistry* (Vol. 1). Canberra: Australian Academy of Science.

Bucat, R. J. (Ed.). (1984). *Elements of chemistry* (Vol. 2). Canberra, ACT: Australian Academy of Science.

Elvins, C., Jones, D., Lukins, N., Ross, R., & Sanders, R. (1990). *Chemistry in context: Part one.* Melbourne: Heinemann Educational Australia.

Garnett, P. J. (Ed.). (1985). *Foundations of chemistry.* Melbourne: Longman Cheshire.

Hunter, R. J., Simpson, P. G., & Stranks, D. R. (1981). *Chemical science.* Marrickville, Australia: Science Press.

James, M., Derbogosian, M., Bowen, S., & Auteri, S. (1991). *Chemical connections.* Melbourne: The Jacaranda Press.

Lewis, P., & Slade, R. (1981). *A guide to H. S. C. chemistry.* Melbourne: Longman Cheshire.

McTigue, P. T. (Ed.). (1979). *Chemistry–key to the earth.* Melbourne: Melbourne University Press.

APPENDIX 2

ENTIRE ANALOGY MAP SET USED IN STUDY FIVE

CHEMISTRY SURVEY

Code: ___________

This survey contains 5 questions - the first one is done for you. Carefully read through this page and refer to it if you are unsure. Also, you may ask questions of the teacher if you feel that this is necessary.

Each question contains an **Insert** which is a picture and/or paragraph from a chemistry textbook used by students of your age in other parts of the country. Each insert is a little unusual in that it attempts to describe something about **Chemistry** in terms of a **Common World** experience.

For *each* of the questions, B to E: (Question A has been done for you)

i) **Study the insert** carefully thinking about the chemistry that you have learned;
ii) Identify the parts of the insert that relate to the **chemistry** and the parts that relate to the **common** world experience;
iii) Fill in the table below the insert by writing down **3 characteristics** of **the common world** part under the heading "COMMON WORLD". **For each** of these, write down the characteristic of the **chemistry** that **matches** the **common world** part (put this in the "CHEMISTRY" column);
iv) Complete the short questions at the bottom of the table by referring directly to that insert.

Now look carefully at Question A which **has been done for you** and see how it has been filled in. Then attempt questions B to E. Allow about 7 minutes per question.

NOTE: There are no right or wrong answers. Please try to fill in as many spaces as possible.

INSERT A

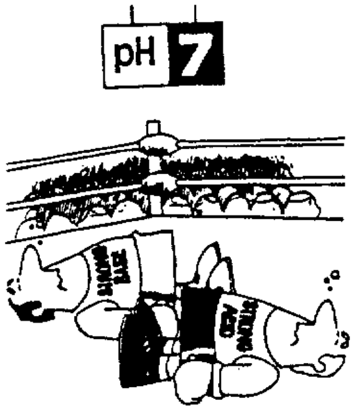


TABLE __

COMMON WORLD Boxers	CHEMISTRY Acids and bases	Office Use
1. Two different people (boxers) interact.	Two chemical species (acids and bases) interact	
2. Both experience a loss of potency	Acids and bases neutralise each other	
3. If the boxers are of equal strength, they may both end up exhausted	If the acid and base are of equal (strong) strength, the end solution is neutral (pH=7)	

Complete the following sentences:

4. Do you recall ever seeing *strong acids and bases* being compared to *a pair of boxers* before? Yes/No*

5. I find that comparing *strong acids and bases* to a *pair of boxers* is/isn't* helpful for me in chemistry because:
   Enter as you wish

*Cross out the part that does not apply

6. Office Use only

INSERT B

FIGURE 2.3 If this football field represents an atom, the nucleus would occupy a region the size of a marble in the centre.

TABLE __

COMMON WORLD Football Oval	CHEMISTRY Atomic Structure	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing *atomic structure* being compared to a *cricket oval* before? **Yes/No***

5. I find that comparing *atomic structure* to a *cricket oval* is/isn't* helpful for me in chemistry because:

....

....

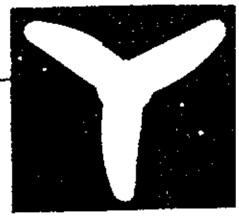
*Cross out the part that does not apply

6. Office Use only

INSERT C

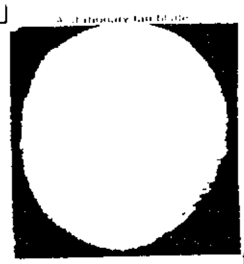
You may ask now the electron can be a cloud of negative charge filling all the volume occupied by the hydrogen atom. Electrons have properties quite different from matter that we can see or touch. These unusual properties are common to tiny particles which move at very high velocities.

We will describe one situation which may be useful to help you understand the space-filling capacity of electrons in atoms. Compare the two photographs



A stationary fan blade

During rapid rotation of the fan, the structure of the blade seems to be lost and it appears to fill a large volume of space around the shaft. At any instant we cannot say where the blade is. Some evidence of the blade can be seen at every point in the volume of space through which it moves. Similarly, some influence of the electron exists at every point in the spherical volume of the hydrogen atom, but we cannot say exactly where the electron is.



A rotating fan blade

TABLE __

COMMON WORLD Fan Blades	CHEMISTRY Electrons	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing *electrons* being compared to *fan blades* before? Yes/No*

5. I find that comparing *electrons* to *fan blades* is/isn't* helpful for me in chemistry because :

   ....

   ....

*Cross out the part that does not apply

6. Office Use only

INSERT D

Chemists think of chemical reactions between elements in terms of atoms of the elements combining in some simple whole number ratio. Thus chemists, although interested in the masses of substances reacting together, are more interested in the numbers of atoms involved in reactions. The fact that atoms are so very small does create problems. For example, if 1 g of a mixture of iron and sulphur is heated in a test-tube, a reaction occurs which involves about 14 000 000 000 000 000 000 000 atoms ($1 \cdot 4 \times 10^{22}$). To avoid having to use such large numbers in calculations, chemists have created an easier unit amount of substance called the **mole**. We shall see below that this is the amount of substance which contains a particular number of atoms. This is a similar idea to file paper being ordered by a school in reams (each containing 500 sheets) rather than in individual sheets.

The number of atoms chosen for a mole of a substance is the number of atoms in one relative atomic mass (expressed in grams) of hydrogen. (Strictly speaking using the modern standard this should be 12 g of carbon-12.)

TABLE __

COMMON WORLD Reams of paper	CHEMISTRY A mole	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing a *mole* being compared to a *ream of paper* before? **Yes/No***

5. I find that comparing a *mole* to a *ream of paper* **is/isn't*** helpful for me in chemistry because:

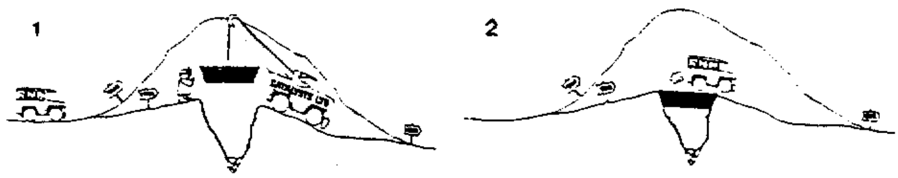
....

....

*Cross out the part that does not apply

6. Office Use only

INSERT E



A catalyst for a reaction provides a reaction path with a lower energy barrier.

TABLE __

COMMON WORLD Bus over a bridge	CHEMISTRY Catalysis/ reaction rate	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing the *effect of a catalyst on reaction rate* being compared to a *bus going over a bridge* before? Yes/No*

5. I find that comparing the *effect of a catalyst on reaction rate* to a *bus going over a bridge* is/isn't* helpful for me in chemistry because:

....

....

*Cross out the part that does not apply

6. Office Use only

APPENDIX 3

ENTIRE ANALOGY MAP SET USED IN STUDY SIX

CHEMISTRY SURVEY

Code: ____________

This survey contains 5 questions - the first one is done for you. Carefully read through this page and refer to it if you are unsure. Also, you may ask questions of the teacher if you feel that this is necessary.

Each question contains an **Insert** which is a picture and/or paragraph from a chemistry textbook used by students of your age in other parts of the country. Each insert is a little unusual in that it attempts to describe something about **Chemistry** in terms of a **Common World** experience.

For *each* of the questions, B to E: (Question A has been done for you)

i) **Study the insert** carefully thinking about the chemistry that you have learned;
ii) Identify the parts of the insert that relate to the **chemistry** and the parts that relate to the **common world** experience;
iii) Fill in the table below the insert by writing down **3 characteristics** of the **common world** part under the heading "COMMON WORLD". **For each** of these, write down the characteristic of the **chemistry** that **matches** the **common world** part (put this in the "CHEMISTRY" column);
iv) Complete the short questions at the bottom of the table by referring directly to **that** insert.

Now look carefully at Question A which **has been done for** you and see how it has been filled in. Then attempt questions B to E. Allow about 7 minutes per question.

NOTE: There are no right or wrong answers. Please try to fill in as many spaces as possible.

INSERT A

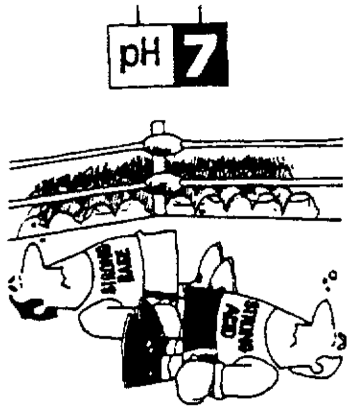


TABLE __

COMMON WORLD Boxers	CHEMISTRY Acids and bases	Office Use
1. Two different people (boxers) interact.	Two chemical species (acids and bases) interact	
2. Both experience a loss of potency	Acids and bases neutralise each other	
3. If the boxers are of equal strength, they may both end up exhausted	If the acid and base are of equal (strong) strength, the end solution is neutral (pH=7)	

Complete the following sentences:

4. Do you recall ever seeing *strong acids and bases* being compared to *a pair of boxers* before? Yes/No*

5. I find that comparing *strong acids and bases* to a *pair of boxers* is/isn't* helpful for me in chemistry because:
Enter as you wish

*Cross out the part that does not apply

6. Office Use only

INSERT B

FIGURE 2.3 If this football field represents an atom, the nucleus would occupy a region the size of a marble in the centre.

TABLE __

COMMON WORLD Football Oval	CHEMISTRY Atomic Structure	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing *atomic structure* being compared to a *cricket oval* before? Yes/No*

5. I find that comparing *atomic structure* to a *cricket oval* is/isn't* helpful for me in chemistry because:

....

....

*Cross out the part that does not apply

6. Office Use only

INSERT D

Chemists think of chemical reactions between elements in terms of atoms of the elements combining in some simple whole number ratio. Thus chemists, although interested in the masses of substances reacting together, are more interested in the numbers of atoms involved in reactions. The fact that atoms are so very small does create problems. For example, if 1 g of a mixture of iron and sulphur is heated in a test-tube, a reaction occurs which involves about 14 000 000 000 000 000 000 000 atoms ($1{\cdot}4 \times 10^{22}$). To avoid having to use such large numbers in calculations, chemists have created an easier unit amount of substance called the **mole**. We shall see below that this is the amount of substance which contains a particular number of atoms. This is a similar idea to file paper being ordered by a school in reams (each containing 500 sheets) rather than in individual sheets.

The number of atoms chosen for a mole of a substance is the number of atoms in one relative atomic mass (expressed in grams) of hydrogen. (Strictly speaking using the modern standard this should be 12 g of carbon-12.)

TABLE __

COMMON WORLD Reams of paper	CHEMISTRY A mole	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing a *mole* being compared to a *ream of paper* before? **Yes/No***

5. I find that comparing a *mole* to a *ream of paper* **is/isn't*** helpful for me in chemistry because:

   ....

   ....

   *Cross out the part that does not apply

6. Office Use only

INSERT F	When the neutralisation of an acid by an alkali takes place, the positive ion from the alkali and the negative ion from the acid remain unchanged in the solution and the mixture of the two in solution constitutes the solution of the salt, produced in the neutralisation. These ions, which play no part in the neutralisation, are sometimes called spectator ions: e.g. $Na^+(aq) + OH^-(aq) + H^+(aq) + Cl^-(aq) \rightarrow \underbrace{Na^+(aq) + Cl^-(aq)} + H_2O(l)$ unchanged spectator ions— together make up a solution of sodium chloride Just as the names of the spectators are not included in the press report of a football match, so the formulae of the spectator ions are not included in our report of the reaction, which is the equation, and so the equation for all neutralisations in aqueous solution is: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

TABLE F

COMMON WORLD Football spectators	CHEMISTRY Spectator ions	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing *spectators ions* being compared to *football spectators* before? **Yes/No***

5. I find that comparing *spectator ions* to *football spectators* **is/isn't*** helpful for me in chemistry because:

   ....

   ....

   *Cross out the part that does not apply

6. Office Use only

INSERT G

An atom consists of a small, dense, positively charged nucleus, surrounded by negatively charged electrons. Electrons play a part in all chemical reactions. We can think of the electrons of an atom as being in 'shells' around the nucleus, like the layers of an onion. Each shell can hold a certain number of electrons. Thus, the first shell can hold one or two electrons. The second may hold up to 8, the third shell up to 18 electrons, and so on. The outside shell, however, can have no more than 8 electrons (only two if it is the first shell). This number of electrons forms a stable pattern which is not easily changed. The chemical behavior of an element depends on the number of electrons in its outer shell.

TABLE G

COMMON WORLD Onion layers	CHEMISTRY Electron Position	Office Use
1.	....	
2.	....	
3.	....	

Complete the following sentences:

4. Do you recall ever seeing *electron arrangements* being compared to *onion layers* before? Yes/No*

5. I find that comparing *electron arrangements* to *onion layers* is/isn't* helpful for me in chemistry because:

....

....

*Cross out the part that does not apply

6. Office Use only

APPENDIX 4

CONTRIBUTIONS FROM THIS RESEARCH

Chapters in Books

Glynn, S. M., Duit, R., & Thiele, R. B. (in press). Teaching science with analogy: A strategy for constructing knowledge. To appear in S. M. Glynn & R. Duit (Eds.), *Learning science in the schools: Research reforming practice.* Hillsdale, NJ: Earlbaum.

Thiele, R. B. (in press). Alternative approaches to the teaching of chemical equilibrium. To appear in B. Hand & V. Prain (Eds.), *Teaching and learning in science: The constructivist classroom.* Melbourne: Harcourt Brace.

Journal Articles and Conference Proceedings

Dagher, Z. R., Thiele, R. B., Treagust, D. F., & Duit, R. (1993). Comment on "Analogy, Explanation, and Education". *Journal of Research in Science Teaching, 30*, 615-617.

Thiele, R. (1990). Useful analogies for the teaching of chemical equilibrium. *The Australian Science Teachers Journal, 36*(1), 54-55.

Thiele, R. B. (1994). Teaching by analogy. *Education in Chemistry, 31*, 17-18.

Thiele, R. B., & Treagust, D. F. (1991a). Using analogies in secondary chemistry teaching. *The Australian Science Teachers Journal, 37*(2), 10-14.

Thiele, R. B., & Treagust, D. F. (1991b). Using analogies in science education. *SCIOS, 26*(2), 17-21.

Thiele, R. B., & Treagust, D. F. (1992). Analogies in senior high school chemistry textbooks: A critical analysis. In H-J. Schmidt (Ed.), *Proceedings of the International Symposium on Empirical Research in Chemistry and Physics Education* (pp. 175-192). Hong Kong: ICASE.

Thiele, R. B., & Treagust, D. F. (1993). Analogies in high school chemistry. *Chemeda: The Australian Journal of Chemical Education, 37*, 19-25.

Thiele, R. B., & Treagust, D. F. (1994). An interpretive examination of high school chemistry teachers' use of analogical explanations. *The Journal of Research in Science Teaching, 31*, 227-242.

Thiele, R. B., & Treagust, D. F. (1994). The nature and extent of analogies in secondary chemistry textbooks. *Instructional Science, 22*, 61-74.

Thiele, R. B., & Treagust, D. F. (in press). Analogies in chemistry textbooks. *The International Journal of Science Education.*

Venville, G. J., & Thiele, R. B. (1993). *Secondary biology and chemistry textbook analogies: A comparative analysis.* Manuscript submitted for publication.

Conference Presentations

Thiele, R. B. (1991, October). *Analogies in secondary chemistry education textbooks: The authors' views.* Paper presented at the annual meeting of the Western Australian Science Educational Association, Perth. (ERIC Document Reproduction Service No. ED 350 152)

Thiele, R. B. (1992, August). *An interpretive examination of secondary teachers' use of analogies.* Paper presented at the Seventh Annual Research Forum of the Western Australian Institute for Educational Research, Perth.

Thiele, R. B., (1993, April). *Analogies in text as a source of conceptual change in senior secondary chemistry.* Paper presented as part of a symposium at the annual meeting of the American Educational Research Association, Atlanta, GA.

Thiele, R. B. (1993, November). *Six science teachers' use of analogies: An international perspective.* Paper presented at the Annual Conference of the Australian Association for Educational Research, Perth.

Thiele, R. B. (1993, November). *Methodological limitations related to the determination of students' analogical reasoning ability.* Paper presented at the Annual Conference of the Australian Association for Educational Research, Perth.

Thiele, R. B., (1995, April). *Analogy Maps: Determinants of Conceptual Understandings?* Paper to be presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Thiele, R. B., (1995, April). *Levels of alternative representations.* Paper to be presented as part of a symposium at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Thiele, R. B., & Treagust, D. F. (1991, July). *Using analogies to aid understanding in secondary chemistry education.* Paper presented at the Royal Australian Chemical Institute Conference on Chemical Education, Perth. (ERIC Document Reproduction Service No. ED 349 164)

Thiele, R. B., & Treagust, D. F. (1993, April). *Analogies in chemistry textbooks.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Thiele, R. B., & Treagust, D. F. (1993, April). *An interpretive examination of high school chemistry teachers' use of analogical explanations.* Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA.

Thiele, R. B., & Venville, G. J. (1993, April). *Secondary biology and chemistry textbook analogies: A comparative analysis.* Paper presented as part of a symposium at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Treagust, D. F., Harrison, A., Venville, G., Stocklmayer, S., & Thiele, R. (1994, July). *Using analogies in science teaching.* Paper presented at the annual conference of the Australian Science Teachers Association, Launceston.

Treagust, D. F., Stocklmayer, S., Harrison, A., Venville, G., & Thiele, R. (1994, July). *Observations from the classroom: Where analogies go wrong!* Paper presented at the annual conference of the Australasian Science Education Research Association, Hobart.

Treagust, D. F., & Thiele, R. B. (1992, June). *Analogies in senior high school chemistry textbooks: A critical analysis.* Paper presented at the ICASE Research Conference in Chemistry and Physics Education, Dortmund, Germany. (ERIC Document Reproduction Service No. ED 357 966)

Treagust, D. F., Thiele, R. B., Harrison, A., Stocklmayer, S. & Venville, G. (1993, November). *Teaching and learning science with analogies.* Symposium presented at the Annual Conference of the Australian Association for Educational Research, Perth.

Treagust, D. F., Venville, G., Harrison, A., Stocklmayer, S., & Thiele, R. B. (1993, May). *Using analogies to enhance the effectiveness of science teaching.* Symposium presented at the Annual Conference of the Australian Teacher Education Association, Perth.

Venville, G. J., & Thiele, R. B. (1992, October). *Secondary biology and chemistry textbook analogies: A comparative analysis.* Paper presented at the annual meeting of the Western Australian Science Education Association, Perth.

Seminars for Teachers and Teacher Educators

Thiele, R. B. (1992, October). *Analogies in science education.* Seminar presented at the Science Education Centre, University of Glasgow, October 21, 1992.

Thiele, R. B. (1992, December). *Research into the use of analogies in science teaching.* Seminar presented at the University of York Science Education Group, University of York, England, December 10, 1992.

Thiele, R. B. (1993, January). *Analogical explanations of chemistry concepts in textbooks and by teachers.* Seminar presented at the Centre for Educational Studies, Kings College, London, January 12, 1993.

Thiele, R. B. (1994, December). *Using analogies to help students understand science concepts.* Seminar presented at the Inaugural Science Conference for Teachers in Catholic and Independent Schools, Fremantle, December 2, 1994.

Treagust, D., Thiele, R., Harrison, A., Venville, G., & Stocklmayer, S. (1993, April). *Teaching with analogies.* Seminar presented at a seminar of the Science and Mathematics Education Centre, Curtin University of Technology, Perth, April 29, 1993.

Workshops for Teachers and Teacher Educators

Thiele, R. B. (1992, June). *Teaching chemistry using analogies.* Workshop presented at the Science Teachers Association of Victoria Chemistry Conference, Melbourne.

Thiele, R. B. (1992, July). *Teaching science with analogy.* Workshop presented at the 41st Annual Conference of the Australian Science Teachers Association, Perth.

Thiele, R. B. (1993, January). *Teaching abstract science concepts with analogy.* Workshop presented at the annual meeting of the Association for Science Education, Loughborough, England.

Thiele, R. B., & Treagust, D. F. (1991, May). *Using analogies in science education.* Workshop presented at the Fourteenth Annual Conference of the Science Teachers Association of Western Australia, Muresk.

Treagust, D. F., Thiele, R. B., Stocklmayer, S. M., Harrison, A. G., & Venville, G. J. (1993, July). *Using analogies to enhance the effectiveness of science teaching.* Workshop presented at the 42nd Annual Conference of the Australian Science Teachers Association, Sydney.

Treagust, D. F., Venville, G., Harrison, A., Stocklmayer, S., & Thiele, R. B. (1993, May). *Using analogies to enhance the effectiveness of science teaching.* Workshop presented at the Fifteenth Annual Conference of the Science Teachers Association of Western Australia, Muresk.

In-service Courses For Science Teachers

Stocklmayer, S. M., & Thiele, R. B. (1993, July). *Recent developments in strategies in teaching science.* In-service presented for the high school science teachers of Chisholm College, Perth, July 27, 1993.

Thiele, R. B. (1993, August). *Teaching using analogies.* In-service presented for high school teachers at All Saints' College, Perth, August 27, 1993.

Radio Interviews

6NR (Curtin University of Technology) (1993, May) with Sandra Farnworth. Discussion of research into chemistry teachers' use of analogies to aid the explanation of abstract concepts.

6RN (Radio National) (1992, August) with Jane Figgus. Discussion of research into analogies in science classrooms.