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Springer

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Metaphor and Analogy in Science Education

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FOREWORD

Years ago a primary teacher told me about a great series of lessons she had just had. The class had visited rock pools on the seashore, and when she asked them about their observations they talked about: *it was like a factory, it was like a church, it was like a garden, it was like our kitchen at breakfast time, etc.* Each student's analogy could be elaborated, and these analogies provided her with strongly engaged students and a great platform from which to develop their learning about biological diversity and interdependence.

In everyday life we learn so many things by comparing and contrasting. The use of analogies and metaphors is important in science itself and their use in teaching science seems a natural extension, but textbooks with their own sparse logic, do not help teachers or students.

David Ausubel in the 1960s had advocated the use of 'advance organisers' to introduce the teaching of conceptual material in the sciences, and some of these had an analogical character. However, research on the value of this idea was cumbersome and indecisive, and it ceased after just a few studies. In the 1980s research into children's conceptions of scientific phenomena and concepts really burgeoned, and it was soon followed by an exploration of a new set of pedagogical strategies that recognised a student in a science class is much more than a *tabula rasa*.

Among these strategies was the use of familiar metaphors and analogies to assist learning of science concepts. It was found that science teachers seemed to use these less often than might have been expected, and when they did, that students could be left with conceptions that had not been adequately differentiated between the base analog and the target science concepts. So began more than a decade of quite intensive research on the use of analogies, metaphors and, in due course, models in the teaching and learning of science.

This book contains much of what has been learnt through this research. Its chapters provide an excellent introduction to how this strategy for teaching/learning science has been explored, what has been established, and the pros and cons of its use.

An important outcome from this research is that it began an interest in the discourse in science classrooms. As significant and purposive examples of research into the discourse between teachers and their students, the studies described in the book can themselves serve as models and warnings for the much more complex issue of studying the discourse in science classrooms more totally.

The editors and chapter authors are to be congratulated and thanked by those of us who have known, but not really known, that these studies were occurring. It will be of considerable use to graduate students and others who may be challenged to extend its studies still further.

Peter Fensham, Emeritus Professor Monash University, Australia/Adjunct Professor Queensland University of Technology, Australia

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METAPHOR AND ANALOGY

Serious thought in science education

1. FROM PARIAH TO PANACEA?

> To draw attention to a philosopher's metaphors is to belittle him – like praising a logician for his beautiful handwriting. Addiction to metaphor is held to be illicit, on the principle that whereof one can speak only metaphorically, thereof one ought not to speak at all. …do not accept the commandment, "Thou shalt not commit metaphor" or assume that metaphor is incompatible with serious thought. (Black, 1962, p.25)

How far we have come! Since the mid-twentieth century, philosophers have accepted that metaphor and analogy permeate all discourse, are fundamental to human thought and provide a basis for mental leaps (see Black, 1962; Goswami, 1992; Johnson, 1981; Lakoff & Johnson 1980; Schön, 1983). Similarly, the potential contribution of metaphor and analogy to cognitive learning (e.g., in schools) has attracted the attention of the science education research community (Gentner & Stevens, 1983). The first important revelation is that metaphor is not merely a linguistic phenomenon. It also is a fundamental principle of thought and action (see Johnson, 1981). The second revelation is that analogies are more specific than metaphors and, despite their wide use in everyday communication and reasoning, their use in teaching is often problematic because the applicability of specific analogies is not negotiated with students. Consequently, researchers have been and are interested in the form and function of analogy and metaphor in learning and teaching science.

These philosophical and educational origins of metaphor and analogy have spawned a significant literature and cognitive theories. These have the potential to enhance science teaching and learning; promote higher-level thinking; and yield new tools for interpreting science education research. To achieve these aims, the book brings together powerful ideas and new developments from international scholars of metaphor and analogy in science education. It also offers theoretical and practical perspectives on metaphor and analogy that should promote concept learning, metacognition and communication.

The book's first theme is the ubiquity of metaphor and how metaphors can help people explore their epistemological and ontological commitments. Metaphoric

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thinking helps teachers (re)conceptualise their role and practice and it can promote professional reflection, action research and educational renewal. These benefits are intrinsically tied to "the metaphors we live by" because metaphor enables us to "conceptualise our experiences" and to pick "out what is 'important' in the experience" and "categorise the experience … dimension by dimension" (Lakoff & Johnson, 1980, p.83, 145). Metaphors have 'entailments' that suggest a range of new ideas, applications and possibilities; this is what makes metaphor a creative tool for looking inwards and for critiquing accepted ideas.

The second theme is analogical thinking as it applies to concept description and explanation and the book explores the theory and use of analogies in classrooms and discusses a range of popular instructional analogies. Analogy is attractive because it is a simple way to explain abstract ideas in familiar terms. Analogy can be capricious, however, because its benefits can be compromised by unforeseen limitations and because it is often used in unplanned, uncritical ways. Several chapters discuss best practice with respect to analogy and metaphor use for concept teaching and learning and how to better use analogies and metaphors to view, interpret and communicate ideas in and about school science.

A third theme interrogates the ways that metaphor and analogy, and the way we think and write metaphorically, can enhance educational research. This is a methodological issue and is advocated by Miles and Huberman (1984). We believe that this is an emerging and exciting research direction. Knowledge in this field has the potential to reshape science teacher education, teacher professional development, curriculum and science education research.

Throughout the book, contributors highlight successful applications of analogies and metaphors in teaching, learning and research, and foreshadow exciting developments and pitfalls to be avoided. Contributors include science teachers and teacher candidates who have used metaphor and analogy extensively in their classroom practice or as a tool to reflect on their practice, as well as researchers who have investigated analogy and metaphor in science education over a number of decades.

2. WHAT ARE METAPHORS AND ANALOGIES?

The terms metaphor and analogy are used in a variety of ways in the science education literature, sometimes interchangeably. Analogy can be distinguished from metaphor in the sense that in metaphor, A is said to be B but in analogy, A is like B. According to this view, when we use the metaphor student as *tabula rasa,* it suggests that the student has no prior science knowledge before entering a science classroom. The student is like a sponge, however, is an analogy suggesting that there are characteristics which the student and a sponge have in common but implying there are ways in which they differ. Another distinction between analogy and metaphor in science education has been that the term metaphor is often assocated with views of teaching (e.g., the teacher as captain of the ship) whereas analogy is more often associated with explanation of science content (e.g., human body as machine). This distinction is evident in the stories of the beginning teachers in Ritchie et al. Yet another distinction is that the comparisons in a metaphor are covert whereas in analogy these are overt. That is, the similarities and differences of things being compared in an analogy are made explicit. This is consistent with Lakoff and Johnson's (1980) thesis that metaphor informs the ways we think and act - often without us being aware of the way in which specific attributes of a metaphor influence us. It is also consistent with Gentner's (1993) (structure-) mapping theory of analogy. However, any metaphor can be mapped. Hence to argue the implications of various metaphors for societies, Lakoff and Johnson mapped the specific attributes of the many metaphors they identified.

Distinguishing between metaphor and analogy becomes even more problematic when one is defined in terms of the other. For example, Robert Snow (1973) defines metaphor as a compressed simile, usually a substitution of one kind of object for another, to suggest a likeness or analogy between them" (p. 82). A further complication is that different cultures prefer different types of metaphor and analogy. The analogy wars between French and English scientists in the 19th century are discussed by Hesse (1966). The French preferred 'mental conceptions' whereas the English favoured 'weights pullies and strings'. This continued a distinction in styles of representation that dates from Descartes and Newton. The culturally-bound nature of metaphor and the implications for their role in science education is taken up by Tobin.

As the varied use of the terms is common-place this pattern of usage continues in the chapters in this book. Nevertheless, this review of the literature and original studies suggests a need to move to a more consistent use of the terms metaphor and analogy. It seems that the term metaphor can be applied to **all** comparisons that feature the identification of some similarity between two things. While not always the case, there appears to be a tendency to use the term analogy when the comparison is extended highlighting a range of similarities and differences between two things. Thus, all analogies are metaphors but not all metaphors are extended into analogies. For example, Shakespeare uses both metaphor and analogy in the following sonnet:

> Shall I compare thee to a summer's day?
> Thou art more lovely and more temperate.
> Rough winds do shake the darling buds of May,
> And summer's lease hath all too short a date:..
> But thy eternal summer shall not fade
> Nor lose possession of that fair thou owest;
> Nor shall Death brag thou wander'st in his shade…
>
> (Clark & Wright, 1928, p.1097)

Here the superordinate metaphor is *a woman-as-summer's day*. As the similarities (and differences) are teased out with the features of a summer's day mapped against the woman's features, the metaphor merges into analogy. Notably, both similarities and differences are identified and then elaborated as they combine to construct a more vibrant mental image of the woman than could be revealed by similarities alone. The value of explicating both similarities and differences when working with analogies is a view argued in many chapters. But an important caveat needs stating: the exhilaration felt when reading Shakespeare, for example, lies in the reader's freedom to build his or her personal reality from the text. This freedom is the life-blood of fictional drama. Much less freedom is permitted in the science classroom where an aim is to construct a consensus that is scientifically appropriate and trustworthy (Guba & Lincoln, 1989). Hence careful analysis of analogy is essential to tease out relevant, irrelevant and misleading features in order to promote understanding where misunderstanding threatens.

When using metaphors and analogy two things are compared as one is said to be similar to, though it is different from, another. The terms used to describe the two things being compared vary considerably and may cause confusion when reading different works in the field. In metaphor and analogy, a familiar entity is used to provide information about, interpret or communicate ideas about a less well known entity. For example, in the environmental movement the notion of "spaceship Earth" conjures up, among other things, the idea of Earth as a finite resource hurtling through space. The 'spaceship' metaphor conceives of the Earth "as a container" (Lakoff & Johnson, 1980) and this effective idea communicates to others the concept that all Earth resources are limited. The features of a spaceship are 'mapped' onto, 'transferred' to or 'related' to the Earth. The terms 'related', 'transferred' or 'mapped' are used in the literature to describe the (sometimes tacit) process of linking selected features of one entity to another. Different authors prefer different terminology. Wilbers and Duit favour relate to transfer because they understand the learners' interpretive actions in a way that denies simple 'transfer' from source to target. Others, such as Aubusson, use the term mapping (after Hesse, 1966) to describe the intellectual process of identifying attributes of the analogy and the analysis of the match and mismatch of each attribute. While there are significant differences in the way terms are used, they are alternatives for the same general process of comparing the target and source in analogy. The range of usage is significant and perhaps deserves further consideration than is possible in this introduction, but the variation in terminology is explained by each writer.

There also is variation in the terms used to describe the entities that are compared in a metaphor or analogy. According to some (e.g., Gentner, 1983), both entities are analogs as an analogy is made up of two analogs that are compared (i.e., the analogy works both ways). Thus spaceship is an analog of Earth and Earth is an analog of spaceship. The familiar analog that provides source information or features to interpret the unfamiliar entity is often called the base domain; whereas the analog to which the information is transferred is called the target (Gentner, 1983). Others also call the analog 'the source' rather than base (e.g., Holyoak & Thagard, 1995) and still others refer to the base only as the analog. In this book, the terms source, base, target and analog have been used according to the preference of each author. In the future, the implications of this useage for how we 'see' analogies working shall be scrutinised.

When we elaborate on a metaphor, it remains metaphor but also becomes analogy. What is unclear is the extent to which scientific reasoning, with its theory building and models, is metaphoric. This is discussed in later chapters but requires some consideration here. Lakoff and Johnson (1980, p.184) assert a set of "facts" about human understanding, two of which are: "that our conceptual system is inherently metaphorical"; and "that we understand the world, think and function in metaphorical terms". Hence, in science, our understanding is littered with concepts, propositions, thinking and mental models (current and past) which are represented in varied ways. Representations of these mental models (Harrison & Treagust, 2000) are metaphoric. The imagery is varied but includes physical structures (e.g., building a DNA helix), verbal representations (e.g., stringy universe), diagrams (e.g., a figure showing a layered structure of the Earth) and simulations (e.g., role plays). School science and science abounds in a plethora of such representations. The metaphoric nature of these, however, can be too readily glossed over. When we say, the Earth *has* the layered structure illustrated in a diagram, that methane *is* CH_4, or that light *is* a wave, we represent and misrepresent what we know. What is meant is: we think the Earth's structure *is like* the diagram shown (but we know the diagram is flawed); we *represent* methane as CH_4 (but our conception of what methane is, is not conveyed by this model alone); and we *understand* light in terms of waves (and other things). Knowing, recognising and making it explicit that when models are used ideas are often being created and conveyed via metaphor and analogy is important. As a consequence, modelling construed as metaphor and analogy has implications for science and is a feature of many chapters.

3. FOUNDING PRINCIPLES

The book's chapters have been arranged in three sections. The first section critically analyses the rationale and theoretical bases for analogy in science education and challenges assumptions that underpin them. The paradox that analogy both misleads and leads people to better understanding is a recurring theme in many chapters. In *Post-festum and heuristic analogies*, Wilbers and Duit remind us that each analogy we introduce in science builds upon the learners' existing mental images. The identification and transfer of attributes from the analog source to the target is idiosyncratic and determined, in part, by existing ideas. Hence students often construct analogical relationships very different from those the teacher intends. They outline a model making use of propositional knowledge to moderate analogical transfer by constructing relationships between target and analogy.

Constructivist epistemology is a dominant paradigm in science education. *Teaching and learning with analogies friend or foe* (Harrison & Treagust) reviews research studies to explore the advantages and disadvantages of analogy and provides a set of principles underpinning the successful use of metaphor in teaching for learning in science. Taylor and Willison reinterpret constuctivism as metaphor and contrast it with competing metaphors such as objectivism. Their chapter, *Metaphor as a key referent for an integral perspective on science teaching*, challenges the dominant position of constructivism in science education by encouraging us to move from a literal interpretation of learning and knowledge in science (as objectivism or constructivism) to a metaphorical interpretation. This opens opportunities for integration of otherwise competing ‘theories’ because, when viewed as metaphors, they have different uses and apply in different situations. The theories then may become complementary or applied in different situations rather than be antagonistic.

4. SCIENCE TEACHING AND LEARNING

The second section reports the use of metaphor in science teaching and learning. It is evident that analogy and metaphor are explicit or tacit features of human discourse and thinking. They permeate science teaching and this section explains how metaphors and analogies contribute to, as well as inhibit learning. The chapters provide examples of the effective use of analogy and a framework to enable the productive use of analogy in science teaching. In *The role of analogy, models, and metaphor in chemistry and teaching for understanding*, Coll discusses how the conceptual difficulties students encounter in chemistry often arise because of the unfamiliar metaphors scientists must use to visualise the invisible world of chemistry. In a similar vein, Venville (*Metaphors for genes*) focuses on the changing image of ‘gene’ in science and on the conflicting multiple metaphors people derive for gene from popular culture. This raises questions of how popular and scientific metaphors of gene interact and distort students’ views of genetics and biotechnology in a way that impacts on life decisions. Justi and Gilbert (*The role of analog models in the understanding of the nature of models in chemistry*) extend the discussion of models in chemistry by illustrating how analogical models have changed over time, historically in science, and how they can change in teaching and learning to create a deeper understanding of phenomena. They argue that analogies are not just important but essential in chemistry. Recognising the challenge teachers face with modelling activities, they recommend ‘discuss and guide’ rather than ‘show and tell’, as well as ensuring student ‘ownership’ by working with students’ own models.

Furthermore, in *Role play as analogical modelling in science*, Aubusson (a university researcher) and Fogwill (an experienced teacher) use a case study to show how students’ self generated analogies can be used to promote deeper understandings in science. They argue that the value of analogy lies not so much in the degree of match but rather on the quality of discourse and thinking that effective use of analogy generates. *Metaphor views of learning, and metacognition* (Thomas) introduces the role of metacognition in learning and discusses how metaphor may be used to improve students’ awareness of how they learn and to allow them to take control of their learning. He cautions, however, against exclusive reliance on metaphor for this purpose and suggests complementary strategies that can be employed. To be metacognitive, an analogy must engage and interest students and this issue is examined in *Analogical transfer – student interest is more than just interesting* (Harrison). Familiar analogies are intrinsically interesting and research confirms that analogies that are planned, tested and revised over time are most likely to promote high-level thinking that leads to new and fruitful relational ideas.

5. TEACHERS AS LEARNERS

The third section outlines the way in which analogy can contribute to teacher education and development. Since Tobin's (1990) article, *Changing metaphors and beliefs: a master switch for teaching?,* many educators have used metaphor to help teachers explore their understanding of their own practice, the beliefs that influence this practice, to examine the roles they enact as teachers, and the roles they would like to play. For example, Russell and Hrycenko report an extended, mostly online, dialogue between a teacher candidate (Hrycenko) and a teacher educator (Russell). They show how metaphor and analogy can facilitate fruitful interactions between educator and candidate and act as a thinking tool to guide teacher learning. Similarly in *Metaphors and analogies in transition: beginning teachers' lived experiences*, Ritchie (a teacher educator) and beginning teachers, Bellochi, Poltl and Wearmouth, discuss their personal metaphors of teaching to illustrate how their metaphors changed and influenced their teaching. They discuss the benefits of maintaining communication networks with each other and the way metaphor facilitated their exchange of ideas. In *Why do science teachers teach the way they do and how can they improve practice*?, Tobin reflects on 20 years of research in science education. He reflects on a case study of his own teaching in an inner city school arguing that, while metaphor is central and valuable, its use must be tempered by the realisation that many elements of social life may not be best captured metaphorically.

6. METAPHOR AND ANALOGY AS RESEARCH TOOLS

Section four proposes ways to use metaphor and analogy in science education research for interpretation and reporting. If metaphor and analogy are essential to creative thought, it follows that they provide a way of producing and communicating knowledge, which are essential aims of education research. Aubusson argues the case for the use of analogy in research (*Using analogy in interpretive science education research*) and provides examples of how analogy can be employed to interpret research findings. He then outlines a sequence of steps to guide others in the use of this technique. In *Metaphors we write by*, Ritchie illustrates how the ways in which people write collaboratively can be interpreted in terms of musical metaphors like duelling banjos or a piano duet. These metaphors are made explicit to explore the implications of such metaphorical perspectives for what research reports say and how they are constructed. The metaphorical interpretation encourages us to think about the implications of collaboration for report writing.

7. CONCLUSION

The chapters that follow are an eclectic collection of accounts of teaching and research that use metaphors and analogies. Even as we reviewed the chapters, we realised that there were no 'right' or 'wrong' analogies and metaphors – just as there was no 'right' or 'wrong' way to explain metaphoric and analogical transfer. Authors take different perspectives and even disagree with each other on the efficacy of, and ways to use metaphors and analogies. This is not surprising and we think it is one of the book's strengths. Metaphor and analogy is about relational thinking involving both social and personal constructions of knowledge. Metaphors evoke mental images that meld past knowledge and experiences with new knowledge, concepts and experiences. The constructivist nature of analogy and metaphor is both a strength and weakness of representational thinking. We invite you to read Chapters 2-15, share the multiple ideas that our contributors have to offer, and critically evaluate each author's ideas.

Chapter 16 summaries the book's themes and revisits the dilemmas that metaphor and analogy bring to teaching and learning. For example, how do teachers orchestrate metaphoric and analogical thinking so that they enhance understanding without misleading students? How do we construct metaphoric and analogical mental images that are commensurate with science without quenching the creative spirit of learners? Which metaphors and analogies enhance high-level thinking while catering for the needs of lower achieving students? Can we generate new knowledge by analogy or is it just a creative and adaptive tool of communication? How can I use metaphoric methods in my research; indeed, do I know how? What do I need to know?

We believe that it is important to explore the implications of the theoretical frameworks and questions offered in this book. We hope readers will meet with provocative ideas in the chapters that interest them; we also hope these ideas will lead them to critically reflect on metaphor and analogy in their practice. We believe that thinking without metaphors is like a world without pictures or a colourless landscape. Whether your interest be learning, teaching or research, metaphor and analogy offer new ways of thinking and have the potential to revitalise science teaching, teacher education and professional development, curriculum and research.

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ALLAN G. HARRISON AND DAVID F. TREAGUST

TEACHING AND LEARNING WITH ANALOGIES

Friend or Foe?

1. TWO EDGED SWORDS

The *Friend or Foe* metaphor in the title raises timely questions about the value of analogies in science education. Science teachers and textbook writers differ widely in their enthusiasm for analogical explanations: some use many analogies (Harrison, 2001; Harrison & de Jong, 2004); others are wary because they cannot predict how their students or readers will interpret the analogies they use to teach science (Treagust, Duit, Joslin & Lindauer, 1992; Thiele & Treagust, 1994). This chapter therefore discusses the importance and role of analogies in the teaching and learning of science. It is now more than 10 years since Duit (1991) reviewed the literature on the use of analogies in science education; therefore, we examine new and old studies and ask, "what have we learned over the past decade about the pedagogical and epistemological value of science analogies?" and, "to whom are analogies most important: science practitioners, teachers or students?" The latter question is important because it asks "are analogies just excellent communication tools or can they generate new knowledge?" We begin our discussion by concentrating on the use of analogies in teaching and learning.

Much of the research to date has focused on how teachers understand and use analogies (e.g., Glynn, 1991; Treagust, Harrison & Venville, 1998), however, students' interpretation of teaching analogies deserve equal attention (e.g., Gick & Holyoak, 1983; Dagher, 1995a). This problem raises a further question about analogies research; "Do students see, interpret and apply analogies in the way intended by teachers and textbook writers?" Studies into student understanding of analogies mostly concentrated on the knowledge developed by "good" or talkative students; but what do the majority of students understand when analogies are used to explain abstract and difficult ideas such as molecules, diffusion and plate tectonics?

Analogies have been called "two-edged swords" because the appropriate knowledge they generate is often accompanied by alternative conceptions. When people 'receive' analogies, they use their past knowledge, experiences and preferences to interpret the analogy so that it harmonises with their current personal

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and social milieu. In modern terms, this is called *the personal construction of meaning*. Science classrooms are a common setting in which analogies are used to enhance concept learning; therefore, improving the way analogies are used in science education has important teaching and learning consequences.

2. MEANINGFUL LEARNING WITH ANALOGIES

When students study new concepts, meaningful learning proceeds when they find and visualise connections between a newly taught context and what they already know. This is especially important in inquiry learning where connections are built between familiar and non-intuitive science contexts. Inquiry includes the following: novel questions and problems are identified; activities are planned; students investigate the questions and problems; the teacher discusses the data and interpretations with the students; and the teacher asks questions, provides 'need to know' information and sometimes offers analogies. If the analogies are appropriate, they promote concept learning because they encourage students to build links between past familiar knowledge and experiences and new contexts and problems. Consider two examples.

Example 1. Harrison and de Jong (2004) provide an example of a socially generated student analogy. A Grade-12 teacher called Neil was explaining the conditions for chemical equilibrium. In answer to a student who asked "what do you mean by dynamic [equilibrium]?", Neil used his "sugar in a tea-cup" analogy. In this analogy, a new molecule of sugar can dissolve only if a dissolved molecule first crystallises out of the saturated solution. As Neil concluded his story, a student called Mal interrupted with:

Mal: Is that happening when you've got like food in a pot and you've got a lid on, and when some evaporates at the same time, some is condensing and dropping down at the same time?
Neil: Yes … it's a closed system if I've got the lid on pretty tight? [St. Yeah …] not completely closed, but it will do… Now, they tell you add this and that, simmer for 20 minutes with lid on. Why tell you to do that? Why leave the lid on?
St.: Liquid stays in the pot.
Neil: And the liquid's got to stay in the pot, why?
St.: Cause otherwise it'll all evaporate and everything will like go dry.

In the three lessons that we observed, Neil used nine analogies and the students contributed one! The lessons were highly interactive; yet the students still found it hard to generate scientifically relevant analogies despite understanding the concepts under discussion. When a student analogy arose, Neil capitalised on it and the students easily mapped the analogy as shown in later interviews. This study is typical and demonstrates that most analogies are teacher generated but, in conducive circumstances, students can generate effective analogies.

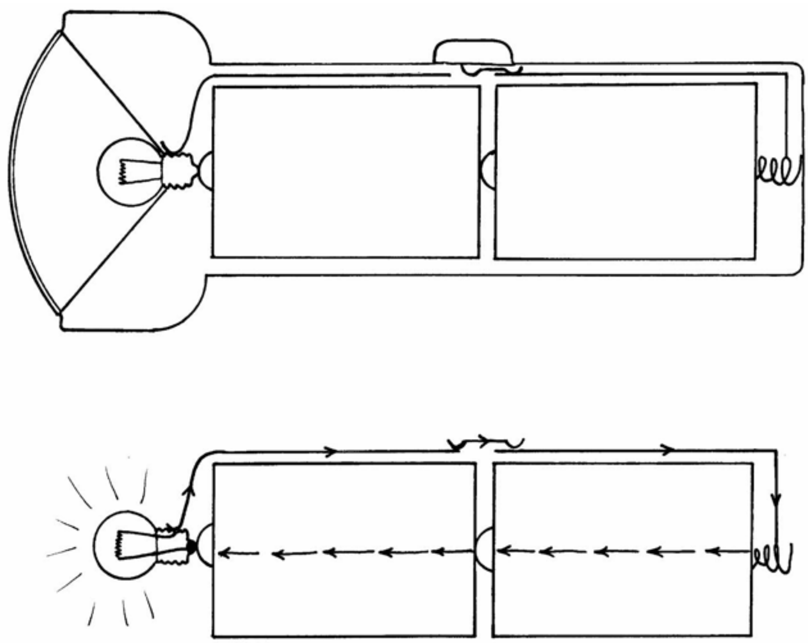

Figure 1a. Series circuit in a flashlight

Example 2. A Grade-9 teacher called Sally was investigating electric circuits. In a short time, Sally realised that her students thought that current is used up in the series circuit found in a flashlight (Figure 1a). This conclusion is reasonable because the light grows dim as the batteries run down. To explain current conservation in the circuit, she presented the continuous train analogy (Dupin & Johsua, 1989) (Figure 1b). The train (representing the current) is clearly conserved while the passengers (representing energy) move from Station 1 (energy in the battery) to Station 2 (energy converted to heat and light). When Sally used this analogy, she 'gave up' part way through the analogy when she realised that her version of the analogy taught the students that current changes speed (and intermittently stops) as the train loaded and alighted passengers. Despite a detailed rehearsal of the analogy using diagrams and a model train, Sally found that the analogy that worked well for other teachers, fell apart in her class. Sally was a perceptive teacher and realised that an alternative conception would result if she maintained the continuous train analogy. She stopped, aborted the analogy, and explained to her students what was going wrong with the analogy and reverted to a classical explanation of the difference between current and energy.

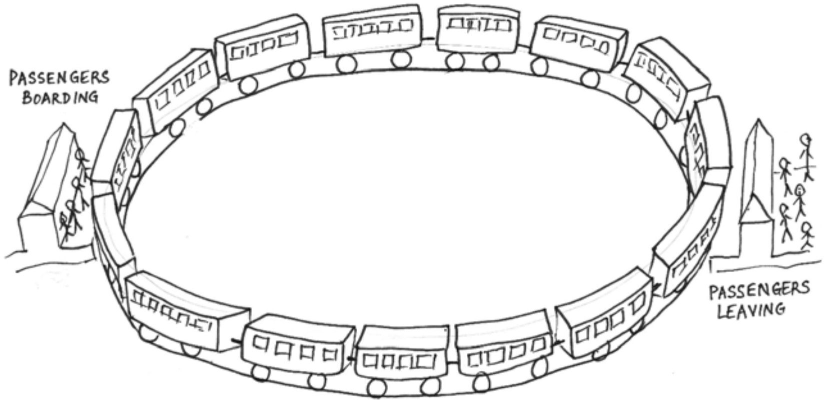

Figure 1b. Continuous train analogy shows that current is not consumed in a series circuit

The problem. Sally's quandary is highlighted by Zook (1991) who warns that teacher supplied analogies are easy for students to access but difficult for them to recite and map (in the above case Sally was like a student). Conversely, students find it difficult to generate their own analogies but, when they do create an analogy, they find it easy to map. This tension is important because most analogies are teacher or textbook supplied. Analogies are easy for some teachers to generate but hard for the students to map and apply. Student sourced analogies are rare and difficult to generate (Wong, 1993) but when they do arise, mapping is easy and meaningful learning follows (Cosgrove, 1995). It is rare for students to generate appropriate analogies that will not lead to alternative conceptions but they easily map the analogies that they do create in their investigations and discussions.

Most studies treat analogy generation as a student problem; however, we argue that many teachers are like students when it comes to analogy choice. The 'teacher acting like student' is demonstrated by their preference for the "water circuit analogy" for electric current (e.g., Hewitt, 1999, p.535). The water circuit analogy encourages the alternative conception that electricity is fluid-like and explains conclusions like electricity escapes from an unplugged socket and resistance is due to friction between the electrons and a cable's insulation (Champagne, Gunstone & Klopfer, 1985). One of the weaknesses of the water circuit analogy is the propensity of teachers to use it to explain all the features of an electric circuit. Multiple analogies are better with each analogy selected for the concept it explains best. Before we discuss multiple analogies, however, we need to more generally examine analogies in science.

3. ANALOGIES IN SCIENCE

Analogies and analogical models are popular in science and help scientists understand and communicate the intricacies, beauty and strangeness of the natural world. Consider these examples: First, Stephen Hawking used at least 74 everyday analogies in *A brief history of time* to explain astrophysics and quantum ideas. To demonstrate that the universe is expanding equally in all directions, he says “the situation is rather like a balloon with a number of spots painted on it being steadily blown up” (p.45). He later muses that we could capture a black hole by “towing a large mass in front of it, rather like a carrot in front of a donkey” (p.115). Second, Robert Oppenheimer of atomic bomb fame claims that most of the significant advances in science used analogy as a thinking tool. He uses the history of science to show that scientific progress is aided by analogical thought and, for example, shows how analogy favoured the discovery of mesons. Third, Bronowski (1973) claims that imagining the workings of a clock helped Johannes Kepler (1571-1630) develop his ideas of planetary motion and fourth, Watson and Crick insisted that they arrived at the double helix structure of DNA by making analogical models that fitted their data. Finally, Peter Atkins’ (1995) book *The periodic kingdom* is one vast analogy. Other scientific discoveries that used analogical thinking are presented in Table 1.

Table 1. Scientific discoveries that used analogical thinking to advance science

Maxwell used water pressure in tubes to mathematically describe Faraday’s electric lines of force
Robert Boyle imagined elastic gas particles as moving coiled springs
Huygens used water waves to theorise that light was wavelike
Konrad Lorenz used analogy to explain streamlined motion in both birds and fish
Kekulé derived his idea for a benzene ring from an image of a snake biting its tail

Our specific study of the explanations used in science lessons began by searching for an exemplary science explanation (Treagust & Harrison, 2000). A model case was Richard Feynman’s first lecture—*Atoms in motion* (in *Six easy pieces*, Feynman, 1994). Analysis of this lecture showed that Feynman used 12 analogies to explain non-observable particle phenomena and five of these analogies are listed in Table 2.

Table 2. Five analogies used in Atoms in motion

paramecia are like "small football shaped things" (p.4)
molecules in water are moving "like a crowd at a football game" (p.4)
if an apple is magnified to the size of the earth, atoms in the apple will be as big as an apple (p. 5)
an atom hitting a moving piston is like a ping-pong ball hitting a moving paddle (p.8)
Brownian motion is like a game of push-ball (pp.19-20)

4. ANALOGIES IN SCIENCE EDUCATION

Analogies are promoted as successful science thinking tools by scientists and seen as problematic by the education research community (Dagher, 1995b; Duit, 1991). We now reflect on the process of analogy. Analogy can be a statement of proportionality or an application of process likenesses from one domain to another. Both are found in science teaching analogies. Statements of proportionality are best seen in surface similarities that could be called procedural analogies and, in their simplest mathematic form, involve deductions. A proportional analogy takes the form of A:B::C:D and is evident in the example 3:6::5:10. Any missing term can be deduced from the other three. A science example is the kinetic theory's depiction of atoms and molecules as perfectly elastic balls and a cell is like a box (the cell metaphor already conveys this surface structural similarity).

Process likenesses between domains are strongly relational and are found in analogies that build concept-process knowledge in new contexts. Such analogies use inductive reasoning to generate systematic or process knowledge in the new context. Inductive thinking resembles the effect a magnet has on an adjacent iron nail – the nail becomes a magnet so long as it remains in the strong magnetic field. Before exploring the "field" analogy, Carey's (1985) principle of inductive projection has relevance. In order to explain how young children understand the structure and function of one animal in terms of another, she demonstrated that 4-6 year-old children projected their knowledge of a prototypical animal (typically a dog or sheep) onto similar and dissimilar animals. Where the new animal was large, inductive projection was strong; when it was a snail or other invertebrate, the projection was weaker. Carey's research suggests that surface likenesses favour analogy identification and mapping but, as other research shows, only process analogy promotes deep thinking and conceptual understanding. These principles are important as we try to understand which analogies are easily recognised (they have obvious surface likenesses) and which analogies foster concept learning (they contain multiple process mappings).

The "magnetic field" analogy referred to above is a relational analogy [or is it a metaphoric analogy with specific entailments (Lakoff & Johnston, 1980)?]. Each electro-magnetic entity in a magnetic field affects and is affected by every other entity in the field and this explains why a nearby iron nail becomes a temporary magnet. This principle also applies to gravitational and electric fields. The electric field concept is the only functional way to explain how the second globe in a 2-globe series circuit influences the other globe and the cell(s) in the circuit. The field metaphor is like a sporting field. For example, in a football game, the addition or loss of a star player immediately affects all the players on both teams. The players, the context and the rules create a web (or field) of interactions. They affect and regulate each other all the time. The field concept is functional and relational and explains what cannot be explained in terms of isolated material objects. Indeed, field explanations can only be understood in process and relational terms. But analogies like the field concept demonstrate analogy's strengths and weaknesses. The explanatory power of the field metaphor is its ability to explain what no other method can do; its weakness lies in the inappropriate mappings that often emerge and lead to the demotion of the field concept to an algorithmic mantra. Fields are often stated as the reason for force acting at a distance but they are rarely explained. Such is the elusiveness of certain analogies. But a closing comment on the field concept is warranted: Why do teachers and textbooks regularly introduce magnetic fields without qualification in Grade-8 science? The field concept is one of science's most relational analogies yet it is just stated, without explanation, to describe forces acting at a distance. (The field concept is likely a mystery to most teachers and students!) Faraday was perplexed by electromagnetic action at a distance and Maxwell needed to design complex mechanical analogical models using flowing water in pipes to make sense of this 'mysterious' phenomenon (Nersessian, 1992). However, research by Stocklmayer and Treagust (1996) showed that many experts working with electricity (electricians, electrical engineers and lecturers of engineering and physics) held a field concept of electricity rather than a particle one.

This brief excursion into analogical thinking indicates the need for an explanatory classification of analogies..

5. A CLASSIFICATION SYSTEM FOR ANALOGIES

Curtis and Reigeluth (1984) examined 26 science textbooks and found that analogies could be classified into three types (see Figure 2). The most common type was the "simple analogy" where the writer said something like "an artery is like a hose" or "activation energy is like a hill". The grounds on which the comparison was based were not stated and the student was left to interpret *how* an artery is like a hose. They also found a second type of analogy where the grounds or conditions for the likeness were stated and they called these enriched analogies. Take the example "activation energy is like a hill because you have to add energy to the reacting substances to start the reaction". In dealing with metaphors, Lakoff and Johnston (1980) call these conditions "entailments". Enriching the analogy does more than tell the student under what conditions the analogy holds; it tells the student that the analogy is about processes, about dynamic functions and not limited to superficial structures. Indeed, the difference between a simple structural analogy and an enriched functional analogy is the addition of some form of causation; that is, a simple analogy is descriptive whereas an enriched analogy is more explanatory. The recognition and mapping problems that Zook (1989) described can be reduced if the teacher explicitly alerts students to the analogical conditions. Our research (Harrison & Treagust, 1993, 2000) demonstrated that explicating the conditions for each analogy reduced the incidence of alternative conceptions.

The final analogy type identified by Curtis and Reigeluth is the extended analogy. Extended analogies contain a mix of simple and enriched mappings or all the mappings are enriched analogies. The "eye is like a camera" analogy is an extended analogy. The grounds on which an "eye is like a camera" are stated in each case and there are multiple shared attributes in the analogy (and some limitations or unshared attributes).

Simple Analogy	ANALOG		TARGET
Enriched Analogy	ANALOG	grounds (limitations)	TARGET
Extended Analogies		grounds (limitations)	
	ANALOG	grounds (limitations)	TARGET
	ANALOG	grounds (limitations)	
	ANALOG	grounds (limitations)	TARGET
	ANALOG	grounds (limitations)	

Figure 2. Simple analogy plus three levels of enrichment for textual analogies (adapted from Curtis & Reigeluth, 1984, p.111).

The eye is like a camera analogy is illustrated in Figure 3. This is a popular extended analogy; but as you peruse the analogy, think about this question: Is the eye an analogy for the camera or is the camera an analogy for the eye? Indeed, in the digital and video-camera age, has this analogy passed its use-by-date? We claim that out-dated, teacher favourite and idiosyncratic analogies can be responsible for many an alternative conception!

The problem with one-analogy-teaches-all was introduced in the critique of the water circuit for a simple series circuit. There are excellent reasons for using multiple analogies when explaining abstract concepts like electricity, atom and molecules, biological systems (e.g., circulation and ecology) and there are problems. On the benefit side, a class of teenage students will present many different interests and levels of prior knowledge and experience. Presenting a menu of analogies as Neil did when explaining chemical equilibrium (nine analogies in three lessons – see Table 3) provides the students with epistemological and ontological choice. They can use the analogy(s) that makes most sense to them to explore the difficult concept. But multiple analogies have a downside – students who think that there is just one right answer to every problem feel confused and wonder, "what is this teacher trying to do to me!" Without help, multiple analogies often lead to multiple alternative conceptions and the recommendation for individual analogy presentation applies equally to multiple analogy explanations: it is crucial for the teacher to summarise the analogies and interrogate students' understanding of the individual analogy and the collection of analogies. We cannot assume that students understand and appropriately map our analogies.

A Representation of an Analogy or Model

The concept or principle being taught

Analog Feature	compares with	Target Feature
1	compares with	1
2	compares with	2
3	compares with	3
n	compares with	n

CAMERA	is like the	EYE
variable aperture suits brightness		pupil size varies with light brightness
image recorded on the film		image on retina is sent to the brain
lens cap protects lens		eyelid protects the eye's cornea
can focus on near and far objects		can focus on near and far objects
black inside of camera stops reflections		black choroid coat stops reflections

CAMERA	is not like the	EYE
is limited to quite bright light		adapts to very low and very bright light
permanent single image		multiple non-permanent images
one image		two images give binocular vision

Figure 3. The camera is like an eye analogy

Electric circuits provide an excellent case for multiple analogies. Some of the analogies that can be used for current conservation include:

- A continuous train that travels a loop and picks up people at one station (the battery) and drops them off at another station (the globe). It is important to identify the train carriages as the current and the people as the energy.
- A bicycle's continuous chain transfers energy from the pedals on the gear wheel (battery) to the sprocket on the rear wheel (the globe). It is important to identify the likeness between the continuous chain and the wire carrying a continuous current.
- A conveyer belt picks up coal at the mine (the battery) and drops it into nearby railway wagons (globe).

- A role-play where a student collects jelly-beans from the teacher (battery) and walks around a circle of students (the circuit) giving jelly-beans to 3-4 students (these students are the globes).

Table 3. Neil's analogies in their order of appearance in the lessons on chemical equilibrium (see Harrison & de Jong, 2004)

Analog (familiar situation)	*Target (science concept)*
1. School dance – 500 boys, 500 girls in hall but only room for 250 couples to commit in the commitment room	Conditions for chemical equilibrium; couples committing and breaking up is continuous, rate committing = rate breaking up, and the hall is sealed
2. Up- and down-hill skier	Activation energy, energy input before energy output
3. Teacher with petrol and lighter	Teacher waving a lighter near a can of petrol illustrates the effect of adding activation energy – explosion!
4. Air flight including route details	Reaction mechanism, many steps produce the overall effect
5. Assembling a model aircraft	Reaction mechanism, many steps, some parallel like assembling two identical wings
6. Balancing on a see-saw	Physical equilibrium; force x distance balanced on each side
7. Being normal and insane	Physical equilibrium is like being mentally stable
8. Excess sugar in a teacup	Dynamic nature of equilibrium; cup sealed, rate dissolving = rate precipitating; process continuous, temperature dependent
9. Busy highway	Dynamic nature of equilibrium; rate cars entering = rate of cars leaving, collision rate is important

6. THE FAR GUIDE

Throughout this chapter we have warned that analogies are two-edged swords. When students are left to interpret analogies on their own, they can just as easily construct alternative conceptions as the desired scientific conception. All analogies break down somewhere and we demonstrated the alternative conceptions that can arise from misinterpretation of the water circuit for electric circuits and the eye is like a camera. All analogies have unshared attributes, they all break down somewhere and they usually break down sooner than later. This problem was well explained by Duit (1991) and Glynn (1991). Glynn therefore developed his six-step Teaching-With-Analogies (TWA) model and this model was evaluated by Harrison and Treagust (1993). Despite the apparent elegance of Glynn's model, teachers regularly forgot to implement one or more steps. This is understandable in a dynamic classroom setting with all the interruptions to which teachers and classes are prone. Based on their research with many schools, teachers and lessons, Treagust et al. (1998) proposed the Focus—Action—Reflection (FAR) guide. The FAR guide has three stages for the systematic presentation of analogies and resembles the planning phases of expert teaching and the action research model. The FAR guide is illustrated in Figure 4. When teachers present analogies using the FAR guide framework, it is our experience that students' scientific understanding is enhanced and the variety and frequency of alternative conceptions are diminished (Harrison & Treagust, 2000).

The FAR Guide for Teaching with Analogies and Models

Pre-Lesson FOCUS	
CONCEPT	Is the concept difficult, unfamiliar or abstract?
STUDENTS	What ideas do the students already have about the concept?
EXPERIENCE	What familiar experiences do students have that I can use?

In-Lesson ACTION	
	Check student **familiarity** with the analog
LIKES (mapping)	Discuss ways in which the analog is **like** the target
	Are the ideas surface features or deep relations?
UNLIKES (mapping)	Discuss ways in which the analog is **unlike** the target

Post-Lesson REFLECTION	
CONCLUSIONS	Was the analogy clear and useful, or confusing
IMPROVEMENTS	What changes are needed for the following lesson?
	What changes are needed next time I use this analogy?

Figure 4. The FAR guide or Focus—Action—Reflection approach for teaching with analogies (Treagust et al., 1998)

7. ANALOGIES – COMMUNICATION OR INQUIRY TOOLS?

Analogical knowledge is not strictly empirical knowledge and this raises several problems. When we use analogies, the analog—target similarities, called mappings, are classified as shared attributes (positive analogy) or unshared attributes (negative analogy). Mary Hesse (1963) proposed a third mapping called the neutral analogy. Neutral analogy can be a source of possible new relationships that raise questions and stimulate new research. But how do scientists judge the intelligibility, credibility and fruitfulness of the neutral analogy? Scientists who understand the positive and negative attributes of analogies will probably use this knowledge to evaluate the neutral analogy. But how was the now accepted positive analogy agreed on in the first place? And, if the new relationship suggested by the neutral analogy is useful (like Kekulé's snake biting its tail), is it new knowledge or is it just a better way of organising data and ideas already held in memory? And when does the scientific community accept discovery generated by analogy? Furthermore, when the theoretical edifice suggested by analogy is established by theory and experiment, is the analogy retained by scientists or only by educators? These questions suggest that there may be significant differences between the way scientists and teachers judge analogical knowledge.

The history of science also shows that a long time may intervene between the genesis of an analogical idea and the acceptance of the resulting theory. Bronowski claims that Kepler's ideas of planetary motion were suggested by the working of a clock, but many years separated the wheels revolving in wheels analogy and the acceptance of Kepler's laws.

So, who decides when an analogy becomes credible and fruitful and what operational criteria are used to make these decisions? In science, new knowledge is unique and deserves to be called a discovery; however, in science education knowledge that is new from the student's viewpoint can almost be axiomatic for the teacher. The philosophical distinction between research knowledge and education knowledge is important because many scientists also are university teachers. Scientists may wear different epistemological or philosophical hats when teaching and when researching science with analogies.

We propose that analogical knowledge may be better described as a thinking tool for scientists because analogy does not actually qualify as empirical knowledge. Indeed, Cosgrove (1995) demonstrated that analogy is an excellent thinking tool in school science provided the teacher understands the concept being taught and can guide his or her students in the inquiry process. As Cosgrove shows, the best analogies are student generated and in the absence of student analogies, teacher analogies that are multiple and presented in a format like the FAR guide can enhance learning. As we have argued in this chapter, analogy is a powerful way to think, construct ideas and test new knowledge. But someone in the process must know and understand the desired learning outcomes; otherwise, the likely result will be more alternative conceptions.

8. CONCLUSION

As we have illustrated in this chapter, on balance analogies are a friend to teachers and students alike but as we emphasise, analogies can be double-edged swords. In order that analogies are used as an effective tool in a science teacher's repertoire, knowledge about their pedagogical function is essential.

In its most elementary form, science teachers' knowledge about analogies should include:

- the suitability of the analog to the target for the student audience and the extent of teacher-directed or student-generated mapping needed to understand the target concept;
- an understanding that an analogy does not provide learners with all facets of the target concept and that multiple analogies can better achieve this goal;
- an appreciation that not all learners are comfortable with multiple analogies because the epistemological orientation of some is to expect a single explanation for a phenomenon.

Additional understanding of how analogies can be optimally used in class can be derived from the history of scientific discovery and from accounts of the ways experienced science teachers use analogies. We do not wish to claim that analogies used in science classrooms will necessarily improve both science teaching and learning. Still, research has compellingly demonstrated that, when used effectively, analogies are a valuable pedagogical tool in teachers' repertoires and this enhancement of practice is our aim in writing this chapter.

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JOHN WILLIAM WILLISON AND PETER CHARLES TAYLOR

COMPLEMENTARY EPISTEMOLOGIES OF SCIENCE TEACHING

Towards an Integral Perspective

1. INTRODUCTION

Over sixty years ago, Dewey reflected that the history of educational theory is marked by opposition (Garrison, 1995). It seems that this is true also of recent educational history where 'paradigm wars' are well established between proponents of the disparate epistemologies of objectivism and constructivism (and between those who favor one form of constructivism over another). Clearly, each of these epistemologies serves contrasting purposes in science education, with constructivism currently in the ascendancy in national curriculum frameworks.

However, relentless competition amongst theories may promote a tendency for science education to move through cycles of fashionable ideas, only to return ultimately to the starting point, resulting in teachers becoming cynical about the latest curriculum development 'fads' (Fullan, 1993). It may also contribute to a sense, especially amongst teachers, that educational researchers do not or cannot contribute significantly to 'real' educational issues within schools.

These are significant reasons for science educators to consider establishing an integral perspective which endeavours to unite otherwise disparate energies (Settelmaier & Taylor, 2001). In this chapter, we consider first divisive antinomies amongst proponents of single epistemologies such as objectivism and constructivism, and contrast this with a call for epistemological pluralism. Next, in the interest of generating more inclusive science teaching aimed at enhancing scientific literacy, we present an argument for uniting these seemingly divergent epistemologies. This involves using dialectics as a mode of reasoning and using metaphor as a key referent for pedagogical and curricular reform.

2. PRIVILEGE OR PLURALISM?

For over 25 years, the thesis of constructivism has challenged science teachers' traditional understanding of their classroom role as transmitters of objective knowledge. Proponents argue that the 'anti-thesis', objectivism, evokes an outmoded

P. J. Aubusson et al. (eds.), Metaphor and Analogy in Science Education, 25-36.

image of knowledge as an entity progressively accumulated and stored in memories and books. They argue that an objectivist view of learning uses an exclusive metaphor of knowledge transfer, which assumes a single (teacher) explanation can fit all receptive (student) minds. In sharp contrast, constructivist-inspired curricula reform calls for inclusive pedagogical practices that enable all students to 'make good sense' of their learning experiences.

Science education research has responded by developing constructivist-oriented teaching strategies for taking account of students' prior knowledge, interests and aspirations. Continuing developments in constructivist theory have highlighted the social context of learning, and the focus of constructivist-inspired teaching is shifting to the role of language and communication skills in building dialogical learning communities. From a critical social perspective, constructivism highlights the disenfranchisement of students under objectivism, and looks for evidence of the benefits of more socially inclusive modes of teaching and learning.

Undoubtedly the notion of a superior educational theory has an appealingly parsimonious quality. However, as Dewey reflected, the rancour that develops around the aggressive-defensive posturings of proponents of either side can be counter-productive. The science education literature is replete with the competitive voices of proponents of single epistemologies of teaching and learning. For example, Kragh (1998) has argued from an objectivist perspective that constructivism is philosophically unsound, has weak empirical support, is subversive to honesty and critical thought in general, and constitutes a frontal attack on the entire edifice of science. On the other hand, Guba and Lincoln (1989) have argued from an avowedly constructivist perspective that the objectivist paradigm needs to be replaced. This contestation also extends to constructivism where there is antipathy amongst proponents of various forms of constructivism.

In science education there is, however, an emerging agenda for epistemological pluralism, that is, for multiple epistemologies (theories of knowledge or ways of knowing) to be regarded as affording mutual perspective-building ways of informing us about student (and teacher) learning. It is our belief that a complementary perspective on the utility of contrasting epistemologies may help to achieve the elusive goal of a more pluralistic and tolerant community.

3. COMPLEMENTARITY

Postmodern curriculum theorists (Pinar & Reynolds, 1992; Slattery, 1995) warn that the philosophy of modernity has restricted our (Western) ability to reason by privileging Cartesian binary and dualistic thinking. When confronted by contradictions inherent in oppositional aspects of reality – male and female, body and soul, thinking and feeling – we automatically resort to well established modes of reasoning. The most common is domination and/or destruction, in which we try to control or eliminate the oppositional pole in order to eliminate the contradiction. This is evident in the contestation amongst proponents of opposing epistemologies in science education.

Yet, constructive postmodernism views the world as complementary and organic, and recognizes that the strength of the whole is derived from a respect for the contribution of each part. It allows us to seek unity-in-diversity without rejecting one of the parts or merging the parts into a new synthesis. We believe that dialectically complementary epistemologies — objectivism and constructivism (amongst others) – can provide a set of unique ways to enable students in science classes to make sense of the natural world. As we shall argue, each epistemology provides a different focus for learning, a different means of engaging in the process of learning, and a different set of possible learning outcomes. This integral perspective affords opportunity for students to learn about the nature of complementarity itself, that is, the philosophical (and socio-political) 'dance' between contrasting epistemologies, within science and without, down the ages and across cultures.

However, our argument for an integral perspective cannot rest solely on the principle of complementarity. There is another obstacle that we need to deal with: the tendency towards literalism.

4. METAPHOR

If, during a conversation, one speaker exclaims, "I see", when she actually means, "I comprehend", and the other turns to gaze in the same direction, then effective communication is restored only when the second person realises the metaphorical nature of the first person's comment and the inappropriate literalism of their own initial interpretation. Equally, if one chooses to use in a metaphorical sense the terms objectivism and constructivism, then communication will be difficult with those who use them in a literal sense. Indeed, we believe that a complementary view of these epistemologies is impossible if a literal view persists, especially one that entails a 'competing theories' notion of their relationship.

Through the lens of the literal we presume to see things as they 'really are', yet many (perhaps most?) of our concepts have metaphorical structurings because of the embodied structuring of mind (Lakoff & Johnson, 1999). Many everyday commonsense expressions – 'that's a clear argument', 'what's your outlook?', 'I've got the picture' – constitute a metaphorical mapping of our sensorimotor-based knowledge about human vision onto the domain of understanding or knowing. Whenever we conceptualise aspects of mind in terms of expressions such as 'grasping ideas', 'reaching conclusions', 'being unclear', or 'swallowing a claim', we are using metaphor to make sense of what we do with our minds. Indeed, we utilise a variety of metaphors that structure the way we conceive of mind: 'mind as body system', 'mind as builder', 'mind as computer', 'mind as container', 'mind as machine' and 'mind as person'. Some of these metaphors give rise to seemingly incompatible perspectives, yet each has a certain viability and currency in its usage (Ernest, 1995; Lakoff & Nunez, 2000).

Metaphor is central also to science. 'Science'—to know, may derive etymologically from a root word meaning 'to cut'—a 'knowing through cutting' (Klein, 1971). To say that scientists have been 'cutting into the fabric of the universe' is using metaphoric language to suggest that they have been doing experimentation or theorisation about the nature of the universe. However, to say that they are conducting 'scientific research into the nature of the universe' has a literal resonance which masks the metaphoric origins of the term 'science', thereby rendering it as a 'dormant' metaphor. Thus 'science' comes to be viewed no longer as a metaphor but as a literal term conveying a precise meaning.

Not only the origins of the concept, but the ongoing practice of science relies strongly on metaphor. 'Plum-pudding', 'solar system', 'wave' and 'cloud' have all been applied metaphorically, successfully or unsuccessfully, to the phenomenon labelled 'atom'. Diametrically opposed ways of conceiving of phenomena can and do co-exist because of fundamentally different metaphors. The wave-particle duality model of light is a classic example.

Metaphor is central also to the communication of scientific ideas. The register of science makes use of nominalising active processes. Verbs that describe observable processes, such as 'moving', 'refracting', 'gravitating', are transformed into nouns, thereby creating (fictional?) entities, such as 'motion', 'refraction' and 'gravity'. This linguistic process has been termed 'grammatical' metaphor (Halliday & Martin, 1993). The metaphorical basis of language and thought means that metaphor is not just an important conceptual tool, but is doubly-buried in the register of scientific English in its expressions and grammar. This implicit use of metaphor tends to make the scientific register seem like a foreign language, all the more bewildering because it seems in many respects to be familiar.

A hallmark of metaphor is that it dispenses with the proprieties of literalism and takes the risk of merging elements and discourses that are supposedly incompatible. The metaphorical impulse might thus be described as dialogic (Seitz, 1999). It is the discursive, risk-taking, merging-of-the-incompatible nature of metaphor that, we believe, provides it with the credentials to help facilitate multi-perspectival dialogue amongst proponents of the epistemologies of constructivism and objectivism. If science educators presently holding a commitment to a single epistemological perspective are willing to accept the metaphorical basis of not only their own epistemology but also of alternative epistemologies, then a complementary notion may gather momentum. But this dialogue can be fuelled only if we can demonstrate that objectivism and constructivism are metaphoric in nature, especially in the context of science teaching and learning.

5. METAPHORS OF CONSTRUCTIVISM

When Kelly used the term 'constructing', he referred to the action of building things that were apprehendable by the senses, such as bricks and wood, and carried it over to building thoughts. As such, it is clearly metaphorical (Spivey, 1997). An appeal of the metaphors of constructivism – making sense, constructing understanding, building ideas – is their dynamism, suggesting that mind is actively involved in manufacturing ideas. The term 'constructivism' has attracted numerous modifiers, and two of these are of interest here: personal and social constructivism.

Personal constructivism can be rooted either in the work of Kelly or Piaget, and focuses on the mindful activity of individuals engaged in making sense of the world. In science education, personal constructivism appears in two forms. The most popular form construes the learner as constructing mind-dependent understandings of natural phenomena. This 'weaker' form of constructivism fits comfortably (for many) with a view of established scientific knowledge (e.g., scientific laws) constituting a close approximation to the 'reality' of the natural world. From this realist perspective, absolute truth is approached asymptotically by science. In science education, the weaker form of personal constructivism has fuelled a fruitful research program into conceptual frameworks and misconceptions, and has been instrumental in the development of pedagogical models of cognitive conflict and conceptual change that serve to replace non-scientific views of the natural world with views consistent with the canonical knowledge of science. Associated teaching metaphors include assessment as a window into students' heads, and teachers as gardeners, tour guides and learning facilitators (Tobin, 1990; Roth & Roychoudury, 1994).

A stronger form of personal constructivism - radical constructivism - arises from the work of Piaget (and from the ancient Greek tradition of 'scepticism') (Steffe & Thompson, 2000). From this perspective, we construct our understandings of natural phenomena by reflecting not directly on the world itself but on our experience of the world, and so our resultant knowledge can be judged only in terms of its viability, or degree of fit with our experiences. Because our experiences include negotiating with others, our sense-making is meditated by the way others make sense of their experience of the same phenomenon. Thus the problem of extreme idiosyncracy (solipsism) is avoided as long as we negotiate meaningfully and sincerely. From this perspective, scientific knowledge can be judged only in utilitarian terms: does it work well for whatever purpose we have in mind? This is a pluralist (some say 'relativist') perspective that helps to provide an opportunity for discussing the viability of varying views on what constitutes a good or worthwhile purpose for science.

The term 'social' modifies the metaphor of constructivism to indicate the interpersonal dimension of knowledge construction, in which individual sense-making is understood to be mediated by social interactions (Tobin, 1993). In science education, social constructivism has enriched our pedagogical perspectives on classroom learning by promoting the importance of engaging students in dialogical activity, including collaborative learning and consensus building: 'learning as co-participation' is a typical metaphor. Coupled with the weaker form of personal constructivism, social constructivism is concerned with shaping 'microsocial' classroom activity, that is, with ensuring students are active participants in a dialogical community concerned with developing the canonical knowledge of science. This can be viewed as a process of (largely uncritical) enculturation into the worldview of science, an important process that prioritises the production of future scientists.

The stronger program of social constructivism arises from numerous sources, including, the new sociology (Berger & Luckman, 1966) and recent elaborations of radical constructivism, including cultural, critical and postmodern perspectives on the role of language, culture and politics in serving the interests of dominant societal groups (Cobern, 1998; Taylor, 1998; Taylor & Cobern, 1998). Critical pedagogies are beginning to emerge in science education, fuelled by ethical principles of cultural inclusiveness, fairness and equity. Science education researchers in indigenous communities embedded within Western nations are currently articulating culture-sensitive science curricula and teaching strategies (Aikenhead, 2000). Japanese science educators are arguing from cultural and linguistic perspectives that Western science should be taught as a foreign language in order to protect the integrity of traditional Japanese culture (Kawasaki, 2002).

Thus, at the heart of increasingly elaborated constructivist theory lies the metaphor of constructing. But what of objectivism?

6. METAPHORS OF OBJECTIVISM

The tricky thing about objectivism is that because, like science, it is a 'dormant metaphor' that has lost its metaphorical appearance it is usually taken literally. When we consider objectivism from a metaphoric perspective it loses much of its threatening dogmatism. Objectivism has as its root a noun, 'the object' (Sutton, 1993) which is pre-eminent and must be studied rigorously as though (metaphorically speaking) scientists can slowly, progressively and communally reveal an underlying reality. A basic tenet of objectivism is that communities of scientists can be confident that, by utilising certain methodological standards, they seem to be coming to increasingly more accurate knowledge about phenomena in the world; seeing them more clearly, perhaps.

Indeed 'knowing as seeing' is a common metaphor associated with both objectivism and constructivism. With objectivism the seeing metaphors are suggestive of 'uncovering' facts and making knowledge 'discoveries'. 'Understanding' is a metaphor associated with taking a (sensory) position from beneath, with the implication of looking up (at the underside) of something. 'To come at it from another angle', a metaphorical expression of how to understand something, gives greater weight to the object in view, as if a partial circumnavigation is required in order to reach a different vantage point from which to more clearly see the object. 'Point of view' is a metaphor for opinion – the viewing point determines the view – yet the phrase has been widely construed to mean 'the view itself'. So, despite the pre-eminence of the object in objectivism, understanding the object is clearly perspectival.

In terms of the learning process, objectivism gives rise to metaphors of 'knowledge as an entity' and 'knowledge as transferable' – which fit a conduit or pipeline metaphor suggestive of communication as an exchange of ideas, as though (metaphorically speaking) ideas can be placed into students' well-prepared minds. These knowledge metaphors relate closely to Lakoff and Johnson's (1999) 'thinking as object manipulation' metaphor, in which ideas are regarded as objects that can be played with, tossed around or turned over in one's mind; thus, to understand an idea is (metaphorically speaking) to grasp it, to have it firmly in one's mind.

Roth and Roychoudhury (1994) have claimed that objectivism is the default epistemology for children in Western schools because it is the only epistemology available. What we are suggesting is that if the concept of objectivism is understood in metaphoric (rather than literal) terms, it may have a legitimate role as a (but certainly not 'the' only) referent for shaping the teaching of science. Indeed, it may be legitimate at times to teach as though knowledge is transferable, as though reality is being uncovered, as though ideas are objects (metaphorically speaking, of course). The pedagogical challenge is to justify the conditions under which objectivist metaphors should be used as pedagogical referents; the key question being: 'for what well-justified pedagogical purposes'?

A further interesting question concerns the interaction between the metaphors of objectivism and constructivism: under what circumstances can they co-exist? We have already indicated that the weaker constructivist program is compatible with objectivist metaphors and that they are likely to be alive (albeit perhaps unwittingly) in the teaching of reform-minded science educators employing conceptual change strategies. On the other hand, it seems unlikely that the strong program of constructivism is compatible with objectivist metaphors, but is this because this program is taken literally rather than metaphorically? Or is there something intrinsically incompatible about some of the metaphors of constructivism and objectivism? Do they, perhaps, have distinctively different domains of applicability? Or perhaps our dualist thinking is getting the better of us, and a dialectical rationality is needed to hold apparent antinomies in tension, perhaps seeking a higher order synthesis. Such a perspective is compatible with Wilber's (1999) integral philosophy which holds that any phenomenon can be understood from four distinct perspectives (arranged in his 4-Quadrant Model) – subjective, intersubjective, objective, interobjective – each of which has its own particular truth claim; none is privileged, each provides a unique and legitimate understanding of the world (Settelmaier & Taylor, 2001).

So how can complementary metaphors be developed for science education?

7. SCIENTIFIC LITERACY AS COMPLEMENTARY METAPHORS

A recent interpretive case study of Year 8 science teaching and learning was conducted with the aim of identifying factors that influence students' engagement in learning science (Willison, 2000). The research was motivated by a concern to overcome obstacles to equity of access amongst students to 'scientific literacy', a term that has many meanings in the literature extending back over 30 years. During the one-year period of fieldwork, a recursive process of analytic induction was undertaken in which data analysis informed and was informed by ongoing reviews of the extensive literature on scientific literacy (Erickson, 1998). Three metaphors emerged from this process and provided somewhat of an integral framework for interpreting the learning experiences of students who were tracked throughout their school day: 'student-as-recruit', 'student-as-judge' and 'students-as-scientists'. Each metaphor gives rise to a distinct epistemological view of pedagogical goals and students' classroom roles (Willison, 2000).

The metaphor of student-as-recruit emphasises students accessing and appropriating canonical classroom-science (i.e., content and skills), and is most closely aligned with the epistemology of objectivism. Students work in labs on prescribed 'cook-book' tasks, designed primarily to illustrate scientific theory and to develop important practical skills associated with doing science. This form of teaching is well aligned with the non-inclusive goal of preparing an academic elite for entry into the professional field of science (and science teacher education).

Student-as-judge is a metaphor that emphasises individual students' evaluation of the knowledge claims of classroom-science. Ultimately, students are persuaded one way or the other about the validity of a scientific claim, however to be recognised as participating in this manner the student needs to manifest some type of judgement about a classroom-science notion being presented by the teacher. The focus of this metaphor is on the sense-making activity within the mind of the individual student, and is aligned with the epistemology of personal constructivism.

Students-as-scientists is written in the plural because the metaphor emphasises social (constructive) processes in the formation of scientific literacy. This metaphor is demonstrated when students develop their own knowledge claims about phenomena and attempt to persuade others about the validity of their claims. Developing their own knowledge claims involves asking their own questions, devising their own experiments, producing their own results and conclusions, and engaging in reflective discourse on the viability of their knowledge and the way it was generated.

The viability of the three-metaphor framework was established by using it to organise a representative selection of the research literature on scientific literacy, dating back to 1972. Of 44 articles analysed all but two contained definitions of scientific literacy that fitted the three-metaphor framework.

8. COMPLEMENTARITY LACKING IN PRACTICE

A year of participant-observation in two Year 8 junior high school science classrooms in a government, inner-metropolitan school in Perth, Western Australia, revealed that students were engaged almost always in enacting the role of recruit (Willison, 2000). In science labs it was unusual to observe anything other than relatively closed investigation tasks in which problem, method and solution were largely predetermined by the text book. Students learned (implicitly) to ignore their 'errant' methods and 'ill-fitting' observations in order to ensure that they were assessed by the teacher as having confirmed classroom-science canonical knowledge and to have conformed closely to its standard discourse practices.

On occasions, a student was seen to be functioning in the role of student-as-judge, especially when judging the classroom-science to be at odds with his/her own life-world experiences. For example, Shelly had observed her father welding and had noticed how the welding material had 'shrunk' into the gap after being heated. From this experience she inferred that metals shrank when heated (as magnesium ribbon appears to do when burnt), and she applied this tenacious understanding to explain the famous heated 'ball and ring' experiment. She argued that when heated the ring 'shrank outwards' thereby allowing the ball to pass through! However, Shelley's science teacher failed to probe her ideas when she offered them in class discussion. After much frustration, Shelly eventually 'accepted' the classroom-science canon that metals expand when heated, although further research revealed that she did not believe her teacher or fellow students, and concluded that "Science is stupid, 'cause you don't know if you're right!". A more epistemologically astute teacher may have encouraged Shelly to voice her alternative ideas, along with those of other students, and managed a discussion about their viability, perhaps discovering appropriate life-world contexts in which students' alternative ideas make good sense.

On one occasion during the year, students were involved in an open investigation into parachutes, which presented an opportunity to enact the role of students-as-scientists. Shelly seized the opportunity, designing, conducting and reporting persuasively her own experiment. Because parachutes were of interest to her out of school, she designed a unique investigation into the relationship between parachute shape and time of fall, keeping constant the surface area, weight and drop height. Most students chose to investigate the simpler relationship between drop height and time of fall (suggested by the teacher). Although she was constrained to work individually, Shelly displayed some important hallmarks of the students-as-scientists role inasmuch as she developed a genuine and relevant research question, enjoyed ongoing freedom of experimental design, generated empirical data and accounted for invalid readings, and reported persuasively about her knowledge claims in terms of classroom-science criteria (i.e., controlled variables, use of mathematical equations, repeat trials, and a null hypothesis).

It is interesting to note that Shelly's success in the students-as-scientists role was dependent, in part, on her student as recruit skills. Bordieu and Wacquant (1992) have argued that "historians and philosophers of science, and especially scientists themselves, have often observed that a good part of the craft of the scientist is acquired via modes of transmission that are thoroughly practical" (p.223). Thus, utilising the students-as-scientists metaphor may help facilitate student learning of classroom-science knowledge, thereby enhancing the role of student-as-recruit. Greater scope in the science class for enacting the roles of student-as-judge and students-as-scientists might provide more meaningful learning activities for a greater range of students as well as enabling students to develop richer (more complex) understandings of the nature of science.

9. TOWARDS AN INTEGRAL PERSPECTIVE

However, we acknowledge the limitation of the three-metaphor framework that tends to promote a narrow view of the aim of science education as enculturation into a canonical science worldview. This limitation arose in this study from the narrow range of epistemological perspectives embedded historically in the literature of scientific literacy (mostly objectivism and the weak program of constructivism) and from empirical inquiry into the restrictive practices of two science teachers. When we think more broadly about an integral approach to science education, one that promotes cultural pluralism, we are thinking about visionary pedagogies that include epistemologies of objectivism and constructivism, especially the strong program of constructivism.

A good example of a potentially integral metaphor is Aikenhead's (2000) notion of 'learning as concept proliferation'. This metaphor was developed from a concern to create a culturally inclusive curriculum of school science for First Nations communities in Canada. Whereas the popular pedagogical model of conceptual change tends to support a view of learning science as 'one-way border crossing', in which indigenous children's non-Western cultural knowledge is replaced by the cultural knowledge of Western (school) science, concept proliferation allows indigenous students' life-world concepts to exist alongside scientific concepts, thereby helping to promote their development as 'two-way border crossers'.

We find it exciting to imagine future possibilities for epistemological pluralism in science classes where potentially integral metaphors, such as 'learning science as concept proliferation' and 'learning science as a foreign language' (Kawasaki, 2002) (and others yet to be conceived) are employed by astute teachers to enrich the learning environment and provide students with the confidence and skills to deal critically and creatively with the dialectical tension between their growing scientific objectivity and evolving cultural identities.

10. IN CLOSING

In responding to Dewey's call to approach conflict in education from 'a level deeper and more encompassing', we feel that it may be better to background the notion of 'theory' because it tends to evoke a competitive and mutually exclusive standpoint. For many years under the auspices of objectivism or constructivism, science education researchers have fortified their respective research programs and refuted competing theories. The competition is understandable when 'theory' is the underlying conception of the nature of these contrasting epistemologies.

We have argued in this chapter that metaphor, rather than theory, has the capacity to facilitate an integral perspective by allowing divergent epistemologies to be perceived as complementary, as united in diversity. In this vein, Lakoff and Nunez (2000) argue that "each mode of metaphorical understanding has different uses. And each is precise in its own terms – But you do not have to choose. As long as you keep your metaphors straight, you can use whichever is most useful for a given purpose" (p.374).

We propose the somewhat controversial view that objectivism and constructivism are metaphorical in origin and substance, that each is significant, and that together they are not mutually exclusive, but rather can provide different viable and valuable understandings about science teaching and learning (and the nature of science). In making explicit the metaphorical bases of these divergent epistemologies, and arguing for a mode of reasoning involving dialectical complementarity, we hope to contribute to a more productive dialogue amongst the proponents of single epistemologies in the science education community.

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JENS WILBERS AND REINDERS DUIT

POST-FESTUM[1] AND HEURISTIC ANALOGIES

1. INTRODUCTION

Analogies have proven powerful tools in generating insight and understanding. However, analogies may also deeply mislead – scientists as well as learners. It appears that this two-sided nature of analogies relates to the following fundamental features of teaching and learning. Students make their own sense of material provided by the teacher as learning aids, and this is especially so with analogies. From the teacher's perspective, analogical relations between base and target domains of analogy properly rest on subject matter structure. They rely on propositionally based knowledge. Students however, interpret base and target domains in fundamentally different ways. Learning by analogy rests on visual perception. It traces a line of concrete visualisation and abstraction by transcending the concrete in a second step. To put it in a nutshell: a student's heuristic analogy is built on mental images rather than propositionally based knowledge (as opposed to the teacher's post-festum analogy). Hence, students seem determined to construct analogical relations other than the teacher's. Using analogies, then, is not simply a process of transferring certain structural features from the base to the target but a process of constructing the analogical relation the teacher aims at.

[1] Post-festum analogies are analogies that are constructed by the teacher from canonical knowledge and are used for the purpose of explaining scientific phenomena.

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2. A THEORY OF ANALOGICAL REASONING

analogical relation
base domain <=========> target domain

Figure 1. Analogy: Relation between base and target domains of analogy

A widely accepted definition determines analogy as a similarity between two domains commonly called base and target domain (Figure 1). The conclusion suggests itself that analogical reasoning is a matter of comparing their similarities. In fact, most theoretical frameworks for analogy and analogical reasoning are based on this assumption which will be questioned in this section. The predominant and most prominent of these frameworks are Gentner's "Structure-Mapping Theory" and Holyoak's pragmatic approach.

2.1 Common characteristics of theoretical frameworks for analogy

The process of analogical reasoning is usually divided into three distinct subprocesses called *access*, *mapping* and *generalisation* (Vosniadou & Ortony, 1989, p.7). From this theoretical viewpoint accessibility of analogy is governed by surface similarities but not by higher-order structures. The propositional structure of analogy is accessed through the mostly unstructured surface of the obviously similar but actually irrelevant. The mapping process is based on mental representations of both base and target. They are mentally represented in their propositional structure whereas the depth and complexity of the base's representation exceeds that of the target's. In principle, mapping is seen as a comparison of similarities between both representations. In Gentner's approach the focus is predominantly on carry over of propositional structures while Holyoak's (1985) pragmatic structure mapping approach also takes account of contextual factors. However, both approaches share the view that mental representations of propositional structures of base and target are crucial for analogical reasoning. The mode of drawing conclusions from base to target is essentially based on formal logic and the logical equivalence of features in both representations (Gentner, 1989, p.210). Moreover the learner making use of an analogy draws on means of assessing the heuristic power of conclusions drawn by analogy. Mapping is exclusively conceptualised as a transfer from base to target. In other words, the symmetrical nature of the analogical relation is not explicitly employed. Generalisation is a matter of abstraction targeting a new concept as the learner builds a new concept by leaving aside the irrelevant surface similarities and the non-analogical structural features.

2.2 Post-festum and heuristic analogies: a kernel of a revised theoretical approach

Each time analogies are involved in the understanding of complex and abstract subject matter they potentially serve different objectives. Analogies may function as a means of illustrating abstract concepts and principles vividly. Their communicational intent may be to impart insight and knowledge. In this way, analogies become an important educational tool in class. If a teacher generates an analogy for these purposes the aim of analogy construction is just as well known to him as the concept the analogy is supposed to illustrate or the theory that it is based on. A student, however, who is confronted with a conceptual analogy finds himself or herself in a completely different situation. He or she is totally ignorant of the scientific concepts and principles at which the analogy aims. Therefore the teacher's use of analogy (e.g., generating an analogy in order to illustrate a concept well known to him or her) will presumably be different from the student's (e.g., searching for an analogy in order to approach an unknown phenomenon). Consistent distinction between the teacher's *post-festum analogy* and the learner's *heuristic analogy* builds the framework for our theoretical considerations. The two terms denote the different psychological processes the teacher and the student go through when making use of analogies. (Post festum [lat.]. Phrase denoting that something happens afterwards. In our case, generating an analogy after having constructed the conceptual framework at which an analogy aims.) This distinction is missing in present theories of analogical reasoning (Gentner & Medina, 1998). In the subsequent section we would like to outline a few arguments in favour of this dichotomy which touch on the epistemological, communicational and psychological dimensions of analogy.

2.3 The epistemological dimension of analogy

The heuristic aim of analogy is a theoretical approach to a yet unknown phenomenon. The target is the ontic object that produces this phenomenon. Generally speaking analogy is the solution to the problem that Plato posed in his famous *paradox of the meno* and which Bereiter (1985) called the *learning paradox*. It is our thesis that analogy is a central way of leaping the epistemological gap between the already known and the yet unknown. In a "pretheoretical phase" a heuristic analogy allows the formation of hypotheses without having constructed a settled theory. The base is some sort of "proto-theory" that is available as a way to model the target. This holds as well phylogenetically for scientific enquiry as it does ontogenetically for individual learning. As a heuristic means, the analogy enables the scientist to plan experiments and to generate expectations with respect to their outcome by tentatively transferring theoretical aspects from the base to the target domain. In a similar way, students are enabled to make theory laden observations when confronted with yet unknown phenomena. Currently employed theoretical approaches to analogical reasoning presuppose that the learner is able to evaluate the quality of his or her analogy based inferences. Gentner's structure mapping theory for example proposes a so called *systematicity principle* conveying analogical matches of high validity (Gentner, 1989). From our point of view these considerations pay only limited attention to the creative aspect of analogical reasoning. A heuristic analogy aims at the construction of analogical relations rather than the detection of objectively and antecedently existing correspondences. It is deeply utilitarian in the sense that it treats some unknown target phenomenon as if it were quite like the base in order to guide empirical action and to yield well-directed hypotheses predicting its outcomes. Or to put it in simple words: analogical transfer does not answer questions, it helps to ask questions. The answers to these questions are beyond analogy. In the case of scientists, they are solely given by experiment. The student relies on observations as well as on the teacher and classmates.

As a proto-theory the heuristic analogy can be seen as a way of overcoming the epistemological chasm between the familiar and the radically new knowledge. If an analogy has proven to be applicable and powerful, it contributes to a modelling of the target phenomenon or the construction of a target concept, either of them paving the way to a comparison of similarities between base and target. Following the above terminology this solely holds for post-festum analogies. If the target concept is not yet canonical or unknown to an individual learner, analogy is not a matter of comparison. Or to put it the other way round: similarity is not the starting point of a heuristic analogy, it is the structure at which the process of analogical reasoning aims. This disagrees with Gentner and Medina (1998) as well as Holyoak (1985) who consider analogical reasoning to be a process of comparing base and target in general and regardless of what the mode of analogy construction is.

It is commonly assumed that analogy is a form of induction (Holyoak & Koh, 1987; Seel & Dinter, 1991). Opposed to this, Bunge (1973) points out that analogies cannot be a source of inductive inferences. Induction is a method to test hypotheses. Heuristic analogies do not test hypotheses antecedently but allow them to develop. Analogical transfer is not amenable to any theoretical systematisation. There is no such thing as the logic of analogy. This in fact makes analogical transfer error prone at its heart. Bunge admits that analogies in fact may be powerful tools but he also claims that "a negative history of science, one recording failures rather than successes, might show that analogies are as often misleading as they are fruitful" (p.126). It is none the less obvious that in the history of science the successful and prolific use of analogies is prominent. Fourier's theory of heat conduction as well as Carnot's theory of the heat engine are based on an analogy to the flow of water. Fourier's theory then was adopted by Ohm when he developed his theory of electricity flow. Huygens developed his wave-theory of light by analogy to the already established wave-theory of sound (Mach, 1910). To treat the phenomenon of light as if it were quite like sound-waves is different from comparing sound- and light-waves. Only in the latter case can you rely on an empirically tested wave-theory of light, which allows you to estimate post festum the soundness of analogical transfer. In the case of heuristic analogies inferences lead to the assumption that something might be the case. Inductive inferences show that something is actually reliable. The nature of heuristic analogical transfer is associative, as Mach (1920, pp.15-16) pointed out. Association though, is a creative process that extends beyond normativity.

2.4 The communicational dimension of analogy

Especially in educational contexts, analogies also serve a communicative function. This implies that analogies can be treated as signs in a semiotic sense. Gentner (1983) as well as Holyoak (1985) implicitly presuppose the idea of analogies as signs. They both share a representational conception of signs (Wilbers, 1999). According to a representational semiotics, analogies work as a means of communication in class because they represent certain ideas, concepts, notions or models. Tracing back to the work of Morris (1955), representational semiotics regards signs as three-dimensional objects, which have a semantic, a pragmatic and a syntactic dimension. Basically the theoretical approaches of Gentner and Holyoak emphasise different facets of analogies as signs. Gentner stresses the syntactic aspect of analogy whereas Holyoak highlights its pragmatics. Within a representational framework communication is regarded as the transmission of information passed on to the other by means of signs which function as representations. Applied to the use of analogies in class this means: the teacher “wraps” a certain idea or concept into a conceptual analogy and thereby encodes information. By unwrapping or decoding the information the students receive and thus learn the ideas and concepts at which the analogy aims. From this point of view analogies are “containers” for the purpose of transporting ideas. This of course meets the information processing model of cognitive psychology held by Gentner as well as Holyoak. From a constructivist perspective a model of communication like this is problematic. Signs do not contain information. They do not work on the basis of packing, sending and unpacking conceptions and ideas.

From the viewpoint of an instrumental semiotics (Wittgenstein, 1969; Keller, 1995) the primary function of signs is to be interpreted. Analogies work as a means of communication in class because they can be interpreted by students. Thus communication is an inferential process. Basically two different kinds of inferences are involved in communicational processes (Keller, 1995, pp.113-114). If we are confronted with radically new material (word, phrase, metaphor, analogy, etc.) we tend to draw associative conclusions. If we face well known material, which is so to speak, “lexical” to us we draw rule-based conclusions. In class, analogies are an instrument of teaching and learning scientific concepts. If students make use of heuristic analogies, they have not yet formed the concepts that shall be learned via analogy. Conceptual analogies are a learning aid that they can make use of by making associations. Via associative inferences they successively form analogical relations which are conceptually generalised in the course of the heuristic use of analogy. Beyond the heuristic analogy analogical inferences gain a new quality. The user of an analogy is now able to make rule-based inferences from an abstract concept the analogy represents to commonalities between base and target. The analogy is not a heuristic tool anymore and has turned into a post-festum analogy that serves communicational and explicative purposes rather than heuristic ones. From now on propositionally based knowledge that has emerged from the heuristic use of analogy guides analogy use. From a heuristic perspective analogical inferences are associations, whereas from a post-festum perspective they are rule-based inferences. In recent years Gentner and Medina (1998) have highlighted the significance of rule-based processing for analogical reasoning. It appears that in Gentner's approach the post-festum-perspective is somehow dominant. Further hints to this thesis can be found in the subsequent section.

2.5 The psychological dimension of analogy

Currently employed theoretical approaches emphasise the role of propositionally based knowledge in analogical reasoning. The above considerations suggest that propositionally based knowledge is solely employed in the construction of post-festum analogies. The rule-based inferences of the post-festum analogy operate on propositional structures. In accordance with various other authors we expect non-propositional knowledge based on visual imagery to be of the essence in the heuristic use of analogies. Zeitoun (1984) underlines the significance of visual imagery for analogical reasoning and mental images, so mental models seem to be of the essence. Clement (1993) takes regard of abstract imagery that he calls *intuitive schemata*. Sfard (1994) shares the view that *image schemata* are crucial for analogy use while Lakoff and Johnson (1980) and Johnson (1987) arrive at equivalent terms with respect to metaphors using the notion of *embodied schemata*. Taking a cognitive point of view, analogy hinges on pictorial rather than on propositional elements of cognition, such as intuitive schemata, mental images, mental models, etc.

From a developmental perspective the way analogies are constructed either depends on general cognitive abilities (and thus age) or expertise in the field in question. According to Vosniadou (1989) it is not the mechanisms of analogical transfer that develops but the conceptual structures on which they operate. She thereby opposes Gentner (1989, p.223) who assumes "a developmental shift from attributional focus to relational focus in production, choice and rating of analogy interpretations" (*relational shift*) from childhood to adulthood. Our theoretical considerations propounded in this chapter, support Vosniadou's thesis. The mode of analogy production changes if the concept the analogy represents has already been formed. This basically holds for experts as well as for novices. It applies phylogenetically to the development of conceptual systems and models in scientific inquiry and ontogenetically to individual learning processes in science classes. The consistent distinction of *post-festum* and *heuristic analogies* expresses this on a conceptual level. With regard to:

1. epistemology, students' heuristic analogies are not a matter of comparison.
2. semiotics, they are not a product emerging from the transmission of information from the teacher to the students.
3. psychology, they are not a process based on propositional knowledge.

We already hinted at the fact that Gentner's structure-mapping approach presumes various features and mechanisms of analogical reasoning in general that strongly relate to our notion of post-festum analogies. Superordinate concepts and conceptual systems make the source and target examples which can be compared to each other. Relevance and appropriateness of analogical transfer may be assessed on the background of conceptual generalisations. Propositional knowledge and rule-based inferences appear to be the very essence of post-festum analogies. But in order to understand the use of analogies in science learning, heuristic analogies should be taken into consideration.

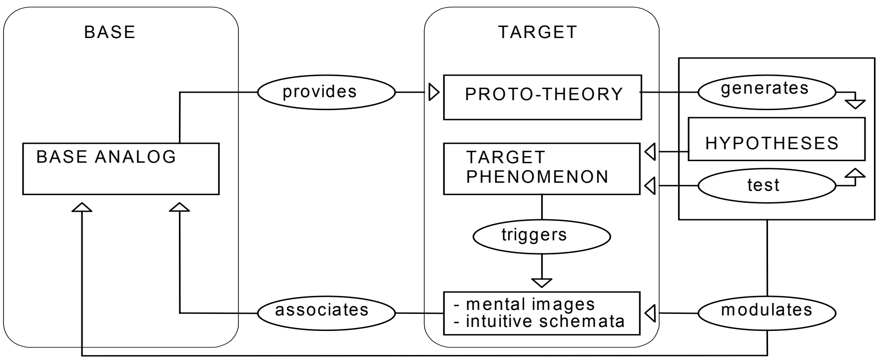

Figure 2. The heuristic analogy: a model of analogical reasoning

Both Gentner's structure mapping and Holyoak's pragmatic approach consider propositionally based knowledge as a starting point for analogy use. As an alternative our revised model of analogical reasoning (Figure 2) claims that intuitive schemata and mental models spontaneously generated by the students when first confronted with the target phenomenon are of the essence in analogy use. They lead to a preliminary associative link between target and base. The subsequent process of analogy construction is guided by these spontaneously generated associations. Or to put it the other way round: the analogy is a means of constructing (propositionally based) hypotheses on the basis of (image like) mental models and intuitive schemata triggered by the target phenomenon. This process of analogy construction which serves a heuristic exploration of the target draws on a better known base analog which provides some proto-theory for the yet unexplored target. This implies that analogies are more of a tool to bring about hypotheses instead of supporting them. The support of hypotheses is a matter of empirical testing and beyond analogy use (Bunge, 1973).

3. A STUDY IN THE DOMAIN OF LIMITED PREDICTABILITY OF CHAOTIC SYSTEMS

The above views of differentiating heuristic and post-festum analogies emerged from the analysis of students' learning processes when they investigated a chaotic pendulum. The major results are summarised in the following to illustrate the significance of the model presented in Figure 2.

A variant of the *teaching experiment* proposed by Steffe and D'Ambrosio (1996) was employed. These teaching experiments draw on Piagetian critical interviews where the interview situation is deliberately turned into a teaching situation from time to time. Instead of interviews with single students a small group setting of four students was employed. Twelve groups of four students (German Grammar school; average age 16) were "interviewed" in two sessions of about 120 minutes each. All sessions were video-taped and transcribed.

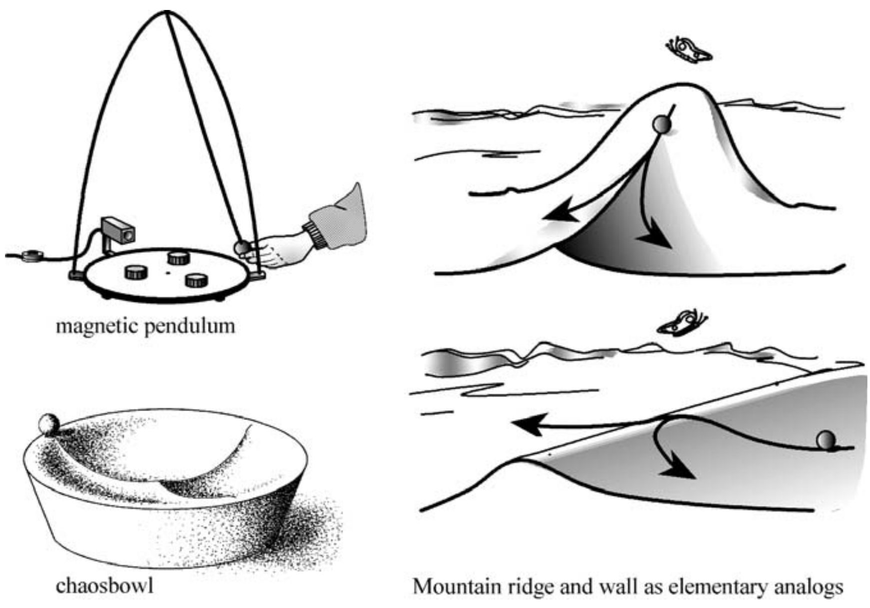

Figure 3. The chaotic pendulum and analogies to explain its behaviour

The focus of the sessions was on investigating a magnetic pendulum as shown in Figure 3. Even if the pendulum is repeatedly released from the same starting position the trajectories diverge and one cannot possibly predict the magnet over which the bob will come to a rest. Briefly put, its chaotic behaviour is caused by zones of unstable equilibrium (the Y-like figure between the magnets where the magnetic forces to the right and left balance out) that are passed by the pendulum bob several times. Such sensitive zones are typical of chaotic systems. The analogical relations investigated by students represent the unstable equilibrium in various artefacts such as a chaos bowl or dice. Students are given much time in quasi-open-inquiry sessions to construct their understanding of the magnetic pendulum. At a certain point of time the two elementary analogies shown in Figure 3 (ridge and wall situation) are presented as drawings. A computer simulation program which allows students to investigate the behaviour of the pendulum in an ideal world is also employed. It offers the opportunity to inquire into its motion under identical starting conditions and without noise disturbing its motion.

The corpus of data comprises video-transcriptions and all artefacts produced by the students during class. There also were homework assignments between the two sessions. Standard methods of qualitative content analysis were used (Guba & Lincoln, 1989). A particular focus was on constructing students' intuitive schemata about the zones of unstable equilibrium. Another focus was on their ways of talking (i.e., their dictions) about chaotic motion. These schemata and dictions were interpreted as hints to mental images the students held with respect to the dynamic of chaos.

4. INTERPRETATIONS

The study confirms that analogies *can* be powerful tools in guiding students towards an understanding of the principle of limited predictability. The theoretical and methodological setting of the study allowed us to construct a fine-grained picture of analogy use, that is, a micro-level description of the role of analogies in learning about chaos theory. In accordance with our theoretical considerations we focused our data analysis on the role of intuitive schemata and mental images for analogy construction and the heuristic use of analogies. Indeed, the intuitive schemata students hold of the notion of unstable equilibrium and the mental images of chaotic motion seem to play a crucial role in analogy use. They both directed the ways the students in our study made use of presented conceptual analogies (e.g., Figure 3).

Space limitations, however, prevent the presentation of references from our data which substantiate the claims made in the subsequent section. Further details and abundantly discussed examples from our data are presented in Wilbers (1999). Key features of the intuitive schemata and dictions derived from the study are outlined below. These are then used to suggest processes of analogical reasoning.

4.1 Intuitive schemata of unstable equilibrium

Data analysis led to the following types of students' intuitive schemata of unstable equilibrium. Every schema includes a particular conception for explaining limited predictability.

- *Zones of decision.* When the system encounters a sensitive zone it has to decide where to go so to speak. Its decisions are random and hence non-predictable.

- *Neutral zones.* There are no forces acting on the ball: Hence small disturbances, predominantly those occurring when the ball is in a neutral zone, determine its future path. As it is impossible to foretell the disturbances the future path is unpredictable.

- *Dividing lines.* Many students are of the conviction that the lines of unstable equilibrium (forming the Y-like lines in the case of the magnetic pendulum) are basically borderlines for the fields of the single magnets, where the one field ends and the other begins. It is interesting that chaotic behaviour does not need any explanation for the students holding this view. It is presupposed in order to explain the random sequence of target magnets. Accordingly the analogies provided are not used in the intended way (for an explanation of chaotic motion).

- *Zones of topple over.* In such a zone, the direction of an object's further motion is random. Chance alone is seen as a generating "force" for future behaviour.

- *Sensitive zones.* This intended view includes that small changes of starting conditions and small disturbances result in small changes of the path the pendulum bob as it passes the zones of unstable equilibrium. If one compares two subsequent paths they more and more deviate when the sensitive zones are passed. At one of the passages it happens that they totally deviate. Only a small number of students in our, study was able to proceed this far in their understanding.

4.2 Dictions according to the dynamic of systems

Second, we analysed students ways of talking about a system's dynamic. We identified the following patterns of diction:

- *Static.* Explanations include the starting point and the target magnet but not any discussion of the trajectory of the moving pendulum bob.

- *Animistic.* Especially in the beginning a remarkable number of students use animistic dictions. However, they do not appear to hamper understanding but merely serve as first heuristics.

- *Dynamic - local.* Among the dictions that include arguments concerning the motion of the pendulum bob there are several students focusing on the behaviour at certain points, e.g., in zones of unstable equilibrium. Local arguments are either animistic or include force arguments (which are often not in complete accordance with the scientific concept).

- *Dynamic - global.* This diction is the intended. Two or more trajectories are compared. Main emphasis is given to the significance of local changes for the development of trajectories.

4.3 Processes of analogical reasoning

The particular intuitive schemata and dictions deeply influence the processes of analogical reasoning we observed. With regard to our attempts towards a revised theory of analogical reasoning we would like to emphasise the following findings:

- Gentner's theory holds that access to analogies as learning aids is predominantly facilitated by surface features. In contrast, a number of cases in our studies show that access is also possible via deep structure similarities between base and target.

- Gentner also emphasises the key role of propositional representations of base and target in the mapping process. There is much evidence in our data that such mapping often does not come about even if students are familiar with the base and should understand it in the appropriate manner. The essential key to engagement in a mapping process in Gentner's sense appears to be students' mental models and dictions of base and target. If students exhibit different frames of mental models regarding the unstable equilibrium and employ different dictions describing a system's motion for base and target, transfer does not take place.

- The mapping process from the perspective of Gentner's and Holyoak's theory of analogical reasoning is exclusively a process from base to target. In the present study and previous studies students usually make use of the symmetrical nature of the analogy relation. In other words, they often switch the roles of base and target, i.e., view the base from the perspective of the target and vice versa.

- Approaches of analogy use in instruction usually hold that intimate familiarity with the base is essential (Duit, 1991). In accordance with findings by Corkill and Fager (1992) there are several cases in our data of students who are familiar with the base and nonetheless do not engage in a mapping process. As mentioned, this occurs if students view base and target within different mental models and dictions and hence do not see the potential explanatory power of the base with regard to the target. But this may also happen if base and target are seen from the perspective of the same (or at least similar) mental models and dictions. In this case students may be pleased with the similarities between base and target they constructed and hence do not feel the need for further search of similarities.

5. DISCUSSION

The model of heuristic analogies (Figure 2) is grounded on theoretical considerations as outlined in this chapter as well as on pilot studies. It has provided a viable framework for the analysis of the present study which is based on 12 teaching experiments with 48 students in the domain of understanding chaotic behavior. Moreover it is supported by the findings of previous learning process studies in the same domain (Duit, Komorek, & Wilbers, 1997; Duit, Komorek & Wilbers, 2001). Nonetheless it is preliminary. Further research is necessary to investigate its validity for analogy based learning processes in general. Its applicability beyond the field of learning about chaos theory has not yet been tested. Moreover the data corpus it has been applied to so far is very limited. If further studies support the model, significant changes of instructional strategies of analogy use like Glynn's (1989) "Teaching-with-Analogies model" (TWA) or the FAR-Guide by Treagust, Harrison and Venville (1996) are necessary. Both TWA as well as FAR are instructional models that presuppose structure mapping as a learning model. Basically, they suggest that all teachers need to do is analyse an analogy in class merely on a propositional level from base to target in succession. The significance of non-propositional knowledge is not taken into account nor is the symmetric nature of analogy considered important.

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ALLAN G. HARRISON

THE AFFECTIVE DIMENSION OF ANALOGY

Student interest is more than just interesting!

1. INTRODUCTION

The many ways that people use analogy to create and communicate knowledge have interested scientists, educators and psychologists for more than 40 years (e.g., Oppenheimer, 1956; Glynn, 1991). It is not surprising, given the popular view of science as a logical and rational enterprise, that scientific, empirical and cognitive methods have dominated analogical research (e.g., Gick & Holyoak, 1983). The rational approach (sometimes called the cold-rational view) has yielded significant benefits for teachers in the form of the FAR guide (see pp. 20-21); however, cognitive studies reveal little about the reasons why teachers and students are attracted to analogy in the first place. This chapter reviews a sample of the small group of studies that comment on the motivating potential of teaching with analogies and concludes that the affective dimension of science analogies should be a research priority. Only by better understanding the allure of analogies can we further enhance the inquiry and teaching power of analogies.

Certain concepts like refraction can only be explained by analogy (Harrison, 1994) and analogies are widely used as conceptual change tools, but the use of analogy to raise learners' interest levels is rarely reported. In their review of the motivational literature on conceptual change, Pintrich, Marx and Boyle (1993), argued that affective factors are largely ignored in concept learning studies. They claimed that affective or "hot-irrational" issues are just as important in concept learning as cognitive factors because interest determines the level of student engagement in cognitive activities. This chapter therefore asks "what do we know about the interest-generating dimension of analogies?" and, "how do interesting analogies enhance cognitive learning?"

2. THEORETICAL BACKGROUND

Two analyses of analogy use in science teaching discuss the conceptual growth potential of analogies (Dagher, 1995; Duit, 1991). Duit showed that analogies are

P. J. Aubusson et al. (eds.), Metaphor and Analogy in Science Education, 51-63.

effective conceptual change agents because they enhance understanding by making connections between scientific concepts and students' real-life experiences, and by helping students visualise and manipulate abstract ideas. He pointed out that analogies "provoke students' interest and may therefore motivate them" (1991, p.666) but interest is the last factor in his list of analogy's advantages. Duit explains in detail the constructivist benefits of analogy, but does not explore the motivational power of analogies and models. The absence of interest and motivation in review papers is easily explained: few studies of analogy discuss this factor.

Motivation and interest are key ingredients in effective learning. If students are not attracted to the concept or context, learning will be limited. It is the student who decides whether or not to engage in concept learning (Pintrich et al., 1993). Students choose to engage in a topic for a raft of reasons including interest in the task, rapport with the teacher, perceived value and utility of the knowledge, self-efficacy and the social milieu. This last factor is often ignored when teaching with analogies. Classrooms are social settings and Vygotsky's socio-cultural theory (van der Veer & Valsiner, 1991) helps us understand why social interaction is useful and it suggests ways teachers can enhance their planning and teaching (e.g., by choosing analogies that are located in a student group's *shared* 'zone of proximal development'). Social knowledge and experience is the most effective source of teaching analogies and both Glynn (1991) and Treagust, Harrison and Venville (1998) insist that analogies be familiar to the students (i.e., drawn from their life-world). If an analogy is not familiar, it should not be used.

Analogical thinking accesses useful structural and relational information from a learner's repertoire of familiar instances or events (the *analog*) and maps structural and relational knowledge onto the unfamiliar science concept (the *target*). The familiar analog informs the student about the unfamiliar science concept. Analogies are especially interesting and motivating when the teacher's analog can be enriched from the students' own experience. If, however, the analog is unknown to or poorly visualised by students, they will feel marginalised or frustrated and this will lower their interest in the analogical discussion. Interest and engagement are crucial to learning — it is "important to begin [by building] the connections between the motivational and the cognitive components of student learning" (Pintrich et al., 1993, p.168).

The *depth* or *rigour* of an analogy also contributes to learning. Gentner and Markman (1997) show that relational learning (as opposed to instrumental knowledge) is the desideratum of effective analogies; therefore, the analogies discussed in this chapter are limited to ones that enhance relational understanding.

Investigating the affective dimension of such analogies is facilitated by Pintrich et al.'s (1993) motivational and self-efficacy theories. Their research program shed light on the benefit of examples like the wheels-refraction analogy and Thagard (1989) insists that motivational factors enhance conceptual change. Consequently, I scrutinised studies in which I participated to find instances of analogical affect on concept learning. These studies comprise Harrison (2001), Harrison & Treagust (1993, 2000), Treagust et al. (1996; 1998).

3. METHODOLOGY

Published papers and unpublished theses were searched to identify potential instances where interest and motivation likely influenced the learning outcomes of teaching analogies. Because these studies dealt exclusively with textbook or teacher-generated analogies, the following analysis is limited by this choice. The concepts and analogies found in these studies were taught by experienced teachers to students in Grade 8-10 science and Grade 11-12 chemistry and physics. As these cases already are reported in detail, their choice was purposeful (Patton, 1990) as they contained instances of analogical affect. Each case was chosen because it contained evidence showing that students were keenly interested in some part of the analogical episode. Nevertheless, for each case, the original data were revisited to clarify events and some new data are added. Analyses like this often are more subjective that the original article because of the time lapse; however, in a converse sense, new interpretive perspectives can add to the data's meaning and impact.

A new perspective that informs this study is the multi-dimensional interpretive perspective elaborated by Tyson et al. (1997). This framework argued that better sense could be made of conceptual change episodes when the epistemological, ontological and motivational dimensions of the teaching and learning were integrated and interpreted together. This disposition is adopted here to try and shed new light on the classroom vignettes that are presented in this chapter. Space limitations mean that the vignettes are compressed and the reader is referred to the original articles should more information regarding each study's theory, method and interpretation be required. The intent of the chapter is to revisit the cases to derive new sense and to generate research questions that will guide future studies into the affective dimensions of science analogies and models.

4. CASES OF AFFECTIVE ANALOGICAL TEACHING

4.1 The Wheels Analogy for the Refraction of Light

Context. A Grade 10 physics class at a girls' independent school was taught by Mrs Kay (pseudonym). Colleagues identified Mrs Kay as an expert teacher and when interviewed to find which analogies she planned using in her lessons, she expressed a desire to trial Paul Hewitt's (1992) wheels analogy for the refraction of light. Mrs Kay found the analogy interesting and felt that demonstrating it made the event real and reduced the possibility of alternative conceptions. She was teaching optics to two Year 10 classes and, as one class had already studied refraction, the analogy could only be used with the second class. The classes were of comparable ability permitting us to later compare the conceptual change effects of the analogy. The wheels analogy was published by Harrison and Treagust (1993) and the comparative study, with the motivational event discussed here, was reported by Treagust et al. (1996). In the 1993 study, Mrs Kay was interviewed pre- and post-lesson and nine girls were individually interviewed post-lesson. The lesson in which the wheels analogy was demonstrated was recorded and transcribed.

The wheels analogy. Mrs Kay enthusiastically led her students through the analogy. First, she demonstrated how light bends towards the normal when it enters a perspex block and then bends away from the normal as it exits the perspex. The top diagram in Figure 1 depicts the set-up: a light box and a large rectangular prism were blue-tacked to the white-board. The room was darkened and the ray bending was demonstrated, and questions like "why does the ray bend towards the normal when it goes from air into Perspex?" were asked.

Mrs Kay introduced the analogy by drawing attention to a large hard card butting up to some soft carpet, a pair of wheels, and some bright fluorescent paint. The students were attracted to the paint, wanted to know its use and excitedly asked "what if we spill it …?" Mrs Kay first conducted a 'dry-run': she rolled the wheels so that they obliquely rolled from the hard card onto the soft carpet. She drew attention to the change in the wheels' direction as first one, then the other, slowed down. Then it was time for the paint. She invited a student to liberally coat the wheels with paint – "this is what all the paint's for … coat the pair of wheels with this nice fluoro paint …" – this was motivating because the bright paint was already a point of interest. Mrs Kay then asked another student to push the paint-coated wheels so that they rolled obliquely from the hard card onto the soft carpet. As the wheels crossed the join, the wheel tracks bent towards the normal. The students were impressed and were talking their way through the analogy with the teacher when a student interjected with

> it's … it's like on the farm when we drive the tractor along the [dirt] road .. sometimes your front wheel runs into a patch of sand and the tractor steers off the road. It sorta pulls the wheel out of your hand when one wheel slows down straight away …

Mrs Kay took this up and added

Mrs Kay:	Mrs P was saying that I should make this point about car wheels changing direction when they go onto a different surface. Mrs P's daughter was driving a car on holidays when she got one wheel on the gravel, and when she got one wheel on the gravel, what happened?
Student:	It slows down.
Mrs Kay:	That slows down, so what happens to the car?
Student:	It goes off the road …
Mrs Kay:	The car spins round if one wheel slows down while the other's going fast, the car can spin. Now Mrs P's daughter got the car out of control and wrote it off … but they were all lucky because they all got out unhurt.

In the follow-up interviews, several students related the 'wheels slowing down and turning' to experiences they had in driving farm vehicles on sandy tracks and skateboards running off concrete paths onto grass.

Discussion. This exchange is significant because the students' concept learning was enhanced by the spontaneous introduction of familiar experiences. This helps

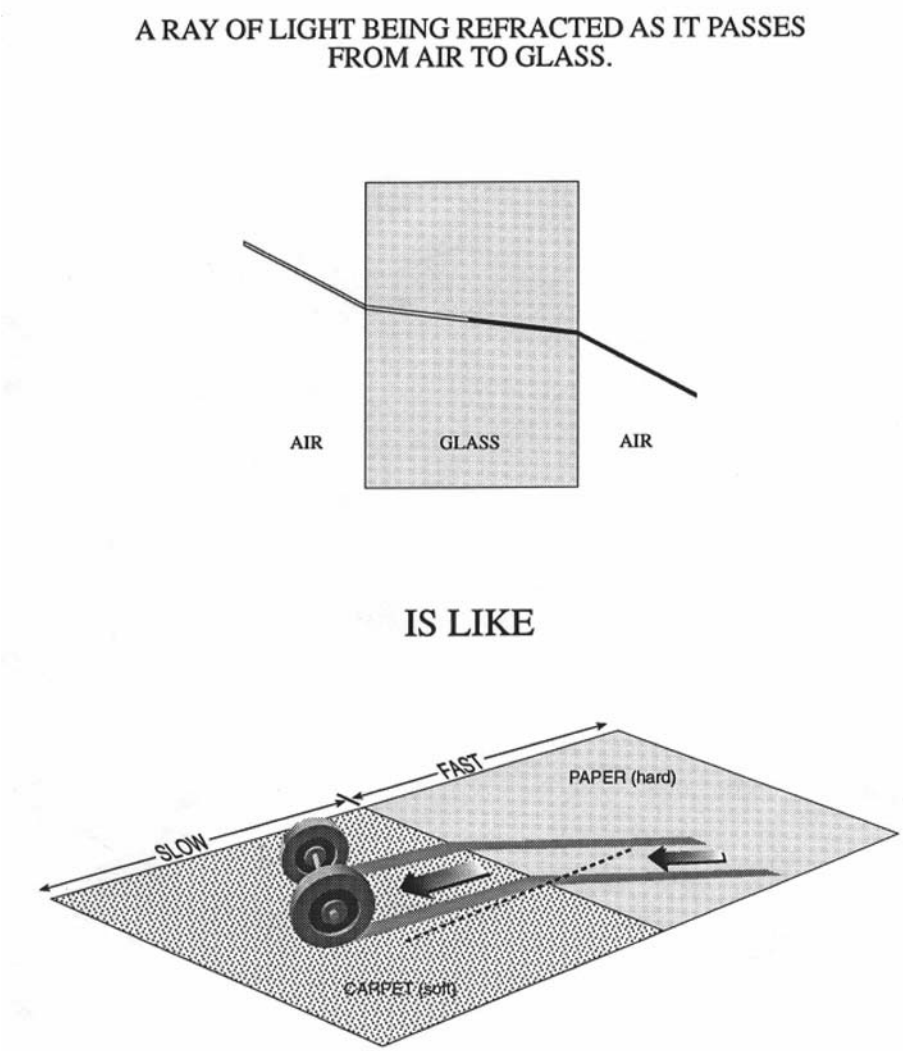


Figure 1. The wheels analogy for the refraction of light

to explain why some analogies are effective and others are not. When the students are able to connect the analog—target to their experiences, they are stimulated to explore the analogy in deeper and more meaningful ways. In this case, I suggest that student interest began with a superficial attribute (the fluoro paint) grew as they added everyday examples and this helped them 'analogise the analogy' to their life experiences. Personalising the analogy enhanced relational concept mappings of the type advocated by Gentner (1983). When the conversation flowed to everyday matters, the students became excited, willingly sought connections and offered new examples. The opportunity for them to tell their stories strengthened the conceptual links that they were making by adding personal relevance. Successful connections like these enrich the analogical mappings because the students see how the science concept explains their everyday happenings.

Eight of the nine student interviews demonstrated an understanding of refraction in terms like, ‘the one side of the ray slows down before the other side so it bends like the wheels’. Jan described it like this:

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

To verify that the students had developed a relational understanding of the wheels-refraction analogy, they were asked if they could explain why light bends away from the normal on leaving the perspex. Cara explained that light bends

> … away from, the normal, because it is, um, the same idea, but the other one comes out from the denser medium first, so it goes faster before the other one catches up, and then it goes on parallel to the other side ... it's the other side that gets there first because it's on an angle and it bends back or goes back on the parallel of the ray it started on, before it got into the dense area.

These vignettes are part of an larger case and further information is available in Harrison and Treagust (1993). The vignettes suggest that it is likely that the students’ interest in the wheels analogy contributed to the analogy’s cognitive effect.

4.2 Analogy and Conceptual Change

Knowing that one Grade 10 class studied refraction with the analogy and the other without led to a study of conceptual change effects of the analogy (Treagust, Harrison, Venville & Dagher, 1996). In this interview-about-instances (IAI) study, conducted three months later, 25 of the 29 students who were taught refraction with the wheels analogy were interviewed and 14 of the 25 who were taught without the analogy were interviewed (using the same protocol). The non-analogical explanation for the second class stated that the side of the light ray that enters the perspex first slows down before the other side of the ray, thus the trailing side travels further than the preceding side causing the ray to bend.

This secondary study explored long-term concept learning where interest can play a role. While this study was not searching for interest-based events, Dana’s interview showed the importance of motivation. At first, Dana was unable to explain refraction, insisted that she was “no good at science” and told how she failed the optics test.

The interview. The interviewer used a think-aloud protocol in which the students conducted activities and were presented with familiar and novel IAI problems. For example, the students were shown two striped pencils placed respectively in tumblers of glycerine and water, and asked to explain why the pencils appeared to break differently at the liquid's surface. Then followed three ray-tracing diagrams that the students were asked to complete (Figure 2 includes a question and Dana's response). Cues like, "how would you explain that to a friend?" were included to encourage the students to reflect upon their own conceptions and to elicit conceptual status information.

Dana's response. Dana was disinterested and vague early in the interview. When asked "what do you think will happen to the ray of light when it hits the surface of the water?" she replied, "it will probably be stopped and spread" (see the lines marked 1 in Figure 3). To the question, "Why does that happen?", she responded, "I don't know", and a similar reply was given to the following questions. Dana did not volunteer any explanation, however simple, to account for refraction.

The planned cues for reluctant students were then presented.

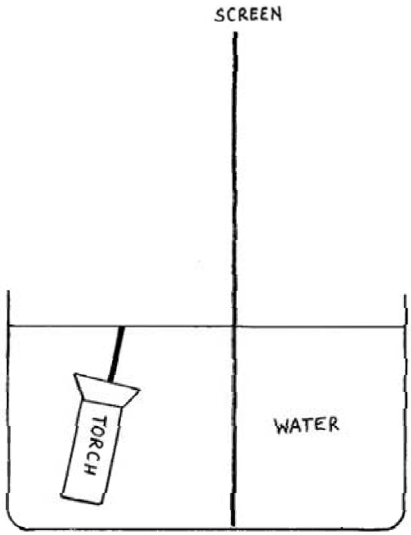
Int.	Can you think of any simple analogy that would help you explain to a friend why those pencils appear to be bent?
Dana	No. I don't think I'd be able to explain it 'cause I don't know myself.
Int.	Right, did Mrs ... use an analogy when she taught you this?
Dana	Umm ... she used a car type of thing with wheels when it was changing from a piece of carpet to paper.
Int.	And what happened when the wheels went from carpet to paper?
Dana	It bent because one wheel got onto the paper before the other one and one is rougher than the other surface.
Int.	So what happened to the wheel that got onto the paper first?
Dana	It went faster so it turned.
Int.	OK. So one wheel was going faster than the other was it? What happened when the other wheel got onto the paper too?
Dana	Then it just went straight from there …
Int.	Does that fit in, in any way with light?
Dana	Yes, because light changes faster in air than it does in water.
Int.	Alright, let's come back to this one [Dana's sketch in Figure 3]. What will happen when the beam of light hits the surface between the water and the air?
Dana	It would probably be bent that way.
Int.	Alright, you draw the line now [line 2, in Dana's sketch]. Nice heavy one so we can pick that from the original [faint] lines. OK. did the wheels help you work that out?
Dana	Yes.
Int.	Did you initially remember the wheels?
Dana	No.

Dana then returned to the IAI cards and the pencils problem and her revised answers were among the best of the 39 students.

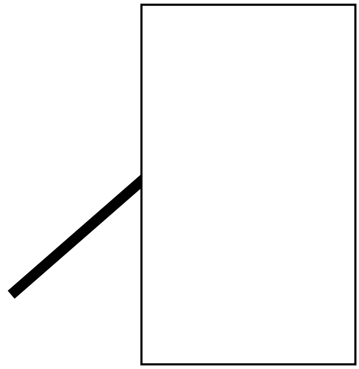
Listening to the tape-recording provides information not evident in the transcript. Prior to recalling the analogy, Dana was quietly spoken and disinterested. After recalling the analogy, she was enthusiastic and the interview produced another four pages of transcript. Dana's initial answer to question 1 was inaccurate and showed

1. If we place a light source in the water as it appears in this figure, what do you think will happen to the beam of light when it hits the surface of the water? Feel free to draw your prediction on this paper. Explain.

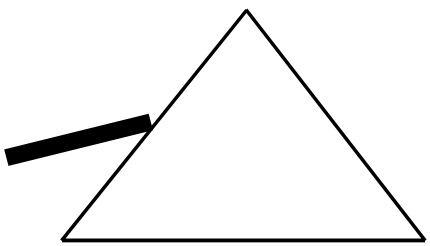
Sketch 1



Sketch 2



Sketch 3



2. a. If a beam of light strikes this glass block from the side shown in this figure, what happens to it? Draw the direction of the beam going through the block if the light is turned on from this side.
   b. How would you explain what you have just drawn to a friend, who has not studied these ideas, so that she could understand what is going on?
   c. Are there any other lines that you could draw on this diagram to show what is going on?

These three questions were repeated for Sketch 3.

A fourth question, not shown here, asked students to observe a pencil standing half immersed in a clear liquid and to describe and explain what they saw.

Figure 2. The three interview-about-instances diagrams (positive images) used in the interviews.

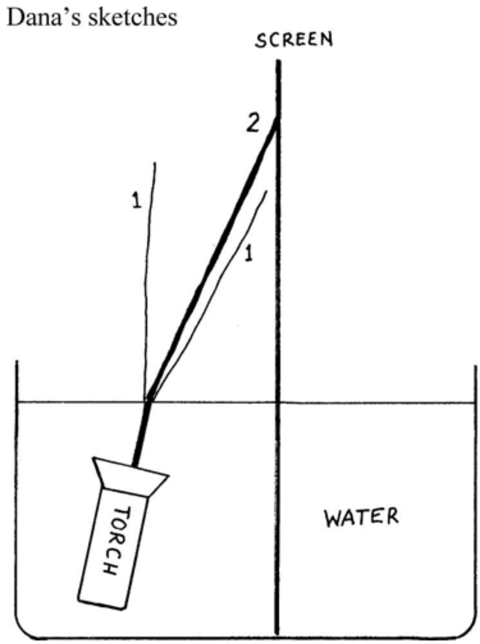


Figure 3. Dana's early (1) and later (2) responses to the torch in water (negative image) questions

little evidence of understanding. Recalling the analogy, led to her becoming dissatisfied with her initial answers and she confidently changed her vague sketch into one resembling the scientifically accepted response.

Discussion. Treagust et al. (1996) discuss the status of Dana's conceptual change after the analogy was recalled; however, the salient issue here is the role of the analogy in motivating her to engage with the questions and think about the problems. What does this mean? Dana is not alone, she belongs to a large group of students for whom physics (and science) lacks the relevance, interest and opportunity for them to grow in knowledge. Students like Dana do not fail science, science fails them because it does not excite their interest. School science no longer has an elitist mandate to cater only for those students who are capable of tertiary science studies. Disinterested students cannot be ignored as "lacking knowledge or ability". School science has a warrant to productively engage students in exploring the science that affects their lives. The *Beyond 2000* report (Millar & Osborne, 1998) asked, "Who is school science education for?" They insist that "teaching science is to enable young people to become scientifically literate – able to engage with the ideas and views which form such a central part of our common culture" (p.2006).

So, why are students like Dana not included in successful sense making about their world? It is not because they are unable because Dana was precise and accurate in her thinking once the analogy was retrieved from her memory. I suggest that the curriculum and her science class's culture, while better than many, still had a way to go before it included all who were able to learn in science. The cold-cognitive approach did not satisfy Dana's needs; but she was able to access an interesting analogy three months later and use it to solve problems she was entitled to expect to understand when the class studied optics and her knowledge was tested. Her failure was a failure of the teaching and testing regime to encourage her to show what she knew and could do. Science should interest all students; this is achievable and one way to build and sustain motivating learning environments is through the use of imaginative and relevant analogies. Most analogies come from the teacher's repertoire and students should be encouraged to contribute their ideas so that they can 'flesh-out' the analogy and see its relevance to them.

4.3 Teachers' Attitudes to Analogies

Teaching-with-analogies and models (Glynn, 1991) and the publication of cognitively beneficial analogies and models (Harrison & Treagust, 1993, 1994a, 1994b, 2000) has helped teachers motivate their students by providing them with interesting analogies. The following excerpt comes from interviews with 10 experienced secondary science teachers (Harrison, 2001). Follow Ian's enthusiasm as he talks about a favourite analogy that he used to heighten interest and explain inheritance principles to his low achieving Grade 10 class.

> The [students] saw videos with actual shots of chromosomes under the microscope but it meant very little to them until they actually made their own chromosomes with poppet beads and had a set of chromosomes which they then … mated with the person next to them, which they thought was really exciting. They had to go through the mechanism of dividing their chromosomes so that when they combined their gametes with the person next door they ended up with somebody who had a similar complete set of chromosomes. They were able to understand how … you end up with an offspring that has the same complement of paired chromosomes. Then we took that concept further by marking the beads as particular genes and then with their breeding they were able to … determine what offspring characteristics would be …. They started getting this idea that there was some predicability and they [were] capable of fairly high-level probability calculations. This class, allowing them time to pursue this model, arrived almost at the same end as the brighter kids but it took a lot more time. And it wouldn't have been possible without an analogy and a model that they can get their hands on …

Ian particularly enjoys teaching these students and offered this story when asked how he explained difficult concepts to such a class. Ian also related his nuts-and-bolts atoms analogy for chemical bonding (Australian Science Education Project, 1974) to show how everyday knowledge can motivate students.

Discussion. It is important to share Ian's enthusiasm for these strategies because they are *his* purpose built analogies and models. His analogies and models work because he designed them with his students' needs in mind. Ian was particularly enthusiastic about his 'breeding' analogy because he believed that it was interesting, familiar and matched his students' capabilities. There is an appeal to the students' sense of naughtiness when he says "they … mated with the person next to them, which they thought was really exciting". Teachers create these scenarios to captivate and engage students because they realise that students need help understanding how science can be made relevant to them.

Ian's desire to interest his students highlights a problem familiar to every classroom teacher: despite the best intentions of the teacher and the provision of excellent learning resources, many students who should learn, do not. The provision of ideal cognitive conditions cannot overcome student reluctance to learn when the student is disinterested and does not want to engage in the learning activities. "Three aspects of an individual's behaviour – choice of task, level of engagement, and willingness to persist at the task" determine the student's level of engagement and his or her learning outcomes (Pintrich et al., 1993, p.168). The popular constructivist principle that it is the student who decides whether or not to join in and learn can insulate us from the importance of interest and excitement. The role of teachers is to suggest interesting examples and analogies that will motivate their students.

Chemistry analogies. My third example is Neil who has taught secondary science for 15 years. Neil extolled the benefits of analogies as motivational and explanatory tools. He spoke for over an hour about the way he uses analogies to capture student interest and most of his ten analogies were advance organisers. This is how he explained his teaching of chemical bonding:

> … I don't often tell them where I'm going, I'm just telling them a story. I talk about being at the dance and having to prise people apart. The attraction is so strong, I have to put the foot in … like the electrostatic positive—negative ions … I talk about girlie bonding and I talk about blokey bonding around the bar or after a football game … that's like metallic bonding because they're all the same types with lots of energy floating around them …
>
> I'm a story teller and once I've got them in the palm of my hand, I say "Oh well, I've just explained to you the basic concepts we're going to do for the rest of the term … and then I'll go back and use these ideas again when I work through the four types of bonding. And it's funny because sometimes I'll get the kid with a bit of a sense of humour who will on their exam … talks about blokey bonding to explain metallic bonding, and I think if it's stuck with a few kids, and helps them explain, perhaps it does channel their thinking. Perhaps they can see the differences [in bonding types].

Discussion. Neil appeared to have just three analogical contexts: boy-girl behaviour, cars, and sport: contexts that interest Grade 11-12 students. His recorded teaching analogies fitted three types: type one focused on provocative ideas that were developed over several lessons (four analogies). In type two, he used motivational stories to illustrate and focus interest on key concepts (three analogies), and in type three he designed specific analogies for specific problems (three analogies). Neil believed that many of his story-analogies were successful because they were interactive; that is, he encouraged students to develop the story by adding comments and asking questions. This approach resembles Mrs Kay's discussion about cars running off the road. Neil's enthusiasm when telling his stories and describing the students' responses (some of them jokes at his expense) suggests a high level of enjoyment by both teacher and students. Neil's teaching analogies seem to fit the 'hot, irrational approach' to concept learning.

Neil's analogies, however, did not appeal to everyone. Sue told how "you remember them more than a textbook explanation [but] you say cars, and a lot of the girls just switch off". A similar finding emerged when another teacher used the Melbourne Cricket Ground to analogically model the spaciousness of a hydrogen atom; too few students in the class were interested in football and cricket to enable them to access the analogy's benefits. A successful replacement analogy employed the proximity of each student's home to the school and different sized balls were used to model the nucleus, electron and the space between them in a hydrogen atom.

5. CONCLUSIONS AND RECOMMENDATIONS

The paper's examples – the wheels analogy, Dana's story, Neil's teaching and Ian's interview show that analogies can interest students provided the stories are contextually, intellectually and socially familiar. Three recommendations seem pertinent: First, teachers need a rich and varied set of analogies that stimulate their own and their students' creative imaginations. When teachers and students co-construct analogical explanations using the students' shared experiences, effective learning often results. Second, teachers need a systematic strategy for presenting analogies so that the analogy's familiarity and interest is assured; the shared attributes are mapped in a way that enhances relational knowledge; and a means exists to check that the students realise when and where the analogy breaks down. This strategy is available in the FAR guide (see pp. 20-21). Third, it is important that we study which analogies interest students, why students are interested in these analogies, and which concepts are best developed using these analogies.

This chapter also has shown that expert and creative teachers carefully plan their analogies and understand the limits of their favourite analogies. Yet research shows that many analogies are ad hoc or reflex-like reactions to student disinterest and lack of understanding. Learning will not be of the desired type or depth while ad hoc analogies are retained. I recommend that only those tried analogies that can be presented in an interesting way be used to explain abstract and difficult science concepts.

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RICHARD K. COLL

THE ROLE OF MODELS, MENTAL MODELS AND ANALOGIES IN CHEMISTRY TEACHING

1. FUNDAMENTAL PROPERTIES OF MODELS: THE NATURE AND LIMITATIONS OF MODELS

Models are of great importance in understanding and communicating chemistry. In this chapter I consider the role of models, mental models and analogies in chemistry teaching.

Because of their central importance in chemistry, there has been much research into the nature and use of models in science and education. Three key themes about the nature and use of models emerge from the literature: models are used to produce simpler forms of objects or concepts; they are used to visualise phenomena; and, they are used to provide explanations for scientific phenomena (Gilbert & Rutherford, 1998; Suckling Suckling & Suckling, 1978). Modelling helps scientists and teachers recognise the key aspects of the target (i.e., what it is he/she is trying to understand) without becoming distracted by too much detail. Models allow us to do this because we focus on the important features of the target that we are interested in (e.g., highlight the structural arrangement of atoms in a ball-and-stick model and ignore the relative sizes of attached atoms).

Because the modelling purpose varies, models themselves also vary significantly. Zumdahl (1989, pp.197-198) comments that models vary “from simple models to predict approximate behaviour to more complicated models to account very precisely for observed quantitative behaviour”. Thus we use simple models, such as the Valence Shell Electron Pair Repulsion (VSEPR) model, which are easy to use and helpful in deciding the arrangement of atoms in a molecule, and more sophisticated models for chemical bonding, such as quantum mechanics, which can explain intricate details of molecular structure and reactivity (e.g., the unusual electron configuration of molecular dioxygen O_2 that is not explained well by other models).

Some forms of models and modelling are used in all sciences (and in other disciplines like the humanities) but they are particularly important in chemistry

P. J. Aubusson et al. (eds.), Metaphor and Analogy in Science Education, 65-77.

because it involves so many complex and abstract concepts. It is this aspect of chemistry that made Zumdahl (1989) claim that models and modelling are of such importance in chemistry that it is difficult to conceive that anyone could understand chemistry without understanding chemistry's models and their use.

Modelling inherently simplifies the target, and because of this, simplifies the extent to which the target (i.e., phenomenon being modelled) and source (i.e., the familiar basis for the model) share various attributes. In other words a model is an approximation (or less 'accurate' representation) of a target. However, any loss of accuracy is compensated for by gains in clarity.

> A salient feature of all models [is] that they represent an approximate description of the corresponding complex systems—the so-called objects, originals or prototypes. In modelling we sacrifice perfect truthfulness because the object is distorted by simplification. This is, however, more a strength than a weakness because a model gains greatly in transparency and conceptual clarity. It deliberately neglects the less relevant details and emphasises the most important facets ... a reliable model exhibits the essence of the property or a phenomenon under study, since attention is focused only on selected and dominant features. (Maksic, 1990, p.xiv)

The fact that all models possess some limitations sometimes leads to confusion when we try to evaluate the 'goodness' or 'fit' of a model. Think of the atomic model for the structure of matter. It is easy to fall into the trap of thinking of atoms as being real (diagrams in text books and scanning tunnelling electron microscope images lead students to this view), whereas what we term an atom is simply our model of a reality we can never truly come to know (i.e., the composition of matter). A good fit with empirical data only means that the model is reliable (we say it 'works well'), but this should not be taken to infer that it is somehow a copy of reality.

1.1 Using Models to Understand Chemistry: Some Issues from the Literature

It is easy to forget that models are human inventions and that, as mentioned above, every model has limitations: we might even say they are 'wrong' in some key aspect. But this is not a weakness or failure for a given model. For example, consider the Aufbau principle, a simple model used to explain the electron configurations for the elements.

> Chromium and copper do not agree with the predictions [of the Aufbau principle]. Detailed studies show that the [observed] configurations of chromium and copper result from complex electron interactions that are not taken into account in the model. But this does not mean that we should discard the simple model that is so useful for most atoms. Instead, we should apply it with caution and not expect it to be correct in every case. (Zumdahl, 1989, p. 366)

The pragmatic use of models that are known to possess limitations is one of the things that differentiates scientists and experts from students and novices. Experts have a greater level of experience with phenomena and models, as well as the culture and norms of chemistry. Experts have greater ability to visualise abstract concepts: "Novices usually have incomplete or inaccurate models, whereas those held by experts includes both sensory (or macroscopic) data from the physical world *and* formal abstract constructs of the phenomena" (Williamson & Abraham, 1995, p. 522).

Grosslight, Unger, Jay and Smith (1991) claim that novices tend to think of models in concrete terms, meaning that students and novices think of models as scale models of reality – the ball or sphere used in teaching really is exactly like an atom – apart from its size. Research indicates that experts recognise the purpose of models, that is, that models are intended to serve the user and frequently require modification as new experimental data are revealed.

Some models are spectacularly successful: important examples are the Watson-Crick model for the structure of DNA and Schödinger's wave-mechanical model of the atom. Schrader (1984) sums up the situation concisely, stating, "some models are so powerful at explaining well understood observations that *they are regarded as facts*" (p. 1001). Zumdahl (1989) supports Schrader's view:

> A model is considered successful if it explains the known behaviour in question and predicts correctly the results of future experiments. It is important to understand that a model can never be proved absolutely true. In fact, *any model is an approximation* by its very nature and is doomed to fail at some point. (p. 187)

Zumdahl (1989) also shows that failure of a model is not necessarily a bad thing since it can alert scientists to fundamental misconceptions and ultimately results in an improved understanding of the concept:

> When a model is wrong, we often learn much more than when it is right. If a model makes a wrong prediction, it usually means we do not understand some fundamental characteristics of nature. We often learn by making mistakes. (p. 366)

This view is supported by other authors and Schamp (1990, p.16), for example, argues that recognising a model's limitations may serve to advance our "understanding by emphasising the *limitations* of any one model rather than focusing on its generality". There is an interesting illustration of this issue in the scientific literature. In the late 1970s, two scientists proposed an alternative model for the molecular structure of DNA. This challenge to the successful Watson-Crick model was controversial and the debate became acrimonious. It was well known at the time that the Watson-Crick model possessed limitations, for example, the rapid unzipping of the DNA chain seemed inconsistent with the entwined double-helix model. However, the remarkable success of the Watson-Crick model meant that many scientists were uncomfortable about challenging its 'correctness'. Hence, it seems that the social context may exert an influence on perceptions of the correctness or otherwise of a model, and there is a long history of this in the development of scientific theories such as evolution and creationism. Lühl (1992) argues that such an approach, what she calls the *historic-genetic method*, "is a way of showing high school students some of the complex interactions which lie behind the 'facts' presented in science courses" (p. 193).

The significance of this approach for the use of models and modelling in teaching students about chemistry's models is that properly briefed learners may learn to "develop their understanding of physical modelling by learning to think in terms of models, and interpreting the ideas of important scientists in terms of models" (Lühl, 1992, p. 193). A teaching approach that involves an appreciation of the historical context of the development of scientific theories, including models, may help students to remain conscious of the nature and limitations of models. The development of the model for atomic structure nicely illustrates this process; we can help students see how scientists developed early models of atomic structure (like the Thompson 'Plum Pudding' model and the Bohr model) and how they came to discard such models after evaluation and testing.

1.2 Typology of Models: Towards a Definition of Models

Because there are so many types of models, the literature contains a variety of attempts to classify models. These schemes are based on the nature or type of model and here I provide an overall classification scheme for the models that are used in chemistry and the sciences (Figure 1).

Models can be classified into two broad categories; physical and conceptual/symbolic (Suckling et al., 1978). Physical models include scale/iconic models and physical models, as the name implies, and are mostly used to represent the form or external characteristics of the target (e.g., Black, 1962). Physical models include maps and diagrams such as reaction schemes and metabolic pathways, and chemical formulae (Trindle, 1984). Conceptual/symbolic models are mental constructs that include empirical models, models that relate variables to theory (Suckling et al., 1978), and a standard, something to be imitated such as a model of a process. An archetype consists of a constructed model that is used to describe some phenomena, the model drawing on concepts and terms from a variety of other domains. Theoretical models are models used to represent abstract phenomenon such as lines of force or bonding, and mathematical models comprise physical properties like density or physical processes and mathematical equations (e.g., $F = ma$, $pV = nRT$). Finally, analogies or analog models can be physical or conceptual/symbolic, and they are models that possess one or more of the target models attributes (Justi & Gilbert discuss analog models in their Chapter).

Physical and conceptual/symbolic models may be static and/or dynamic; for example, scale models and maps and diagrams are typically static in nature, a standard and archetype models are more commonly dynamic, but mathematical models and theoretical models can be either static or dynamic. These model types are not necessarily mutually exclusive and, for example, a physical model also may be an analog model, and a mathematical model also a theoretical model. Tomasi (1988) points out that any overlap of model types may result in confusion that is exacerbated by the complex relationship between theory and experiment. To illustrate, a mathematical model comprising sophisticated calculations of wave-functions results in considerable detail about atomic structure, but a simple static pictorial model arising from these calculations (e.g., representations of molecular orbitals) serves to focus on chemically interesting aspects of the structure that helps us visualise the formation of chemical bonds in molecules.

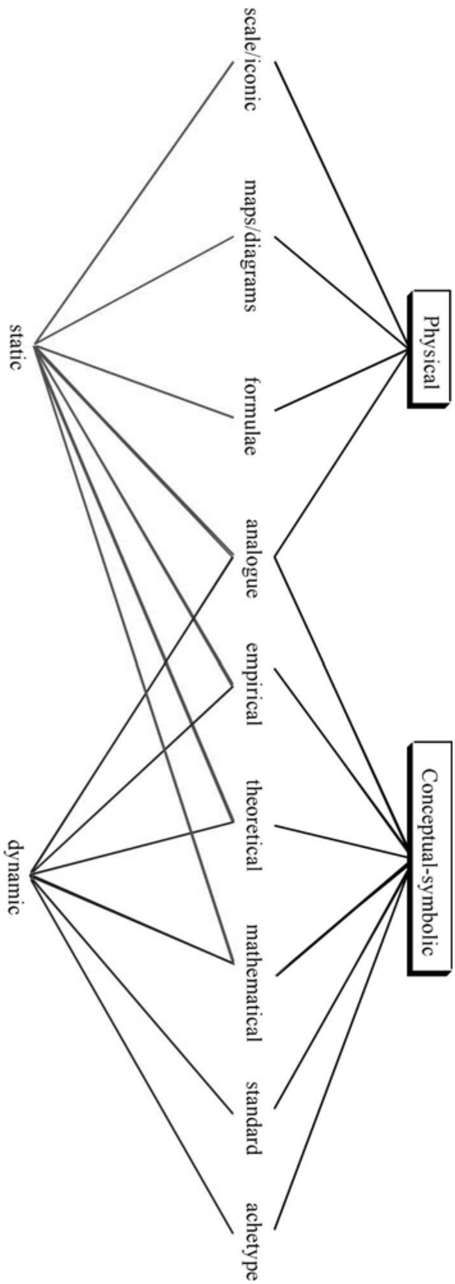

Figure 1. Models identified in the science education literature.

The literature suggests that mental models represent personal mental constructions, although the process of construction may be influenced by a variety of factors. This personal nature of mental models means that they are intrinsically difficult to investigate. Gilbert, Boulter and Elmer (2000) point out that what we encounter during research inquiry or teaching are an individual's *expressed* mental models; in other words, how they describe or express their mental models to researchers and teachers. Furthermore, an individual's mental model may not be the 'neat' or consistent artefact that appears in textbooks; but are likely to be 'sloppy' and 'inconsistent', whether or not they are able to describe or express their personal mental models.

2. THE USE OF MODELS, MENTAL MODELS AND ANALOGY FOR TEACHING CHEMISTRY

2.1 Teaching Chemistry Using Models and Mental Models

The above discussion helps us realise that, despite their great value in understanding chemistry, teaching students about chemistry's models is not simple. Many researchers argue that confusion in the use of models has its origins in the mode of instruction. For example, Smit and Finegold (1995) found that South African physical science pre-service teachers viewed models as scale models of reality due to their earlier exposure to physical models of the human body, insects and skeletons. Similarly, Barnea, Dori and Finegold (1995) report that Israeli pre- and in-service chemistry teachers failed to distinguish between a mental image and concrete model, believing that a model is simply a way to describe a process or phenomenon; apparently, these students failed to realise that models also could be used for purposes such as predicting chemical phenomena.

A complication for teachers when teaching students about chemistry's models is that sometimes the models are attempting to model other models. This sounds a little odd; consider this insightful comment from Walton (1978): "A major difficulty is that the atomic theory from which ideas of molecules and crystals derive is itself a model of the nature of matter" (p.11). In other words, some models we use to teach *build upon other underlying models* and we need to be sure that students understand the underlying models first before introducing new more complicated models. As you might expect, students' ability to understand and manipulate mental models increases with educational level. Kleinman, Griffin and Kerner (1987) found that individuals were capable of increasing levels of abstraction and were able to hold a greater number of mental images as their educational level increased. Experts and students educated to the doctoral level were able to retain and manipulate an enormous number of mental models. Undergraduates tend to conceptualise by word association, whereas images possessed by experts are not necessarily of real-world objects; rather they can be of abstract images, that is, constructs based on abstract models.

Overall, research across a variety of cultures and educational levels suggests that many students prefer simple, realistic-looking mental models. For example, studies of high-achieving Portuguese students' mental models for the structure of the water molecule and Australian senior secondary school students' mental models for atomic structure revealed that students preferred space-filling models which they saw as real models for the substances being studied. Similarly, Taber (1998) found that UK A-level learners' preferred mental model for covalent compounds was the simple octet rule. In New Zealand, we found that Year-12 and new entrant tertiary chemistry students prefer realistic-looking space-filling and ball-and-stick models of chemical bonding and molecular structure (Coll & Treagust, 2001, 2002). This might seem unsurprising, but we also found that such preferences were prevalent amongst senior level tertiary undergraduates (i.e., at the latter stages of their undergraduate degrees) graduates (i.e., masters level) and postgraduates (i.e., doctoral level). We think this occurs because teachers have not really emphasised the *need* for higher level and more sophisticated mental models. But why would even PhD candidates engaged in cutting-edge chemical research use a complex model (like molecular orbital theory or ligand field theory) if they did not have to?

Bent (1984) suggests that learning the appropriate use of models is a complex task—making parallels between learning chemistry via models and learning a language. He argues that the difficulty arises during instruction, and models often are presented as abstractions outside the learners' framework. Bent recommends that chemistry instructors introduce a model only when it is a necessary consequence or an immediate expression of an experiment or an observation, and argues that "no model ought to be introduced unless its use can be made utterly clear to the student and unless it will be used again" (p. 777). Gabel, Briner and Haines (1992) similarly argue that teachers should model the physical phenomena they are representing *as often as possible*. If we have to teach a model, let's draw upon the literature and think about how we might teach it better.

One of the principal difficulties faced by students in using two-dimensional structural models presented in textbooks is responding appropriately to visual diagrammatic clues. These clues are generally obvious to experts and teachers but not to novices; consequently, alternative conceptions can be triggered by inappropriate diagrams that highlight and exaggerate particular features that students then take literally. Good examples of this include diagrams used to show the intermolecular interactions between solids, liquids and gases. Often such diagrams exaggerate the spacing between particles in liquids (typically because authors are trying to show the greater movement between the particles in the liquid phase). This often leads students to form the alternative conception that the particles are spaced out. A nice way to avoid this uses a physical analogy that employs polystyrene balls and a stream of air (Taylor & Lucas, 1997). The likelihood of inaccurate interpretation can be reduced by encouraging students to draw their own diagrams, and by guiding them to be more critical of diagrams in textbooks and other curriculum material.

2.2 The Use of Combined Manipulatives and Multiple Models for Teaching Chemistry

The use of combined manipulatives; two-dimensional representations, three-dimensional computer simulations, and three-dimensional ball-and-stick molecular models; has been reported to enhance students' long term retention of depictions of molecular structures. Students using combined manipulatives "did not have to transfer a two-dimensional molecular representation into a three-dimensional mental model" (Copolo & Hounshell, 1995, p.302); thus the students were able to relate the two-dimensional representation to the concrete three-dimensional molecular model more effectively than using two-dimensional or three-dimension representations alone. Solomon (1995) suggests that such transfer is more straightforward when using mechanical models because the obvious differences between the mechanical model and theoretical model reduce the likelihood of model confusion.

Although research studies have lauded the value of combined manipulatives, a number of authors argue that experience with physical or two-dimensional models alone serves to improve chemistry understanding of abstract concepts. For example, Gabel and Sherwood (1980) showed that the manipulation of molecular models by high school chemistry students over a long period of time led to improved chemistry achievement for high school level learners. Interestingly, learners at both formal and concrete Piagetian levels benefited from this modelling.

There are some chemical concepts, like chemical bonding, that students find especially difficult. This has spawned a number of studies into ways of teaching such topics by the use of multiple models and analogies. Some studies suggest that teaching using multiple models can enhance student understanding of scientific concepts. Harrison and Treagust (2000) investigated students' understanding of the multiple models for chemistry concepts and claimed that students who peer-negotiated the shared and unshared attributes of common analogical models (in this case for atoms, molecules and chemical bonds) used these models more consistently in their explanations. Likewise, students who used multiple models of particle theory display more scientific understandings of particles and their interactions than their classmates who concentrated on the 'best' single model. Furió, Calatayud, Barcenas and Padilla (2000) call the latter concept 'functional fixedness' in which students become fixated on a single model or structure of the concept under study.

Students use personal views and inferences to decide the criteria for model fit or model suitability, whereas scientists and experienced others hold more pragmatic and empirical based-notions. In other words, experts see a need for evidence and fit that is more far-ranging than mere personal belief. Hence, teaching students to appreciate the notion of multiple models (including analogy and scientists' use of analogy for understanding) is crucial. This is reported to be enhanced by constructivist-based approaches; the usual things like identification of prior conceptions (both scientific and alternative conceptions) and integration of such conceptions into classroom pedagogy. Such an approach has been reported to enhance student understanding of complex chemistry concepts like thermodynamics and the energetics associated with chemical bonding. Other constructivist-based approaches reported to be successful in enhancing student understanding of chemical concepts include appropriation of language and the use of social and personal narratives to features of phenomena such as evaporation.

2.3 Teaching Chemistry Using Analogies

Humans use analogy constantly to help make meaning clear. We do this naturally in conversation. The next time you see someone struggle to explain something (science or other topics) note how often s/he resorts to the use of analogy. A few years ago, I was fortunate to hear Nobel Laureate Alan MacDiarmid speak about his research. I was struck by how frequently he made use of analogy when explaining his work to the general public. Why do people use analogy to explain phenomena? The use of analogy is effective because it allows us to relate our scientific ideas to ideas that students (and others) find familiar. This makes the unfamiliar (i.e., what we are trying to explain or teach) familiar by drawing on what the student or other individual already knows.

Analogies are powerful tools of explanation and there are many reports in the literature exhorting teachers to use analogies to aid understanding of complex abstract, scientific concepts. As might be expected, the concepts deemed most likely to benefit from the use of analogy are those which students find conceptually difficult such as atomic structure and chemical bonding (Coll & Treagust, 2002). Interestingly, these are the same topics scientists use analogies to help themselves to understand the concepts. So, by teaching with analogies we are in many respects following the approach of scientists, as they construct understanding of abstract phenomena.

The chemical education literature abounds with examples and descriptions of analogies. Pogliani and Berberan-Santos (1996) suggest that there is considerable "educational value of the many analogies between human behaviour and chemical behaviour" (p.950). They illustrate their point by describing an analogy using ideas of inflation and devaluation of motor vehicles (which should be familiar to students) to help students understanding of chemical kinetics. The use of analogies in teaching for understanding is dealt with in detail elsewhere in this volume but overall, analogies are used in science and chemistry instruction for a variety of purposes and at a variety of educational levels: to illustrate basic chemical concepts like solubility and kinetic theory (Taylor & Coll, 2002); to model physical properties and the use of sophisticated instrumental techniques such as mass spectrometry and nuclear magnetic resonance (NMR) spectroscopy; to model molecular structure; to model chemical reactivity and equilibria; and, to describe and understand stereochemistry.

2.4 Analogies in Textbooks and Classroom Practice

In spite of the extensive use of analogy in chemistry teaching, there have been comparatively few studies about actual use of analogy during instruction. Duit (1991) suggests this is probably true for the sciences in general: as he puts it "little is known about how analogies are used in the classroom" (p. 659). Research into the use of analogy in chemistry and science teaching has centred on two themes: the prevalence of analogy in curriculum materials such as textbooks, and in classroom practice and students' use of analogy or analog models. Dagher (1995a,b) reviewed the literature about the effectiveness of analogies in science education and she classified the studies into one of two main categories based on whether the analogies were included in text, or whether they were presented or facilitated by a teacher or researcher. She found that the literature indicates that the level of guidance provided to readers, the degree of interaction permitted, and the way the analogy is presented in textbooks are the main factors that determine the effectiveness of learning via textbooks. This is consistent with Thiele and Treagust's (1994) report that a broad range of analogies employed in chemistry textbooks greatly varied in the extent of mapping (i.e., the examination of similarity or correspondence of likeness between the target and source). Vosniadou and Schommer (1988) found that children as young as five and seven years old were able to see similarity between source and targets, but their ability to transfer information could be improved if they received explicit instruction about the transfer process. There is a real lesson here for chemistry teachers: we cannot simply assume that students can map shared attributes between model and target, we need to show them how to do this if we want them to make best use of analogies for understanding chemistry.

Other studies found that analogy in chemistry classrooms aids understanding for abstract chemical concepts such as the conservation of matter. For example, Stavy (1991) and Taylor and Lucas (1997) found that the use of acetone and a highly coloured substance, elemental iodine (I_2) in water helped overcome the common student alternative conception that vaporisation does not involve conservation of mass. Students were able to offer a scientific explanation for the evaporation of acetone if they observed the sublimation of iodine first. A similar study by Taylor and Coll (1997) found that the use of a highly coloured substance (potassium permanganate) acted as a bridging analogy and proved effective in remediation of alternative conceptions for Fijian and ethnic-Indian pre-service primary teachers. However, research also has revealed that even senior-level learners retain realist views of analog models that is consistent with secondary school students' use of other models (Gabel, Briner & Haines, 1992).

Chemical bonding is a very difficult subject for many students and there are a number of comments in the literature with authors suggesting that teachers should use analogies when teaching bonding theories. Remarkably, however, there have been few reports in the science education literature of investigations into classroom use of analogy for chemical bonding. Instead the literature consists primarily of examples of appropriate analogies, and exhortations for their use. Licata (1988) provides an analogy for covalent bonding related to eating one's lunch. Sharing one's lunch is a non-polar covalent bond, unequal sharing of lunch is a polar covalent bond, and stealing someone's lunch is a co-ordinate covalent bond! Self-generated student analogy is very limited and I feel there is real potential here for us to help students better understand complex bonding theories by judicious use of analogy during teaching.

3. CONCLUSIONS AND IMPLICATIONS FOR PEDAGOGY

This chapter has reviewed much material and I would like to sum up and reflect on the research effort into models and model use in chemistry and discuss what this means for classroom practice (the term model here includes analogies). Chemistry as a scientific discipline is dominated by models and analogies. As chemistry educators we need to teach students how to understand and manipulate chemistry models in an appropriate fashion. The literature gives us some important clues as to how we might teach chemistry models and modelling more effectively.

First, a reoccurring theme in the literature is that we need to ensure that students begin to understand both the nature and purpose of models and analogies. They need to understand that models are thinking tools: tools for understanding, tools that scientists use in a highly pragmatic fashion. One feature of model use that students seldom understand is that scientists use models to generate explanations and make predictions. Models are not solely teaching tools, but play an important role in scientists' understanding of chemistry itself. Indeed, we cannot say we (or our students) understand chemistry unless we understand chemistry models and their use.

Second, we need to ensure that our students understand that models are approximations of some reality, a reality that we cannot ever come to know absolutely. This means that any model must by its very nature possess some limitations compared with the target. Sometimes these limitations are obvious, other times they are much more subtle. Students need to see model limitations as an intrinsic feature of modelling and not some sort of failure or bad thing about a given model. The fact that a model has limitations does not make it of little value, rather we need to understand what the limitations are, and use the model in appropriate circumstances.

Third, students need to understand that models, no matter how successful and realistic appearing, are not copies of reality. This is especially true for realistic-looking concrete models like ball-and-stick or space-filling depictions. The literature suggests that this occurs when students become fixated on 'the' best model. Certainly, we need students to understand that some models are better than others because they possess more explanatory power and are better able to explain empirical data but they need to understand that scientists do not automatically discard a model that has a few limitations.

Fourth, students need guidance in the use of models. The nature of training in model use will vary depending on the specific model, but we need to help students to use models *before* we introduce them. For two-dimensional figures, for example, students need careful training in appropriately responding to visual clues.

Maybe the best reason for teaching students about models is because the use of models and modelling is how scientists come to understand the complex, frequently abstract, concepts that comprise their particular disciple: in short, models make it easier for us to understand complexity. Chemistry is a complex subject, but it also is an exciting subject. Teaching students about chemistry does mean we need to teach them about chemistry models and the use of chemistry models. Sometime both of these are difficult for students. The literature has provided us with some excellent indications of how we might achieve this, and help our students to appreciate this fascinating discipline.

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METAPHORS FOR GENES

1. THE BEWILDERING & RESTLESS GENE

As our understanding of molecular genetics increases at an exponential rate, commentators debate whether the gene will continue to be the core explanatory unit of biology in the twenty-first century (Fox-Keller, 2000). Today, scientists convey metaphors of a somewhat 'bewildering' (Falk, 1986, p.170), 'restless' (Tudge, 1993, p.75) and 'anarchic' (Tudge, 2000, p.141) gene that is a 'vague and slippery concept' (Morange, 2001, p.27). Due to the list of 'weird and wonderful' (Morange, 2001, p.27) examples of genes described by working biologists, it is difficult to find a universally valid definition of a gene. While several definitions might suffice, none of them include all known cases (Fox-Keller, 2000; Morange, 2001). While this may be the current state of affairs, the simplicity and allure of the gene concept developed in the twentieth century has resulted in the image of genes as clear and distinct causal agents being deeply embedded in popular, including school, scientific thought. In the light of current scientific writing, however, we must acknowledge and accept the deceptive and increasingly complex nature of the contemporary gene concept. The complex, abstract and unfamiliar quality of the gene is part of the reason why metaphors are frequently used by scientists, historians, researchers and teachers, particularly when discussing sub-microscopic aspects of molecular genetics. But how should the concept of the gene be taught in school science in order to educate a population that will increasingly be employed in fields that utilise biotechnology such as medicine, microbiology and agriculture? What metaphors are appropriate for teachers when explaining genetics to a population of students who will increasingly be required to make decisions of a scientific, medical and ethical nature?

By the end of introductory genetics courses in high school, and even by the end of senior school biology, research has shown that few students develop a conception of a gene that is consistent with or useful in today's genetic-information age (Kindfield, 1994; Venville & Treagust 1998; Wood-Robinson, 1994). Most students complete introductory genetics courses with a view of a gene as being like an active

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particle that can influence characteristics in an unknown way (Venville & Treagust, 1998). This is how geneticists viewed genes more than 50 years ago, before the discovery of the structure of DNA. Clearly much needs to be done to improve the teaching and learning of this important field of science. Research from a constructivist and socio-constructivist perspective over the past two or three decades has highlighted the importance of ascertaining what students already know about science concepts before teaching begins. As a natural extension of this research, conceptual change approaches to teaching and learning have been the focus of recent research aimed at improving students' understanding of science (Treagust, Duit & Fraser, 1996). A critical aspect of all conceptual change teaching approaches is for teachers to probe students' understanding about a concept prior to instruction. Empirical research has played an important role in providing teachers with information about the kinds of pre-instructional conceptions that students are likely to have in science. The aim of this study was to add to this useful information by investigating 9 to 15 year-old students' unreflective and practical understandings of fundamental genetics concepts, in particular the concepts of gene and DNA. Ascertaining this information is an important prerequisite to improving the teaching and learning of this exciting and rapidly evolving field of science.

The unreflective and practical understandings that students have are described by Bliss (1995) as their ontological understandings because they represent the basic nature of the way that students see aspects of their world. Research into ontological understandings of genetics and inheritance have largely focussed on adults and students older than 14 years because these topics are not usually formally taught in schools until that age. Some studies have examined younger children's understandings. For example, Solomon, Johnson, Zaitchik and Carey (1996) found that only after six years of age do children start to differentiate biological inheritance from cultural transmission and environmental influences on characteristics. Springer (1999) argued that a "theory of kinship" (p. 47) emerges when children learn that babies grow inside their mothers. Research studies such as those by Solomon et al. and Springer focused on emerging theories of biology and kinship and did not explicitly examine developing genetics concepts in children. In order to examine the ontological understandings that children have of genes and DNA, the research reported in this chapter focused on the metaphors used by students in conversations about inheritance and genetics. Because young children rarely have formal instruction about genes and DNA, they are unlikely to be able to use scientific vocabulary and explanations of these abstract concepts. The metaphors used by students during such discussions were therefore thought to provide a potential, and otherwise inaccessible, insight into the ontological nature of the children's conceptions. This method has previously been successful with 15 year-old students whose ontological conceptions of the gene were described with metaphors such as *active particle*, *passive particle*, *set of instructions* and *active set of instructions* (Venville & Treagust, 1998).

2. DESIGN AND METHODS

Qualitative data collection methods were used for this study in order to probe deeply and analyse intensively students' understandings of foundational concepts of genetics. The method was designed as a cross sectional, developmental case study (Cohen, Manion & Morrison, 2000) of children from the age of 9 to 15 years so that a snapshot of a spectrum of understandings could be captured. The interview data were analysed quantitatively and qualitatively so that both broad patterns as well as detailed descriptions of student understanding could be ascertained.

2.1. Sample

The sample consisted of 90 students, approximately 15 students from each of Years 5, 6, 7, 8, 9, and 10 and included 39 females and 51 males. Each group of students was randomly selected from four different schools so that students with a broad range of interests and school attainment levels were interviewed. The schools were two primary schools and two secondary schools. Each primary school is a feeder school to the two secondary schools. One primary and one secondary school are located in a suburban neighbourhood and the other pair of schools is located in an area closer to the central business district of Perth. Due to the potentially sensitive nature of the genetics topic, parents and students were fully informed about the content and duration of the interview through an information sheet. A permission form was sent home and only students whose parents or guardians gave their written permission were interviewed. Students also were informed about the research, asked to sign a permission form before they were considered for interview and were informed that their participation was voluntary and that they could withdraw from the interview or research at any time.

2.2. The Interview

The students' understandings of the concepts gene and DNA were determined through one-on-one interviews taking the format of interviews about concepts (Carr, 1996). This interview approach was successful with 15 – 17 year old students (Venville & Treagust, 1998); however, modifications were made to the interview technique so that younger students' ideas about inheritance could be appropriately investigated (Seigal & Peterson, 1999; Solomon et al., 1996). All interviews were audio tape-recorded and summary sheets were used by the interviewers as a second method of data collection.

The interview consisted of four parts. The aim of the first part of the interview was to determine whether the interviewees could differentiate between genetically inherited traits and socially and culturally acquired traits. This was done through the exploration of a story about a Fijian girl being adopted by Australian-European parents and a tiger cub being adopted by a dog. The aim of the second part of the interview was to determine the interviewees' understandings of how and why offspring resemble their parents. That is, to probe for a genetic theory through which the interviewees could differentiate between visible characteristics (phenotype) and microscopic, causal mechanisms such as genes or DNA (genotype). The interviewees were shown various photographs of dogs and puppies and were asked questions about whether they thought any of the dogs were the puppies' parents, why puppies look similar to their parents and/or what they think causes the similarities between parents and offspring. The aim of the third part of the interview was to determine the interviewees' conceptions of the means of genetic inheritance. If individual students had either spontaneously mentioned or had heard of genes, DNA or chromosomes, then he or she was asked questions such as: Where do you think genes are in the body? What do you think genes look like? and, How do you think genes work? The aim of the fourth part of the interview was to determine whether interviewees incorporated their understanding of genetics/inheritance into a theory of biology. The students were shown a variety of pictures of living and non-living things including a bird, cat, fly, dinosaur, tree, a small plant, car, fire, Sun and a cartoon digimon character and asked whether each of these things had DNA or genes (depending on which terminology individual students were most comfortable with).

2.3. Analysis

The data were analysed quantitatively and qualitatively. The quantitative analysis involved the use of the taped interviews and interview summary sheets to create a database of each student's responses to each of the interview questions. These responses were coded and scored, generally with 2 points given for the scientifically accurate answers, 1 point for partially scientifically correct answers and 0 for incorrect answers. Each student was given a total score for the whole interview. All scores were converted to a score out of 10 and Figure 1 was created by counting the number of students in each decile. In order to determine if there were any significant changes in the students' thinking about genetics as they got older, the sample was divided into a younger group and an older group on the basis of whether they were in primary school (ages 9 – 12) or high school (ages 12 – 15). This divided the whole group almost in half. The younger group (n = 48) had generalist primary school teachers and the older group (n = 42) studied science with specialist science teachers. Sixteen students from the older group had studied an introductory reproduction and genetics course for 10 weeks in Year 10 (the last year of junior secondary school). None of the other students had studied a formal genetics course, but some had considered genetic engineering and other genetics related issues in their classes.

The qualitative analysis of the data involved three researchers independently isolating the metaphorical themes that recurred in the interview data. This was followed by a process of discussion and negotiation during which themes were collectively affirmed and disconfirmed by the researchers. The themes also were reconciled with the database to determine whether evidence from the quantitative analysis supported these themes. The interview tapes then were used to search for excerpts from the interviews that exemplified the themes and two students, Bradley (10 years old) and Alice (14 years old), were selected because the ideas they expressed in their interviews reflected the metaphorical themes that were identified through the analysis. Both Bradley's and Alice's final scores on the interview were in the sixth decile of the total primary and secondary interview scores respectively (Figure 1). These students were not selected to be representative, but to give the reader an insight into the conceptual awareness and metaphors that young students construct about genetics prior to instruction.

3. RESULTS AND DISCUSSION

3.1 Knowing and Understanding Genes and DNA

The majority of students interviewed had heard of the terms gene and DNA and many spontaneously referred to these terms when asked to explain why offspring tend to resemble their parents. More secondary students were able to differentiate between inheritance and some kind of genetic causal mechanism than younger children. While they could often use the words in appropriate ways, primary children tended to have a poor understanding of concepts such as genes and DNA. Some of the secondary students had a better understanding of these concepts, however, many did not. Some students did not differentiate between the concept of a gene and the notion of characteristics. For example in the interview excerpt below, Bradley explicitly said that the bright pink tongue and floppy ears of a dog are examples of genes.

Bradley (Year 5, 10 years old)

Interviewer: What do you think the difference is between genes and DNA?
Bradley: DNA is in our blood and genes are, genes are like things that are passed on. Like DNA can only be passed on when you mate. Genes can get passed on anyway. Genes, they are sort of like, like these [dogs] would probably have the genes of having a bright pink tongue, that's a gene.
Interviewer: Sure.
Bradley: And they would have the gene of floppy ears, that's a gene, that's something that gets passed on through all animals of that species.
Interviewer: Like a characteristic, do you mean?
Bradley: Mm.
Interviewer: Okay, and what about DNA?
Bradley: DNA's in our blood and DNA is used to identify things. Like I can identify a lot of crime, forensic scientists that have to sample DNA that can be hairs it can be anything, they can sample DNA and they can match it up with this, with the prime suspect. So that's DNA, it's pieces of the body that can be used to identify things.
Interviewer: Mm, and what do you think DNA looks like?
Bradley: DNA can come in many forms. I know that they can do DNA in the staircase thing, but DNA can be hair, DNA can be fingerprints, DNA can be anything.
Interviewer: And where abouts in the body do you think DNA is?
Bradley: Ah.. outside, the outside pieces of body, like hair, fingerprints, footprints.
Interviewer: So it's the outside things?
Bradley: Yeah, the outside body that can be identified.

Bradley was articulate and expressive compared with many of the other 10 year-old children and used sophisticated vocabulary such as “forensic scientist,” and “prime suspect.” Bradley recognised that DNA can have the form of the double helix which he referred to as, “that staircase thing.” He explained that DNA is an external factor that makes individuals unique or different from other people. Many of the students, like Bradley, associated DNA with the idea of a fingerprint or footprint, which is not surprising given the common terminology of a *DNA fingerprint*. This combination of ideas, that DNA makes you different, that it is externally located on the body and is associated with fingerprints and footprints, conveyed a strong metaphor evident in many students’ interview transcripts of DNA as an *identification tool*. A further interesting aspect of Bradley’s understanding of genetics was that he seemed to believe that genes and DNA are different things. Contrary to his idea that DNA is something that makes individuals different or unique from other people, Bradley said that genes are something that makes people look like their parents, or are characteristics that are like their parents’ characteristics. The idea that genes and DNA are different things was consistently expressed, not only by younger children, but also by older, high school children. More than two thirds of the primary children and more than half of the secondary children, who were specifically asked whether genes and DNA were different or similar, said that they are different. The following excerpt demonstrates that 14 year-old Alice initially described genes and DNA as having different functions with genes being responsible for making us look like our parents because they “form things” in our bodies and DNA is “to tell us apart from other people.” When asked by the interviewer, Alice eventually recognised the similarities between the genes and DNA that she described. She said they are similar because they both come from parents, but she did not articulate any understanding of a similar (or the same) structure or function.

Alice (Year 9, 14 years old)

Interviewer: What do you think it is that makes us look like our parents?
Alice: Genes.
Interviewer: And what do you know about genes?
Alice: Something like hormones and stuff that form things, I’m not really sure.
Interviewer: That’s okay. You said they form things, what do you think they form?
Alice: Into like, I don’t know mum and dad they mix together and they form this eye sort of thing like make parts like out of their genes.
Interviewer: So the genes come together from the parents and make the new thing look the way it looks?
Alice: Yeah.
Interviewer: Okay, where abouts in your body do you think genes are?
Alice: In your head, heart.
Interviewer: In your head and heart, okay, anywhere else?
Alice: I think, I’m not sure, they might be around everywhere, are they around everywhere?
Interviewer: They could be, but… go on.. you were about to say head, why did you say those things first?
Alice: Because they are like more functioning, they are more use than the hands and stuff.

Interviewer: Controlling?
Alice: Yes, they control us more.
Interviewer: But the genes could be everywhere, you think?
Alice: Yes.
Interviewer: Why did you think that?
Alice: Because like that's how our hands, sometimes, I don't know, look like our parents' hands.
Interviewer: Sure. Do you think they are actually where, we, you know like our genes for our eyes might be in our eyes, and our genes for our nose might be in our nose, and genes for our hands are in our hands?
Alice: Yes.
Interviewer: Okay, and what do you think a gene might look like if we could see it?
Alice: A round little spot, like a lot of them together.
Interviewer: Okay, and what do you think the genes actually do to make our eyes the way they are or our hands the way they are?
Alice: What do they do?
Interviewer: Yeah, what do they do, or don't they do anything?
Alice: They just form us, don't they, like they make us what we are.
Interviewer: Okay, so they build us?
Alice: Yes.

Later in the interview

Interviewer: What do you know about DNA?
Alice: Blood, isn't it, like if you want to know who your parents are, you do a blood test for DNA and then you can tell who your parents are.
Interviewer: Okay, do you know if DNA is used for anything else? Why is it in our body?
Alice: I think it's like everyone has like different DNA and it's like to tell us apart from other people.
Interviewer: Okay. So it's there to tell us apart from other people?
Alice: Yes.
Interviewer: So do you think there is something similar between DNA and genes, are they the same thing or are they completely different, do you think?
Alice: I think they are similar.
Interviewer: Why?
Alice: Because genes come from your parents and I think DNA comes from your parents too, isn't it? You got some of it from your parents. Yeah, so they're not that much different.
Interviewer: What do you think DNA looks like?
Alice: Blood.
Interviewer: Just like blood?
Alice: Yeah, just like blood, a bit sloppy.

Alice, unlike Bradley, was able to differentiate a characteristic from the causal mechanisms of inheritance or "genes." Alice's image of the gene was that it is like a "round little spot, lots of them" and that the genes for hands are in the hands and that the genes for eyes are in the eyes. The idea that genes for a particular body part exist only within that body part is certainly a plausible idea and was a common belief in pre-Mendelian understandings of inheritance. One view of inheritance that gained popularity during the 19th century was the atomistic view. This theory suggested that each part of the body produces small particles and when the embryo forms the particles remember the structure of the body part of the parent from where they came (Dunne, 1965).

A metaphor that seemed to be expressed by Alice was that the gene is the *builder* of the body. While the term 'builder' was introduced by the interviewer, we feel that the term is an appropriate label for the metaphor that Alice expressed. Alice said, for example, that “they (genes) just form us … Like they make us what we are”. Earlier in the interview, she said, “they form this eye sort of thing, like make parts …”. It could be argued that a “formation metaphor” is more literal but a “builder metaphor” is more commonplace and less cumbersome.

Alice’s idea that genes are at the site of a particular body part is consistent with this metaphor of the gene as a builder. The problem with this metaphor is that the notion of a single discrete gene for a body part, like a hand or an eye, is far too simplistic. There are many genes that are expressed in the genes in the cells of our hands or the cells of our eyes, all of which contribute to the construction, control and maintenance of our hands and eyes. Without an understanding of the biochemical nature of cells and living things, in particular of proteins, it seems that a simplistic link between genes and observable characteristics of the body is a fruitful explanation of observed patterns of inheritance for some students. Alice made a brief mention of hormones in association with genes. She said that genes are, “something like hormones and stuff that form things, I’m not really sure”. It is not clear whether Alice understood that genes code for the production of hormones, rather, the evidence suggests that her association between genes and hormones is simply that they both “form things”. This also may indicate misconceptions in her understanding of hormones.

Even though Alice was four years older than Bradley, it was apparent that her understanding of genes and DNA was only marginally better. This finding was consistent with our quantitative analysis of the data. Figure 1 shows that secondary students on average scored only 1 decile higher on their interview than primary students, even though some of these students had studied an introductory genetics course. Alice did seem to be able to differentiate genes from characteristics and was able to recognise that there is some similarity between genes and DNA because they both come from parents. Students like Alice, who are about to start their first unit of formal science about genetics need to be helped to appreciate the complexity of genetics. They need to understand that genes are the instructions for, not the builder of, organisms and that all organisms have a full set of genetic information in every cell, but only parts of it are actively expressed.

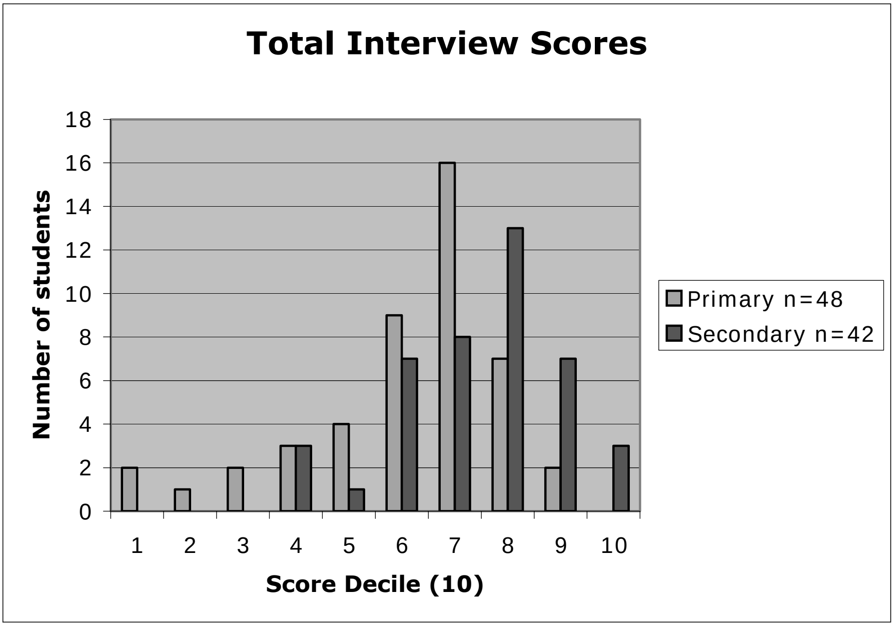

Figure 1. Students' total scores on the interview

4. UNDERSTANDING GENES AND DNA ARE ESSENTIAL FOR LIFE

Few students were able to clearly and consistently identify common living things as having genes and/or DNA. Secondary students were marginally better at this than primary students, however, a large number of primary students could not do this at all. This is largely because a considerable number of primary students had poor conceptions of the basic concepts of genetics such as gene and DNA. For example, some students made unscientific claims in this part of the interview because they believed that the main function of DNA is for identification. These students felt that some non-living things could have DNA because they could be identified or because they are produced from data, like a computer program. For example, when asked whether a cartoon character, digimon, has DNA, Bradley said yes, because it is generated from a computer, which, in his mind, also has DNA.

Bradley (Year 5, 10 years old)

Bradley: Ah, it depends. Digimon is a computer program but you can find DNA on the computer. If you got it as like one of those little digimon things it would have DNA because that's the DNA inside the computer, that's producing the characteristics. So yeah, if it's in that form.
Interviewer: So computers have DNA?
Bradley: Yes, that's the things that make them go around and you can identify it by looking at its DNA by looking at its mother board. You can sample like motherboards and that's DNA.

Bradley's use of the term motherboard is consistent with an understanding that the motherboard of a computer stores information just like DNA does in living things. His conception of DNA could be construed as sophisticated because he seemed to associate the notion of DNA with the notion of data or information that can generate something, like the way that data in a computer can generate a character like a digimon. The notion of data in a computer as a metaphor for DNA in a living thing could be considered a very good one, particularly for a child of 10 years. However, Bradley used the metaphor literally. His theory of biology and his lack of knowledge that DNA is only in living things, and that this is different from data in computers, rendered his understanding incorrect from a strictly scientific point of view. Another student interviewed felt that cars have DNA because each model of car can be identified as being different from other models. These examples demonstrate that even though the idea that DNA can be used for identification is consistent with scientific practices, such a narrow understanding of DNA has implications for the students' broader understanding of living things and their theory of biology. For students, like Bradley, who readily make some kind of metaphorical connection between data and DNA, it is possible that teaching could be tailored to help them understand that DNA is a special kind of data or information that is a set of instructions about how living things grow and function.

A consistent lack of confidence that plants are living things and that they reproduce sexually, also created many difficulties when students were asked to discuss the kinds of things that might have genes or DNA. For example, the following interview excerpt shows that Bradley correctly said that a tree has DNA, but expressed the seemingly bizarre idea that the tree would get its DNA from the Sun, water and ground. This idea is possibly the result of a combination of two things; Bradley's rudimentary scientific understanding that plants require sunlight, water and nutrients from the soil to generate more plant material (a relatively sophisticated idea because young children often believe plants get their food from the soil) and his poor understanding of plant reproduction.

Bradley (Year 5, 10 years old)

Interviewer: What about a tree, do you think that's got DNA?
Bradley: Yes, a tree has a lot of DNA because um, like you can see because a tree reproduces but it doesn't reproduce with another tree.
Interviewer: It doesn't have babies, does it, it has seeds.

Bradley: Yes, it has seeds, but that's used for like different, like the Sun would shine on that tree and it would form seeds, so that's the DNA being passed on from the Sun, which is the heat on to the tree and the rain will pass its DNA, which is the moisture, on to the tree.
Interviewer: To make a new tree, the DNA comes from the Sun and the rain?
Bradley: Yeah, and things like the ground, they would feed, like from the ground.
Interviewer: The tree does?
Bradley: Mm hum.
Interviewer: So it gets DNA from the ground as well?
Bradley: Mm hum.
Interviewer: And it puts all that together to make the seed?
Bradley: Yeah, it makes the seed and the seed goes in the ground and grows.

Indications of a poor theory of biology also were not restricted to the younger students. There was evidence that some older students had misconceptions about cartoon characters and uncertainties about whether plants are living or not. The following interview excerpt demonstrates that for 14 year-old Alice, the problem was not that she did not understand that all living things have genes, but that she thought that the digimon would get its genes from its parents and that plants' characteristics are not readily identifiable as being similar to other plants. Alice also was not sure if the Sun has genes, because she wasn't sure if the Sun grows or not.

Interviewer: I've got this picture here. Which of these things do you think have got genes in them?
Alice: The digimon.
Interviewer: Why do you think the digimon's got genes in it?
Alice: The parents might look like that and they, they form and stuff.
Interviewer: Sure.
Alice: The cat might have like the fur and that might be the same and stuff. The bird, like the colour of it and things, the dinosaur, yeah, maybe the fly. Is that it, I think so.
Interviewer: Anything else?
Alice: Maybe the plants and the tree.
Interviewer: Why would you think that?
Alice: Like colours, growing, just like the same kind of plant, yeah.
Interviewer: And what about the car?
Alice: No.
Interviewer: The Sun?
Alice: I'm not sure about the Sun.
Interviewer: Okay, why aren't you sure about the Sun?
Alice: Especially if it grows, does it grow, I don't know whether it's like, mm I'm not sure.
Interviewer: And the plant?
Alice: No, I don't think there is any genes in it is there?
Interviewer: I don't know. So alright, so you've said these things, why have you said these things?
Alice: The living things.
Interviewer: Oh I see, do you think all living things have got genes in them?
Alice: Yeah.
Interviewer: But you're not sure whether this one is living or not.
Alice: Yeah.

5. CONCLUSION

The results of this study revealed that many students used metaphors to express their understanding of concepts related to genetics. For example, genes were described as "dots" that come from, and make people look like their parents, that cause people to look the way they do, or “build” their bodies in a certain way. Conversely, DNA was described as being like a “fingerprint” that identifies individuals as being different from everyone else and is externally located on the body. The metaphors are fascinating in that they suggest opposing functions for genes and DNA. That is, genes are seen by many students to make individuals the same as other people, and DNA is seen to make individuals different from other people. What is obvious to geneticists, but not to many students, is that both genes and DNA, essentially being the same thing, influence our genetic makeup, and make organisms similar to, *and* different from, other organisms. We can speculate that these metaphors are largely initiated and sustained by students’ exposure to the media and the every day way in which we discuss molecular genetics and inheritance. For example, genes are often referred to as the cause of diseases and in every day conversation we tend to talk about genes causing our characteristics. DNA, however, is more often referred to in the context of paternity cases and the identification of criminals and unidentified bodies in forensic science.

The results of this study confirmed previous studies that young children often fail to recognise plants as living things. Moreover, this study found that many students think that plants do not contain DNA and that some non-living things do. This is likely to be connected with the strong metaphor of DNA being an identification tool, expressed by many students. There is very little about this metaphor that would enable students to make the connection between DNA and living things. Rather, the metaphor may encourage students to think about the function of DNA in a non-biological way.

The educational implications of this research are important. For example, teaching strategies may need to focus on approaches that will coalesce the divergent metaphors that students have for the concepts of gene and DNA. As teachers, we also need to talk more openly about words and representational language. In particular, we need to discuss explicitly biological metaphors, such as the DNA fingerprint and explain to students where metaphors are useful and where they breakdown. Finally, the results of this study indicate that genes and DNA certainly have the metaphoric power to invoke ideas about data storage and transmission and there is potential here for teachers to capitalise on and enhance this kind of thinking. These findings point to important future research questions about how this can best be achieved in school.

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PETER J. AUBUSSON AND STEPHEN FOGWILL

ROLE PLAY AS ANALOGICAL MODELLING IN SCIENCE

1. INTRODUCTION

This chapter considers the use of role play as a way to promote learning in science. It is argued that role play can enhance learning when students cooperatively design and develop their own role plays to give expression to their mental models. First a theoretical underpinning of role play as analogical reasoning is outlined. Then, examples are used to illustrate how it has been used effectively in science classes. The aim is to provide a general argument, justifying student generated role play to model ideas in science and to provide guidelines for teachers to promote the more effective use of the strategy. The case that analogical reasoning can be a sophisticated way of thinking and that it is central to understanding and theorising in science has been made (see e.g., Chapter 2). So, the emphasis in this chapter is on the reasons for using and how to use role play as a strategy for analogical modelling in school science.

2. WHY ROLE PLAY IN SCIENCE?

The potential advantages of role play have long been recognised. According to Ladrousse (1989) they encourage students to create their own reality; develop students' ability to interact with other people; increase students' motivation; help build up students' self confidence, allow students to bring their experiences into the classroom; are fun; help to identify misunderstandings; and provide shy students with a mask allowing greater participation. In science education, role plays have also been recommended for their potential to make learning in science more attractive to students (Hildebrand, 1989) and because they allow students to look at occurrences from a different perspective.

Studies of role plays are often associated with research incorporating drama strategies in science (Butler, 1989; McSharry & Jones, 2000). Frequently the role play is used to enable students better to perceive an alternative perspective on a controversial issue in science. They involve the students playing the part of another

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person (either a specific person, generalised or a caricature). The role could be a scientist, a local farmer, an indigenous land owner, an environmentalist or a politician in order to better understand issues or the dynamics of science in a social context (Hiotis, 1993). Less frequently, research on role plays reports teaching and learning where students act out aspects of a scientific model or theory to explain phenomena they are learning about. Sometimes this is called simulation-role-play (Aubusson, Fogwill, Barr & Perkovic, 1997) or analogical modelling role play (Harrison & Treagust, 2000). Typically the role play is designed primarily by the teacher and performed by students (e.g., Mackinnon & Aucoin, 1998). The aim is to provide role played models which most clearly portray the ideas of science. They serve to enable knowledge transfer from the analogy (role play as base domain) to the phenomena being studied (the target domain). Rarely, role plays are designed by the students themselves. Employed in this way, role play is used as an analogy to enable students to generate deeper understanding. They simulate their interpretations of theory. It serves to clarify students views and bring to the fore students' explanations of phenomena. The role plays are socially constructed by students and result from students sharing different views. Students may be physically involved, for example, by "walking around in such a manner that the direction is analogous to the motion of electrons, through a wire" (Treagust, 1993, p.293). These student produced role plays can be classified as personal analogies (Duit, 1991).

An appealing feature of role play lies in its potential to assist students to develop and create their own mental models as, "in trying to understand science students draw on available mental models" (Gardner, 1991, p.157). In science, students' mental models are inferred from observations of phenomena and interpretations of theories. For many years it has be claimed that non-threatening, social and enjoyable opportunities should be provided where students may develop and build on these models (Chester & Fox, 1966; Goodrum, Hackling & Rennie, 2001; Tobin & Fraser, 1988; Yager & Lutz, 1994). Encouraging students to role play and discuss their own mental models can provide such opportunities (Aubusson et al., 1997). Yet student generated models are rarely successful, according to Harrison and Treagust (1999). Nevertheless, though student designed role plays are rarely reported, these reports indicate positive learning outcomes for primary (Cosgrove, 1995) and secondary (Aubusson et al., 1997) science students. Cosgrove showed that, over a series of lessons, primary students could develop a role play, model of electric current, where the electrons-children acted as energy carriers. Aubusson et al. (1997) reported three case studies of student produced simulation role plays developed in three secondary classes in which students designed and performed their own role plays to model electric current (in two classes) and the circulation of blood in a third class. Both studies claimed the role play analogical modelling had been successful, but this begs the question, 'what do we mean by success?' when using modelling as a learning strategy and role play as analogical modelling in particular.

We assert that an analogy is successful not when it most accurately portrays ideas per se but when it promotes conversation, central to producing, evaluating and modifying the analogy, that helps students to clarify and to improve their scientific understanding. All models are flawed and hence all models break down (Maksic, 1990). There is always the danger that students may confuse the model with reality or the classroom analogy with the scientific theory it is designed to emulate (Harrison, 2000). A good analogy of itself does not portend good learning. Indeed there is a danger that efforts could be misplaced in seeking analogical perfection in the expectation that there is 'a holy grail to explain the phenomena' (Heywood, 2002, p.239). The break down of an analogy is not of itself a bad thing as it is, in part, by identifying, analysing and (perhaps) improving the analogy, that learning occurs.

When using models, learning is more likely if the analogies are negotiated (Treagust, Harrison, Venville & Dagher, 1996). Harrison and Treagust (1999) note that this is consistent with science viewed as community seeking consensus but cautions that "classroom negotiation will not construct scientists' knowledge per se" … but "negotiation does help students construct … science understanding" (p.423). Given that students are likely to understand phenomena and scientific theories less well than their science teacher and scientists, their models are more likely to break down. However, they have greater, not less, potential to engage students in analysis of *their* analogy. Comparing attributes of the base and target to determine and analyse the points of agreement, disagreement and ambiguities may lead to extensive consideration of their own thinking, its strengths and weaknesses. Though, there is a risk that students may attend to the extraneous attributes of the model without recognising the significance of critical explanatory attributes (Gilbert, & Boulter, 1989). As a consequence misconceptions may be further entrenched or develop rather than replaced or altered. Nevertheless, their own models provide a way to teach from "where the students are at", to connect with contexts relevant to students and build on or modify students' initial views. The 'success' of student generated analogical role play cannot be judged alone by the degree of perfection of the role play generated independently of the discourse involved in its construction, enactment and review. Sometimes, the role play proceeds through many iterations over many lessons and the 'final' role play may never satisfy all students, particularly those who best recognise its flaws. Nevertheless, students may still exhibit ample evidence that they have developed better scientific understanding of phenomena under investigation. This is well illustrated in the case study of Steve Fogwill's junior secondary class's self constructed role plays of electric circuits, first in small groups and then as a whole class discussing and selecting the best features from each group's role play (see Aubusson et al., 1997). The next section of this chapter reports a recent episode in analogical role play over a series of lessons with a senior chemistry class. This episode is based on guidelines for analogical role play recommended in Aubusson et al. (1997). The final section of the chapter then discusses the effectiveness of the strategy.

3. A THREE LESSON SEQUENCE OF ANALOGICAL ROLE PLAY

First the context in which the role plays arose is described. Then descriptions are used to illustrate significant episodes of the role play process and thinking. Each of these is framed by a short commentary.

3.1 Context

Steve, coauthor of this chapter, is a science teacher in an Australian coeducational senior secondary government school. Peter, also coauthor, is a lecturer in science education. They have worked together on three research projects investigating approaches to teaching in science. One of these studies focussed on role play. Peter was aware that Steve had continued to use role play in his science teaching and invited Steve to collaborate to explore the role plays that were integral to his teaching. Steve later described the process as follows:

> I thought it was a good chance to delve further into what I do with my students. Peter acted very much as the academic and critical friend in talking through the role play processes I use with my students and helped me to decide which examples to report. As it turned out Friday afternoons was a time when it was possible for the two of us to sit together and talk. Peter came to the school approximately every fortnight … During our sessions we discussed and made notes about the various facets of the role play process I encourage my students to use. E-mail communication using editing tools took over (from face to face meetings) as the chapter came together.

Sometimes parts of the chapter were written together at the school. At other times Peter would draft sections based on our conversations and notes. Then these would be passed to and fro electronically as information was checked and ideas developed. The voice of the chapter is now neither Peter's nor Steve's but reflects agreement on ideas and perceptions arising from their interaction.

> To facilitate deeper understanding of the methods we use on a daily bases in our classrooms and encourage the sharing of those methodologies that can enhance learning, I encourage others to work in partnership with similarly motivated academics. (Steve in response to an inquiry from a chapter reviewer about the writing process and voice of 'teacher' and 'academic'.)

Steve often uses role play in his teaching and has a reputation among staff and students for doing so, partly because it is considered an unusual, even odd, teaching practice. The series of role plays reported here was the first occasion that he had used role play with his year 11 (16-17 year olds) chemistry class. They had done a practical investigation: 'The extraction of Copper from Copper Carbonate'. In the investigation, copper carbonate was reacted with dilute sulfuric acid forming copper sulfate. Copper electrodes were placed in the copper sulfate solution and copper was collected at the negative terminal. During this process, the solution stayed blue. This electrolysis was repeated with carbon electrodes and the solution lost its colour. Students enquired about bubbles that formed at the positive terminal and discussion led to the addition of universal indicator showing that an acid was formed as oxygen bubbled off and hydrogen ions went into solution (replacing the copper). After completing the practical, students used molecular model kits to interpret what they had observed and explain what happened to the ions in the chemical reactions. During this modelling process the molecules were constructed. These were then broken up into models of ions. The ions were placed on a table (representing a beaker). Two metre rules, placed on the table, represented the positive and negative electrodes. Students were asked to demonstrate what they thought was happening to the copper ions during the electrolysis phase of the practical activity. This modelling was led by the teacher (Steve) and during the process, their was further discussion about the chemical reactions that had occurred. Students were able to demonstrate that copper ions were attracted to the negative electrode and sulfate ions to the positive electrode.

In the following lesson, the students then were asked to write their response to, “Explain the path of copper in the process” (of extracting copper from copper carbonate). This had been thoroughly outlined in the class discussion when using model kits. Steve explained that, at the time, he “thought this would be the culmination of a series of four, 50 minute lessons. The expectation was that they would have learnt, understood and simply demonstrated this understanding”. Reading the responses to the question revealed a wide range of understanding. Several students either had understood little or simply could not express their understanding. The following student statement was embedded in one of the best responses. “The Cu^{2+} (copper ion) is +2 and because it has two extra protons, it was attracted to the SO_4 which has two extra electrons”. It indicated a possible misunderstanding of how the copper becomes an ion (perhaps gaining protons rather than losing electrons). In a follow up discussion, she explained that she meant that in the copper ion, there were two more protons than electrons. She agreed what she had written could be misinterpreted. This student took a leadership role during the role play construction. Another student’s response was more typical and indicated a lack of attention to ion formation. Something that was an integral part of the learning tasks. “The copper carbonate reacted with the acid and the copper came out. Then the copper atoms went to the electrode”. Discussion with this student revealed that he had not understood the ion formation of copper at all.

3.2 Description Lesson 1

Steve decided to use a role play to help students clarify and develop their ideas because he thought it would help them to visualise the chemical reaction and verbalise their ideas about the chemistry.

The students were asked to assemble as one large group of fifteen to consider the practical they had done; the reaction that had occurred; and to design their own role play to show what they thought was happening to the atoms, ions and molecules in the extraction of copper. The challenge was for them to show what they knew and to enhance their understanding by constructing a role play to represent the culmination of the class's ideas. Part of the requirement was that they talk through what they were representing in each feature of the role play as they developed it. An expectation was that, while they were seeking understanding through role play models, they would eventually need to be able to express their understanding verbally. Hence the role play model needed to generate a clearer understanding that could not only be presented as a role play but also represented orally and later, in writing.

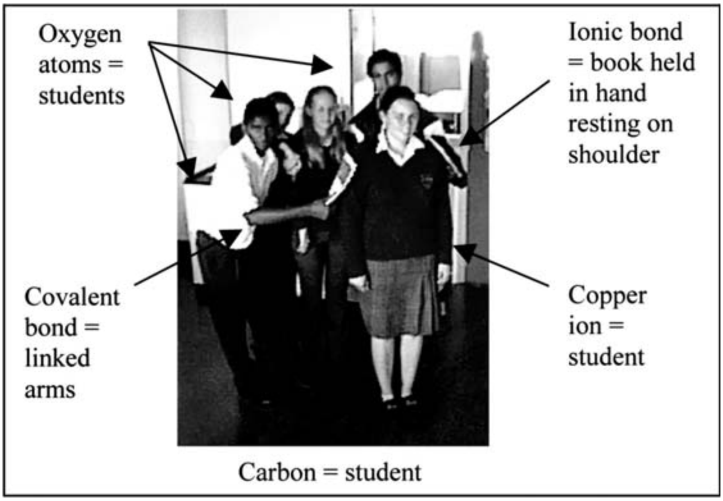

Figure 1. Student generated role play

The students made the copper carbonate molecules with five students (Figure 1). They put labels on themselves, for example, the copper ion students wore a Cu^{2+} label. Four students represented the carbonate ion (CO_3^{2-}), one was carbon and three others were oxygen atoms. They represented the covalent bonds between carbon and oxygen by linking arms. One oxygen student linked both arms with the carbon atom representing a double covalent bond. The other two oxygen students formed a single covalent bond by linking one arm with the carbon student. These two also held a book in their other hand, representing an "extra electron". The students explained that they were trying to show not only that the carbonate group was negative but also the location of the "extra electrons". The students decided to model the copper with a student who held her arms by her sides (representing a lack of valence electrons to share). The two oxygen students with the extra electron (book), held their books (electrons), resting on the shoulders of the copper ion to represent the ionic bonding. Here the students were showing how they thought the copper ion was held in the copper sulfate molecule.

When the clump of students representing the copper carbonate entered the water the carbonate group of four students separated slightly from the copper ion student. The oxygen students in the carbonate group retained the electron books, leaving the ion negative and in solution. The copper student with arms by her sides was now a positive ion in solution. The idea discussed by students, that they wanted to convey in the role play, was that the copper ion was stuck to the carbonate because it (the copper ion) was positive and was attracted to the negative oxygen atoms on the carbonate ion. But, when they were in the water, the water somehow separated them. This was all revealed as they were talking about and designing and modifying their role play.

3.3 Commentary

The role play and associated discussion revealed what was known and unknown. The students knew that water interacted with the copper carbonate but didn't know precisely how. Initially, Steve allowed this to pass at the time of the role play development. The role play and associated discussion had served a diagnostic function and indicated what needed to be considered in future lessons. Later in the lesson Steve raised this problem, "how did water contribute to dissolving ionic substances?"

In this part of the role play event, the students had demonstrated dissolving with copper carbonate separating into its ions. Others in the class had similarly constructed a model of sulfuric acid (an H_2SO_4 molecule) out of people and books. One group of students formed copper carbonate and another sulfuric acid (H_2SO_4). The students used the same principles to model the H_2SO_4 molecule as had been used to model the copper carbonate. They had worked as one team to use themselves to model different aspects of the chemistry. Each had considered and responded to the others' ideas as they were represented in the role play.

3.4 Description Lesson 2

During lesson two of the role play, the two groups of students interacted to show the reaction between copper carbonate and sulfuric acid. It was interesting to watch students construct their ideas about bonding and recombination of atoms and ions. During the formation of carbon dioxide for example, when one student saw the single linking of arms between the two oxygen students and the carbon person she commented, "No, No. You have to hang on with both arms because it's a double bond".

The $CuCO_3$ students dumped themselves into water (the air around them) and dissolved themselves. They showed this by moving apart, leaving a gap between the copper ion person and carbonate group of students. Then the H_2SO_4 group with a similar small gap between the two hydrogen ion students and the sulfate group of students, moved over for the reaction. In the process, the copper joined with the sulfate, standing close to the two sulfate group's oxygen atoms that held spare electrons (books). The oxygen students in the carbonate group kept the electrons (books) when the copper left.

The two hydrogen ion students that left the sulfate group, joined with an oxygen student from the carbonate group forming water. Here there was an interesting moment when the students realised that for the oxygen atom to join with the two hydrogens, the oxygen would need to take both books (electrons). They worked out that this was fortunate for them since it allowed the other oxygen (the one that gave up the book) to form a double bond with the carbon atom.

The students then decided that the carbon dioxide students were "not in it any more". As they were a gas, they bubbled off and were not further involved in the role play. The carbon dioxide students, represented this by standing off to the side.

3.5 Commentary

When modelling the reactions, the covalent and ionic bonding posed some problems for the students. The students were not sure how to represent water using the models that they had developed for the oxygen and hydrogen when they were part of copper sulfate and sulfuric acid. In particular, the so named “oxygen girl”, who formed the water, took both the electrons (books) with her when she went over to form the water with the two hydrogens. When the hydrogen and oxygen students came together, they couldn’t decide what to do with the electron books that she held. They tried the oxygen touching them on the hydrogen but rejected this, one saying, “No. That’s an ionic bond. That’s not a covalent bond.” The alternative was for the oxygen and hydrogen to link arms mimicking the covalent bond formed previously but they were dissatisfied. They still said, “What do we do with the books (electrons)?” They were having fun, were amused and laughing but trying to think through the problem. They were genuinely trying to work out and represent what happens but also were aware that at some time in the future they could be expected to write about the reaction.

One of the key benefits of the role play was that it promoted student conversation and the use of language associated with the chemistry. Students said what they thought about the reaction and clarified their understandings. As part of this process the students got feedback, both from the model and each other’s responses to their ideas. There was a little confusion about how to “turn an ionic bond (which seemed to be forming in the role play) into the covalent bond” (which they knew was formed). There was difficulty adapting one model to work effectively in the other. For example, in solving the issue in organising the hydrogen and oxygen electrons (books) in the formation of water, the books (electrons) were put aside and students simply linked arms to represent a covalent bond, as they had done before.

Such imperfection in the role play was no disadvantage. It was useful as it helped identify things to be considered and clarified. Identifying the imperfections seemed to reinforce the notion that the role play model was not real but a representation of views. The identification of mismatches between the role play and what is known or observed also encouraged students to improve the role play to better represent and review their ideas. Often the students were dealing with the implicit question, “how could they alter the model to show more clearly what they thought was happening?” It is also apparent that the process did not merely involve presenting their initial ideas about the reaction in a better way but rather the modelling helped them to generate deeper understanding of the chemistry and to represent this understanding both verbally and as a model.

3.6 Description Lesson 3

The students moved on to role play the next part of the reaction, where the copper sulfate was electrolised, forming copper at the negative electrode. They decided they had to have water taking an active role. They realised that water played an important part in the reaction (see above) in the first role play but seemed unsure how it contributed to dissolving. As they did not have enough students to play the role of water in lesson one, they had ignored the matter for the time being. To them, at the time of lesson 1, it was not crucial to thinking through the reactions because water was not a reactant. They had compromised by having the air as the water but were not now satisfied with this solution. In lesson 3, they extended the role play to account for the formation of copper at the negative electrode. They wanted to use a water molecule to take the copper ion to the negative electrode that they represented with a chair. They had a sulfate ion made of five students, the same copper student and three students who had made the water molecule. All these had been modelled in the earlier role play (see above). By this time they discarded the books and used linked arms to represent bonds. The sulfate students went to the positive electrode. The oxygen end of the water molecule 'pushed' the copper to the negative electrode, a seat with two books (electrons) on it. Then the copper student picked up the books and happily (now being "a complete atom" according to the student) sat down on the electrode seat. The SO_4^{2-} was just hanging about and they were not sure what to do with it. They commented that they had seen bubbles in the experiment and that they expected the sulfate ions went to the positive electrode. They speculated that this may have had something to do with the bubbles. While this was not role played it was discussed. They were not sure what was happening and therefore could not construct a model. Steve reminded them of the indicator test performed during the experiment, explaining that when oxygen was produced an acid was formed and this had turned the universal indicator red. They went on to further consider this matter in later lessons.

3.7 Commentary

In the role play, the students decided what was important to model in order to explain the observations they had made and to represent the knowledge they brought to bear on the problem. There were limitations to their understanding. There were some observations they were not yet able to explain or ready to model. More importantly, through the process both students and teacher became aware of where the edges of their understanding lay, where to go next and suggested how to build on the ideas that had already developed.

4. DISCUSSION

Some students were initially reluctant to be involved in role plays but once they tried it they admitted that it helped them to understand the reactions. Experience has shown Steve that, getting students to try role play as modelling for the first time, requires him to be enthusiastic and encouraging to convince them that it is a worthwhile learning experience. In this senior chemistry class, only one student needed additional encouragement to be involved. Developing a classroom atmosphere where students can do and say things without fear of failure, to be able to express ideas and hypothesise with confidence helps to create a classroom environment where role play models work well. Student generated role play, in turn, promotes such a classroom environment.

The role play provided physical, concrete models to represent different ideas about chemical reactions. Interaction between students ideas and representations in the role play was moderated by their discourse; they expressed their views and evaluated the merit of both their views and the ways in which their views were represented. They subjected their ideas to scrutiny, as well as sensitising the way in which the ideas were portrayed by their role play. The role play enabled their ideas to be viewed and subjected to scrutiny – tested against other ideas, observation and evidence derived from the modelling. They built their role play on their initial understandings but also clarified and developed better understandings. Critical to this seems to be keeping the role play dynamic and evolving. By this we do not mean that it merely involves people moving but rather that the role play should not be a fixed rendition of a set of ideas, proposition or theory. Rather it should be flexible and progressively modified contributing to ideas and modified as the new ideas develop. In this way, ideas can be represented and visualised more easily, manipulated, scrutinised and developed.

The role play is always an imperfect representation of that which it attempts to model. There is a danger that it may mislead. However, we contend that students are often aware of the shortcomings of their models, as was the case in the role play described here. They chose to focus on some salient aspects of their models and ignore others. There is a risk in analogy that students may attend to trivial or inappropriate aspects of an analog and ignore the critical or relational features. A role of the teacher is to help students to focus on critical evidence, observations and understandings related to the phenomena as well as critical attributes of the model. Students often fail to see what the teacher knows to be important and this problem is not limited to science. For example, an English teacher was having trouble explaining to her class what a moral was in a story. Being a good teacher she illustrated the point with an example, one of Aesop's fables. She told the story of a dying man who told his children that he had buried his fortune in the orchard. After his death the children dug throughout the orchard looking for the buried treasure. In time the orchard blossomed and bore fruit. Fruit was taken to market and sold. Unwittingly the children's hard work had made them wealthy, while they ever cursed their father. Having completed the story, the teacher asked her students what the moral or main message of the story was. A student raised her hand, shaking it, demanding the chance to answer the question. When asked, the student responded with certainty, “Never trust your father!” There is little doubt that analogy, fables and parables have been part of human learning since humans first began to share ideas in speech but they are open to misunderstanding, particularly when the trivial attributes are mistakenly appropriated and transferred.

One of the advantages of using students’ self designed analogies is that the students themselves not only determine but also make explicit which aspects of the analog and target are important, which parts have explanatory value and attempt to model these. Hence, their thinking is revealed to both teachers and peers. Both teacher and peers engage in conversation to clarify the explanation, the model and purposefully explore the attributes which are salient to understanding the phenomenon. The presentation of the role play model is crucial to learning through analogy. It provides a concrete representation but the explanation (the story) that students provide with their role play gives the representation meaning. A student going to a chair, picking up some books and sitting down has no intrinsic meaning in chemistry. The associated explanation, however, where the girl is the copper ion, the books are electrons and the chair the electrode does have meaning. This representation provides a shared basis for conversation about the phenomena under study. We argue that much of the learning that occurs is brought about by the discourse associated with the analogical reasoning rather than by the role play per se.

5. CONCLUSION

The evidence that analogical role play provides a motivating, interesting and enjoyable way to sustain student engagement with ideas may be reason enough to include the strategy in the teaching repertoire. But analogical role play provides much more than affective gains. Role plays can be used to portray ideas and promote discussion. As the role plays evolve in response to this discussion they provide a powerful way to encourage students to think scientifically through analogical reasoning. The dialogue used and developed in the process of producing and analysing the role plays contributes to a successful learning experience. It not only helps to enhance understanding of the concepts being studied at the time but fosters learning during discussions in subsequent lessons.

It is tempting to avoid analogical role play, particularly where the students construct their own model, because the model must by its very nature be incorrect. Yet in classes such as Steve's, the thinking and learning which occur are difficult to deny.

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GREGORY P. THOMAS

METAPHOR, STUDENTS' CONCEPTIONS OF LEARNING AND TEACHING, AND METACOGNITION

1. INTRODUCTION: METACOGNITION AND THE NEED TO CONSIDER STUDENTS' CONCEPTIONS

As a teacher I have always been interested in how students learn. My experiences in schools and now universities has seen me continually question how to teach students how to learn and, more recently, how to teach pre- and in-service teachers to teach their students how to learn. I see these tasks as central to education, especially given the pace of change in the world and the importance of learning and thinking efficiency in all spheres of human endeavour. Not surprisingly, while a teacher, this interest led me to investigate and use the thinking skills programmes, such as de Bono's CoRT program (de Bono, 1988), that were prominent in the 1980s and early 1990s. However, overriding the use of such practical programs was my interest in the substantive issue of metacognition which I define as an individual's knowledge, awareness, and control of his/her thinking and learning processes and strategies and also his/her knowledge of others' learning processes and strategies. My investigations into metacognition and how to develop and enhance students' metacognition led me to question many of the so-called 'thinking' activities and thinking programs in schools. I found it necessary to question a widely-held belief among many educators and colleagues that students would develop metacognition and learn how to learn well simply according to whether or not teachers employed certain classroom teaching and learning activities; even powerful strategies used in science education such as Predict-Observe-Explain (POE), Concept-Mapping and Venn Diagrams. My position was and still is that these activities are extremely valuable for helping students to learn science. This view is supported by abundant empirical studies in science education. Their value lies in their use as tools that enable students to transform their ideas and thoughts into tangible, often two-dimensional written or drawn artifacts that can then be

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reviewed, scrutinised, and possibly modified. However, I argue that using them by themselves is not sufficient to maximise the development and enhancement of students' metacognition. There is a need for students to have opportunities to consciously reflect on these strategies and assess their viability in relation to their own learning contexts. When and if students do so, they will use their conceptions of teaching and learning as referents in the reflective process. If teachers do not explicitly encourage such reflection, the opportunities for students to develop metacognition are greatly diminished.

It occurred to me that, just as there was a need for cognitive tools such as POEs and concept maps to enable students' science concepts to be made tangible and available for scrutiny, there was a need for a tool that could be used to make students' conceptions of learning 'visible,' subject to scrutiny and possibly to change. Further, such a tool might enable teachers and researchers to present what might be, for students, alternative conceptions of teaching and learning to them to consider. I saw this as essential because what has become increasingly evident over the years is that students are not passive players in the schooling process. Rather, they are key determinants of what occurs in classrooms and what learning takes place, even if the teacher supposedly wields considerable authority. Students bring to classrooms their own conceptions and beliefs about teaching and learning which influence their behaviours and cognitive processes and, therefore, the behaviours of teachers and the learning environments of the classroom. Their conceptions of learning are essential elements of students' metacognitive knowledge. However, such conceptions are most often tacit, difficult for students to elaborate, and therefore not the focus of discussion between teachers and students. In this way they are similar to students' alternative science conceptions that may be strongly held and that have been shown to influence students' learning of canonically acceptable science. Just as there is a need to acknowledge and understand students' conceptions in relation to science and to assist students to become aware of such conceptions and to modify them where necessary; so too is there a need to engage students who might possess inappropriate, possibly maladaptive conceptions of teaching and learning for their learning context in the processes of making these conceptions explicit, available for review and subject to processes akin to those of conceptual change. Therefore, the tool that I was searching for as a teacher needed to be flexible enough to facilitate two tasks:

1. to make students' conceptions of teaching and learning 'visible' and therefore available for scrutiny; and
2. to enable viable conceptions of teaching and learning to be communicated intelligibly to students so that they might assess their plausibility and consider their potential viability and value.

2. ENTER METAPHOR

Around the time I was searching for my 'tool' the writing of Ken Tobin and his colleagues (Tobin, 1990, 1993; Tobin & Tippins, 1996) came to my attention. Tobin had been using metaphor as a tool for helping teachers to make explicit their tacit conceptions of teaching and learning. In trying to shift these conceptions to be more constructivistly oriented, with the ultimate aim of changing teachers' behaviours, they had achieved some success. Tobin had used metaphor as a master switch to assist teachers to change these conceptions and, in so doing, their teaching behaviours. Such aims with teachers struck me as being parallel with my aims for my students. Therefore, I asked myself, "Could I too use metaphor with my students?" Metaphor appealed to me because it was a language device and was congruent with my constructivistly oriented view of how to improve science education and my own teaching. Language, according to von Glasersfeld (1996, p.7), "enables the teacher to orient the student's conceptual construction by precluding certain pathways and making others more likely". Further, as the primary form of figurative language, metaphor is central to the way language works (Bartel, 1983; Richards, 1936). I decided my question was worth seeking an answer to and so I set about trying to understand 'metaphor,' my potential tool.

3. DEVELOPING A PERSPECTIVE ON METAPHOR

The literature on metaphor is extensive, bridging linguistics, literature, psychology, and sociology. Therefore, I began by reviewing the literature that others in science education had referred to and this led me to the literature beyond science education. It quickly became apparent that metaphor was seen from a variety of perspectives. Theories and notions of metaphor are historically, socially, and linguistically determined and these variable determinants may explain the lack of a universally accepted theory of metaphor (Hawkes, 1972). Metaphor coexists with analogy as a variant of figurative language with metaphors and analogies being close relatives in that the terms metaphor and analogy are sometimes used interchangeably. Substantive similarities have been identified between metaphorical and analogical thinking to the extent that analogy might be considered a necessary condition for metaphor. Metaphors suggest some form of objective analogy, without stating explicitly in what the analogy exists.

I consider that two noteworthy perspectives of metaphor are evident. The first of these is what I term a structural, pragmatic perspective. It refers to understanding elements of metaphor and how each of these mechanically operates to create new meaning. From the literature, I adopted a blend of terminology from Richards (1936) and Indurkhya (1992) to conceptualise the elements of metaphor that were salient to my purposes. The word 'target' was adopted to represent the term or concept that is clarified or amplified in the metaphor. Providing a sense of directionality in a metaphor is an important facet of metaphor interpretation and construction and use of the term 'target' provides this directionality; some characteristic is 'aimed' at the target. The term 'source' was adopted to represent that which is known, the secondary subject that is used to characterise, clarify or amplify the target. Source is synonymous with origin and was chosen to reinforce the understanding that a characteristic that is transferred to the target in a metaphor has its origins in the source of that metaphor. The term 'ground' was adopted as it is suggestive of a 'common ground' relationship between the target and source. An individual constructs understanding of a metaphor when his/her understanding of the source is related to, and compared with, his/her understanding of the target. The shared elements of these two sets of understandings constitute the ground. This conceptualisation was consistent with that 'taken' across the literature; that an individual's comprehension of a metaphor is "guided by interpretive frames of reference that are grounded in their prior knowledge or experiences" (Weade & Earnst, 1990, p.134). As a teacher who held constructivist views, such an acknowledgement of the importance of prior knowledge in the interpretation, the development of metaphors was crucial for my appreciation of how they operate to create new meaning and how they might reflect what individuals already perceive to be evident. Further, the degree of dissimilarity between target and source in a metaphor results in the ground of the metaphor being initially hidden. The metaphor surprises its audience, provoking anomaly and producing emotional tension within its audience. I saw such tension as important as it seemed appropriate to use the tension invoked by metaphor to assist students to confront their beliefs, their tacit knowledge, and their understandings of what learning is.

The second perspective is what I refer to as a conceptual perspective. It reflects the writings of Lakoff and Johnson (1980) and Lakoff (1993, 1994). Metaphors are seen as metaphorical concepts, that is, those organising, structuring concepts that undergird our talk and give rise to sub-categorisations of the metaphorical concept that bear connection to the central 'them' of the metaphorical concept. Cooper (1986) argues that metaphorical concepts are overarching, commonly shared understandings that shape discourse and social cognition and that they are used in conversation to effect or to cultivate familiarity, custom, or intimacy between speakers. People's culturally acceptable interpretation of specific metaphors and their shared linguistic knowledge of established metaphorical practice develops this intimacy and enables them to interpret other related metaphors and expressions. If, as Lakoff and Johnson asserted, our language is metaphorically structured, then by examining students' metaphors for learning and their roles as learners we might be given a window into their culture in relation to teaching and learning. Further, because Lakoff and Johnson suggested that, as well as defining everyday realities, metaphors create the possibility of new social realities for us by getting us to try to understand how a metaphor, not previously considered, may be true or could be made to be true, I saw the potential of creating new social realities for my students about what constituted learning. This potential was similar in orientation to Tobin's for using metaphors to create new realities for teachers.

Both perspectives of metaphor seemed useful to me. Firstly, students might be able to express the essence of their understanding of learning and their roles as learners in science classrooms through metaphor. To do this they would need to consider their possibly tacit conceptions of learning and teaching and seek to identify or to develop a metaphor or metaphors in which the target concepts of teaching and learning were informed by their choice of the source concept. Secondly, I might be able to use a metaphor that reflected a constructivist conception of learning to inform students of what for some might be new possibilities in relation to how they conceived of learning. This might consequently lead to students modifying their knowledge, control and awareness of learning and their learning processes, that is, their metacognition. Thirdly, I might be able to, as Tobin had done with teachers, use changes in students' metaphors to monitor changes in their conceptions of learning and seek correspondence between any such changes in their metaphors with congruent changes in their learning processes. In what follows I draw on my research into each of these potential uses of metaphor and draw conclusions related to the efficacy of metaphor for each potential use.

4. AN INITIAL INVESTIGATION OF STUDENTS' USE OF METAPHOR: GROWING IN CONFIDENCE

My preliminary investigation into students' use of metaphor took place in 1995 with secondary school science students (14-17 years old). I was immediately impressed with how students could use metaphor to communicate what they considered key elements of their conceptions of their roles as learners and the roles of teachers. A review of some examples of different students' metaphors from a preliminary study (Thomas & McRobbie, 1995) points to some interesting elements of the metaphors. Students' metaphors entailed varying levels of active processing and passive acceptance of information. Further, different views of the roles of teachers are evident in some metaphors.

The view of the student as an information recipient and storer of information is evident in metaphors (b) and (c) in Table 1 as well as in the illustrated metaphor shown in Figure 1. Such a view of the role of the student is widespread in educational and social thought and reflects the cultural press about what is meant by learning science (McRobbie & Tobin, 1997). However, it is widely criticised (e.g., Scheffler, 1991) because it places the student in a position where passive acceptance of information from the teacher is the norm and the student has no independent motive or expression of choice.

Following this study I was more confident that students understood and might be able to use metaphor to communicate their conceptions of teaching and learning and the roles of students and teachers. The initial study was followed by a larger interpretive case study (Thomas, 1999; Thomas & McRobbie, 2001) in which I, as a participant observer, sought to explore in more depth the aforementioned potential uses of metaphor with my class of Year 11 chemistry students in a non-streamed Australian school. In this study I triangulated data from multiple sources that included student journals, semi-structured and stimulated recall interviews, the Learning Processes Questionnaire (Biggs, 1987), and video analyses to build metacognitive profiles of individual students and to propose credible and trustworthy conclusions regarding the efficacy of metaphor for use with students in relation to the three aforementioned potential uses of metaphor.

Table 1. A selection of students' metaphors for communicating conceptions of teaching and learning and the roles of teachers and students

Metaphor	*Entailments of the metaphor and interpretation*
(a) I am an ant. I like to find my own food. However, sometimes I pick up too much food (information) at once and I have to break it down. When I get too much food I don't know what to do. Sometimes I leave it and find something else to eat…other times I make the effort to divide my food.	Learning is an active process. Knowledge is like food to be consumed. The student likes to be in control of his/her own learning. Sometimes there is too much information selected that requires that the student feels a need to analyse it. However, sometimes the student will ignore the situation of too much information and prefer to find new information.
(b) I am like a container with some leaks because I take in information but some leak out after a while. I do not refill with the same information. I would like to be a container with no leaks because I take in the information and it stays there and does not need to be filled with the same information.	Learning is about storing information. Some information is forgotten and needs to be taken in again and re-stored. When information is forgotten new information takes its place. The student has a preference to improve his/her information storage capacity and make learning more efficient.
(c) A teacher is like a caterer who serves up information rather than food. The students don't always enjoy what they are being fed, so the caterer tries to make it more interesting. It is still the responsibility of the student (not the caterer) to eat.	Teaching is about transmission of information. It is the responsibility of the teacher to make the diet interesting for the consumer but it is still the consumer's responsibility to take in the information.
(d) Being a chemistry student is like being on a merry-go-round and the teacher is the operator. His job is to make sure everyone stays on course and does not fall off, but has fun doing it.	The teacher sets the directions about what students' are to learn. The teacher's responsibility is to ensure that all students make progress and do not fail, and to ensure that the learning is a fun process.
(e) I am a mountain climber. Before I take the next step up the cliff of the mountain my last step must be secure. I don't take the next step until I'm satisfied with the present one. As a learner I will not attempt the difficult questions/ideas/issues if I don't know the basics. The basics are my foundations. If I climb too quickly the mountain will shake.	Learning is sequential, a step-by-step process that requires that the student understands the basics and does not try to learn new material unless the previous material has been understood. If the student tries to learn new material or attempt new problems before the past material is understood this can be problematic.

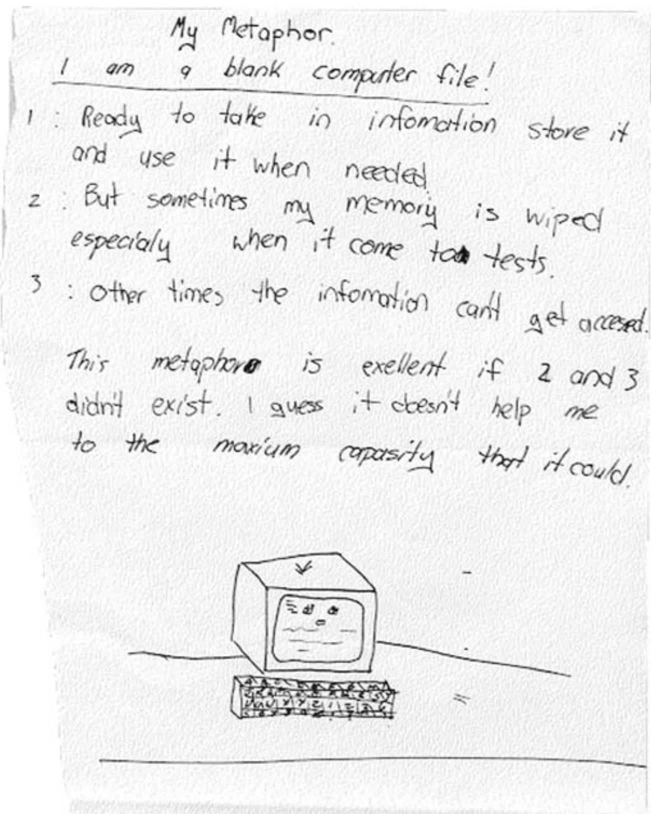

Figure 1. A Year 9 student's metaphor highlighting passive learning tendencies. (Thomas & McRobbie, 1995, p. 11)

5. METAPHOR AS A MEANS OF PROBING STUDENTS' CONCEPTIONS OF TEACHING AND LEARNING

One question that came immediately to mind in the larger study, and that built on the 1995 study, was whether there was congruence between students' metaphors and their learning processes and their classroom environment perceptions and preferences. This was a prominent question because I saw a need to evaluate the credibility of students' metaphors in a more robust manner if they were to be used as evidence in relation to, and as representations of, students' conceptions and learning processes and any changes to those conceptions and processes. If there was evidence to support congruence then I might be able to propose that students' metaphors could be used as historical markers for their conceptions of teaching and learning and of their learning processes at any given time and, therefore, able to be used in pre-and post- fashion to monitor changes in such conceptions and processes. In answering that question McRobbie and I (Thomas & McRobbie, 1999) reported that, (a) students were able to use metaphor to describe themselves as learners in their chemistry classroom, (b) students' metaphors were congruent with their conceptions of their roles as learners, their learning processes and their classroom environment preferences, and (c) students' metaphors were sensitive to and highlighted different personally prominent aspects of their conceptions that each individual student perceived was significant at the time of the research. One student, Beverly, outlined her metaphor as follows:

> My learning is a person eating an apple. Slowly but surely I nibble my way through my chemistry, absorbing all the nutrients and letting the unimportant stuff pass out the other end. Just as I enjoy eating apples and they are good for me – my chemistry is also good and I enjoy learning (eating) it. The core of the apple is the test at the end of the unit and every new unit is a new apple. The core gets chucked away but all the nutrients from the previous apple are in my body still and this helps my brain to comprehend new topics (i.e., I refer to stuff I learnt in my previous topics to help me understand new stuff.)

Beverly was a highly motivated achiever in chemistry. She was diligent in class and studied chemistry regularly at home at nights and weekends. Chemistry learning for Beverly was characterised by her systematically understanding material through an active process of deconstructing and recoding chunks of information into more manageable pieces. Her learning processes also involved identifying the relationship between new information and her prior knowledge and discarding what she thought was irrelevant detail. Data from multiple sources consistently suggested that, consistent with her high levels of academic achievement, Beverly used significantly more deep and achieving approaches to learning than most other class members. However, the selectivity of Beverly's metaphor is apparent in that, even though in interviews she reported value in collaborating with other members of her class to assist her learning, "if somebody else has a different understanding or they've read different things, or they've drawn from different sources, then you can combine your ideas and come up with a much broader knowledge of the whole thing," the role of such social interaction for her learning is absent from her metaphor. McRobbie and I concluded that, due to the selective nature of what may or may not be communicated by students through their metaphors, metaphor would be most appropriately used as one element of a raft of methods for investigating students' conceptions of teaching and learning and their learning processes.

Interestingly, such a use of metaphor was seen as a highly reflective and metacognitive experience by students. For example, in reporting on her development of her metaphor Beverly suggested, "It (developing the metaphor) made me sit down and actually think about things I hadn't previously thought about, about how I actually learn. I've never had to describe how I learn to anybody before." Such intimations were not uncommon amongst students and their prevalence suggests that, at least in the class of students involved in this study, students' knowledge in relation to their learning processes is indeed often tacit, requiring an opportunity and a means to make it explicit, and not often the object of investigation or reflection in science classrooms.

6. USING METAPHOR TO PRESENT A CONSTRUCTIVIST CONCEPTION OF LEARNING

Having established that students could use metaphor as a means for making their tacit conceptions of teaching, learning and their learning processes explicit, I sought to use the metaphor 'learning is constructing' to communicate with students about a view of learning and complementary learning processes consistent with constructivism. Because constructivism was the epistemological referent for my research and my teaching I saw this metaphor as appropriate. Further, such a view of learning is widespread in the literature (e.g., Fosnot, 1996; Marshall, 1996; Spivey, 1997) with Spivey suggesting that constructivism itself is a "cultural metaphor that belongs to a large group of people interested in communication" (p. xiii). The use of metaphor with students consisted of three elements. Firstly, I presented the metaphor to the students for their interpretation and asked them to identify key factors of the source of the metaphor, 'constructing'. I then asked them to relate these to their existing conceptions of learning. In doing so I recognised that each individual might identify a different ground of the metaphor and that it was therefore important to allow students to identify entailments of the metaphor that were salient for them. Once students had selected personally salient entailments of the metaphor they were given the opportunity to trial processes and activities that were consistent with their interpretations. These interpretations included that learning (a) requires developing a sound base of ideas, (b) requires that ideas be linked together in a firm but malleable structure, and (c) involves monitoring the constructive process. These interpretations suggest that using the metaphor served as a means of communicating valuable propositions about learning that students themselves could identify without difficulty. The ground of the metaphor was very apparent to them and their linguistic knowledge of metaphor facilitated a plethora of entailments. Finally, to reinforce these valuable interpretations of related learning processes, and students engagement with these, I modified my classroom discourse with the aim of illustrating, emphasising, and reinforcing to students the value of the metaphor as a referent for learning and learning processes. Comments from me such as "What ideas can be linked to this new information, and how can they be linked?" exemplified such change in what was said by me in class. Students noted the value of my use of language entailed by the metaphor for maintaining a focus on their conceptions of learning and their learning processes. For example, one student (Debbie) suggested, "You remind us [about learning and learning processes]…at the front [of the classroom] by mentioning constructing and then I think, 'Oh, learning is constructing.' If you weren't doing that then it probably wouldn't happen." Obviously there is a need for teachers to maintain a focus on using a language of learning in classrooms and the short term use of a metaphor for promoting consideration of a particular conception of learning; and the development of valuable learning processes may not be sufficient for some students.

The intervention was influential in acting as a master switch for some students who altered their conceptions of learning and their learning processes. One such student was Tim. Prior to the intervention Tim had little procedural metacognitive knowledge and lacked a language to describe in any detail the learning processes he employed. He found it difficult to come up with a pre-intervention metaphor because, as he put it, "It's hard to decide on what I do." Tim's default metaphor for himself as a chemistry learner was, "I am a calculator… I work for a while and then I switch off... that's just like my brain. If I don't use my brain it'll just switch off and I won't think anymore. All this chemical information goes in… [usually it just goes in one ear] and out the other side." One key concern in relation to Tim's learning processes was his lack of understanding of the value and use of his existing science knowledge for learning new information. As he suggested, "Once I learn [something] I usually think, 'Oh, this mustn't be relevant for anything else'." This lack of associating new information with existing knowledge was a major impediment to his learning chemistry with understanding. During the intervention Tim proposed the following entailments that he thought could be associated with learning: "…labour, you must put in the effort; design, to design something you first need a plan or idea; and joining, joining the knowledge from the past with the present to be able to learn". Tim enacted some of the entailments of the metaphor, altered his learning processes and was aware of doing so, and became increasingly in control of his new cognitive processes. He suggested:

> The metaphor's the principle of the way I learn. I just go on with what the metaphor's taught me. I just think about what we've done in the past, which is what the metaphor's really saying…when I see something new I find out where it fits in with what I've learnt in the past. Way back ago we had a test and we were talking about buckyballs, and I was reading about a week ago that they've now got 120 carbon atoms or something like that; like the next step up from buckyballs. Before we'd done the metaphor I would never have considered those sorts of connections. In the past I just read though [the text] and hope to learn it off by heart. I still read the text… but now when I read, I think "Where does '*this*' fit in with what I've already done?" and "How does it fit?" and I can tell myself "*This* has to do with *that*".

7. METAPHORS AS MARKERS OF STUDENT CHANGE

For Tim and others in the class the metaphor acted as a guide for altering their conceptions of learning and their learning processes and for articulating their newly developed conceptions and processes. These changes were further evidenced in the changes in students' metaphors for themselves as learners. For example, Debbie prior to the intervention described herself as a "person in maze" in relation to her learning. The journey through the maze represented "a struggle but not impossibilities". The maze itself represented "different paths to learning, different ways of learning through different techniques, different ways of dealing with things". Debbie admitted, "I haven't explored many of these pathways". Debbie, like Tim, provided evidence of substantial revisions of her conceptions of learning and her learning processes and these changes were consistent with her post-intervention metaphor for herself as a learner.

> Learning is creating a collage and I am a collage creator. The collage is the overall result, the overall picture that the learner has created…a representation of the learner's mind, the product of learning. Many different materials are used and each material enhances the other and the overall production. Separated from the collage, each different material is of little significance, use and meaning. It's not until it's placed amongst the other materials in certain places that they become useful, accessible and meaningful. By putting them together in a certain pattern they mean something. Concepts/information are placed in/on our mind and are linked by understanding. [I] link different information/concepts with different links. Use the wrong glue on a material and it will fall out of place and wreck the collage. Use a wrong link and the information/concept will be misunderstood and useless.

It is clear from Debbie's metaphor change that, following the intervention, she developed a different, more cognitively oriented and proactive conception of learning and of herself as a learner when compared with her maze metaphor. Her changed conception is also metaphorically structured and carefully considered. The change in her metaphor was also very consistent with changes to her learning processes as reported in Thomas and McRobbie (2001). This was the case for many students. Such intimations from students made it apparent that it was possible that metaphors could be used as one form of evidence of change/s in students' conceptions of learning, of themselves as learners, and of their learning processes even if, as was the case with Beverly's metaphor, the new metaphor only communicated some aspects of the students' total conception. The efficacy of metaphor for use with students seemed clear.

8. CONCLUSION

My strongly held view is that, as well as teaching students science well, there is a need to teach students explicitly about learning, what it means to learn, and how to learn. For students such metacognitive knowledge is invaluable irrespective of their future learning and career paths. However, students possess often tacit conceptions of such matters that are difficult to access and therefore difficult to scrutinise, evaluate, and challenge. To make such conceptions explicit and to teach students about such matters with a view of altering, as necessary, possibly maladaptive conceptions a language tool is necessary. In this chapter I have proposed the following points that demonstrate the value of metaphor as a means of engaging students in metacognitive reflection, development, and enhancement.

- Students can understand metaphor and characterise their conceptions of teaching and learning and their roles as learners using metaphor.
- When students use metaphor to conceptualise their conceptions of learning, their roles as learners, and/or their learning processes it is a highly metacognitive experience.

- A conception of teaching and learning consistent with constructivism can be communicated to students using metaphor.
- Changes to students' conceptions of learning, their roles as learners, and/or their learning processes can be monitored to some extent using metaphor.

The metaphors that we and our students use, both consciously and unconsciously, as referents to guide our thinking and action should be the focus of continued interest and research in science education. Through their explication and consideration we have the potential to improve students' metacognition, their learning of science, and our own teaching, and in so doing meet important goals of science education.

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ROSÁRIA JUSTI AND JOHN GILBERT

THE ROLE OF ANALOG MODELS IN THE UNDERSTANDING OF THE NATURE OF MODELS IN CHEMISTRY

1. MODELS AND MODELLING IN CHEMISTRY

Models play a vital role in chemistry because they can serve a wide range of functions. They can represent complex phenomena, make abstractions more readily visualizable, enable predictions to be made, provide the basis for the interpretation of experimental results, and, most importantly, enable explanations to be devised (Francoeur, 1997; Gilbert, Boulter, Rutherford, 1998; Tomasi, 1988; Rouse & Morris, 1986). These functions are made possible by the scope of their attributes. They can be made to concentrate on different aspects of a phenomenon, being produced for different purposes. The phenomenon represented can be an object (e.g., a distillation apparatus), an event (e.g., the collection of a required distillate), a process (e.g., the progressive separation of types of molecules), or ideas (e.g., the distribution of molecular velocities in a mixture). They are readily adapted or replaced as scientific circumstances require. Lastly, they enable discussion between scientists to take place readily.

Chemistry is essentially a science of abstractions. As a consequence of this, chemists must represent the phenomena they observe (at the macroscopic level), the ideas with which they try to explain such phenomena (at the sub-microscopic level), and a shorthand summary of what is going on (at the symbolic level) (Johnstone, 1993). At the macro-level and sub-microscopic level, models are used to facilitate the visualization of what is happening. In doing so, all the characteristics and roles of models above mentioned permeate chemistry. Chemical models may be static or dynamic. They may be expressed in concrete (three-dimensional), visual (two-dimensional or pseudo-three-dimensional: computerised), and/or verbal modes of representation. At the symbolic level, mathematical equations, or the special language of chemical equations, are used. Moreover, chemists are able to transform models from one mode of representation into equivalent representations into other

P. J. Aubusson et al. (eds.), Metaphor and Analogy in Science Education, 119-130.

modes (Kozma & Russel, 1997). The transformation of models in this way focuses attention on different aspects of them for example, their relationship to quantification, their behaviour through time, and the reproducibility of their behaviour (Boulter & Buckley, 2000). Thus chemical knowledge is produced and communicated with the use of several models, which evolve and are changed as the field of enquiry advances.

Chemical ideas seem to have been visually, verbally, or mathematically, modelled ever since they were first produced. However, the production of the first concrete models for atoms by John Dalton at the beginning of the nineteenth century was as a landmark in the way that models have contributed to the development of chemical knowledge. The visualization of cause and effect became possible for the first time. Following him, leading scientists, such as Kekulé, Van't Hoff, Pauling, Watson and Crick, have made increasing use of concrete models to present visually, develop and discuss their ideas about molecular structures. This enabled them to predict the behaviour of the substances they were modelling and to speculate about the spatial arrangements of atoms and functional groups in their structures (Francoeur, 2000). Molecular models thus became obligatory tools in the study of the stereochemistry, properties, and reactivity, of substances which, in turn, corroborated atomic theory (Francoeur, 1997).

In recent years, computational models and modelling have become comprehensively established in chemical research. Two factors seem to have contributed to this. First, the study of the dynamics of chemical reactions – the mechanisms by which they occur – required the production of more complex models. Static and rigid molecular models, as well as their two-dimension representations (formulas and equations – even when curly arrows are used), were shown to have a limited utility for this purpose. Second, the introduction of quantum mechanics provided chemistry with a new research programme (in Lakatosian terms) which allowed chemists to go beyond qualitative descriptions and even to predict the properties of materials which have not yet been synthesised (Erduran, 2001; Mainzer, 1999). The ability to access large amounts of data on a variety of aspects of chemical substances and to present data at a number of different representational levels (Ealy, 1999) has made computational modelling an essential tool for investigating known and new substances and their transformations. The approach is also vital in probing the properties and uses of new materials – undoubtedly one of the currently most important areas of chemical research.

2. MODELS AND MODELLING IN CHEMISTRY TEACHING

In order for students at all educational levels to develop a comprehensive understanding of chemistry they should come to address all of Hodson's (1992) list of general purposes for science education. They should: (i) come to know the major chemical models (including their scope and limitations); (ii) have an adequate view of the nature of models and be able to appreciate the role of models in the accreditation and dissemination of the products of chemical enquiry; and (iii) be able to create, express and test their own models. Moreover, modelling activities may also provide especially valuable opportunities for teachers to monitor students" progress in changing from their initial mental models to an understanding of established models (Duit & Glynn, 1996). Therefore, the key to the achievement of a comprehensive understanding of chemistry is the act of modelling. It is from building and manipulating a model that we can learn more than simply by looking at a representation of it (Morrison & Morgan, 1999).

An analysis of historical examples of the ways in which modelling resulted in the development of important scientific knowledge shows that this is a dynamic and complex process. Each scientist's reasoning is influenced by both the purpose for a particular model and the whole context in which it is produced. On account of this, there are no general rules for model construction (Morrison & Morgan, 1999). However, in order to guide science teachers in the introduction of modelling activities into their classes, we developed a general framework for the modelling process (Justi & Gilbert, 2002). This is a logical idealisation of what takes place but, in the present absence of classroom-based case studies, cannot be seen as a representation of what actually takes place. This framework is presented in Figure 1 and explained next. In an educational situation, the *purpose* for which a model is to be built must be clear to the students. By having such a purpose in mind, they may focus their attention on the entities to be modelled. These may arise from simultaneous *observations of* and *experience with* the phenomenon. They may be direct or indirect, qualitative or quantitative, depending on both the purpose of the activity and the context in which it takes place. At the same time, students may think about possible *sources* from which the model might be derived. As a result of such a process, an initial mental model would be produced and expressed in a suitable mode of representation: material, visual, verbal, mathematical, gestural. This process of expression may be seen as cyclically developmental in respect of the mental model, with the act of expression leading to a modification of it.

Having produced a model, the next phase would involve testing it. This may start from an exploration of the model's implications through *thought experimentation* conducted in the mind. As Reiner and Gilbert (2000) have commented, it is likely that scientists always mentally rehearse the design and conduct of empirical experimentation. It is only when the outcomes of this mental activity seem successful that actual empirical testing takes place, where this is possible. If the model fails to produce predictions that are confirmed in the thought experimental testing phase, then an attempt would have to be made to modify it and to re-enter the cycle. However, if it passes the thought experimental phase, it would go on the *empirical testing* phase. This would entail the design and conduct of practical work, followed by the collection and analysis of data, and finally by the evaluation of the results produced against the model. If the model fails at this stage, an attempt would have to be made to modify it and subsequently to re-enter the cycle. However, if it passes the empirical testing phase, the student would feel confident that the purpose for which it was constructed has been *fulfilled*.

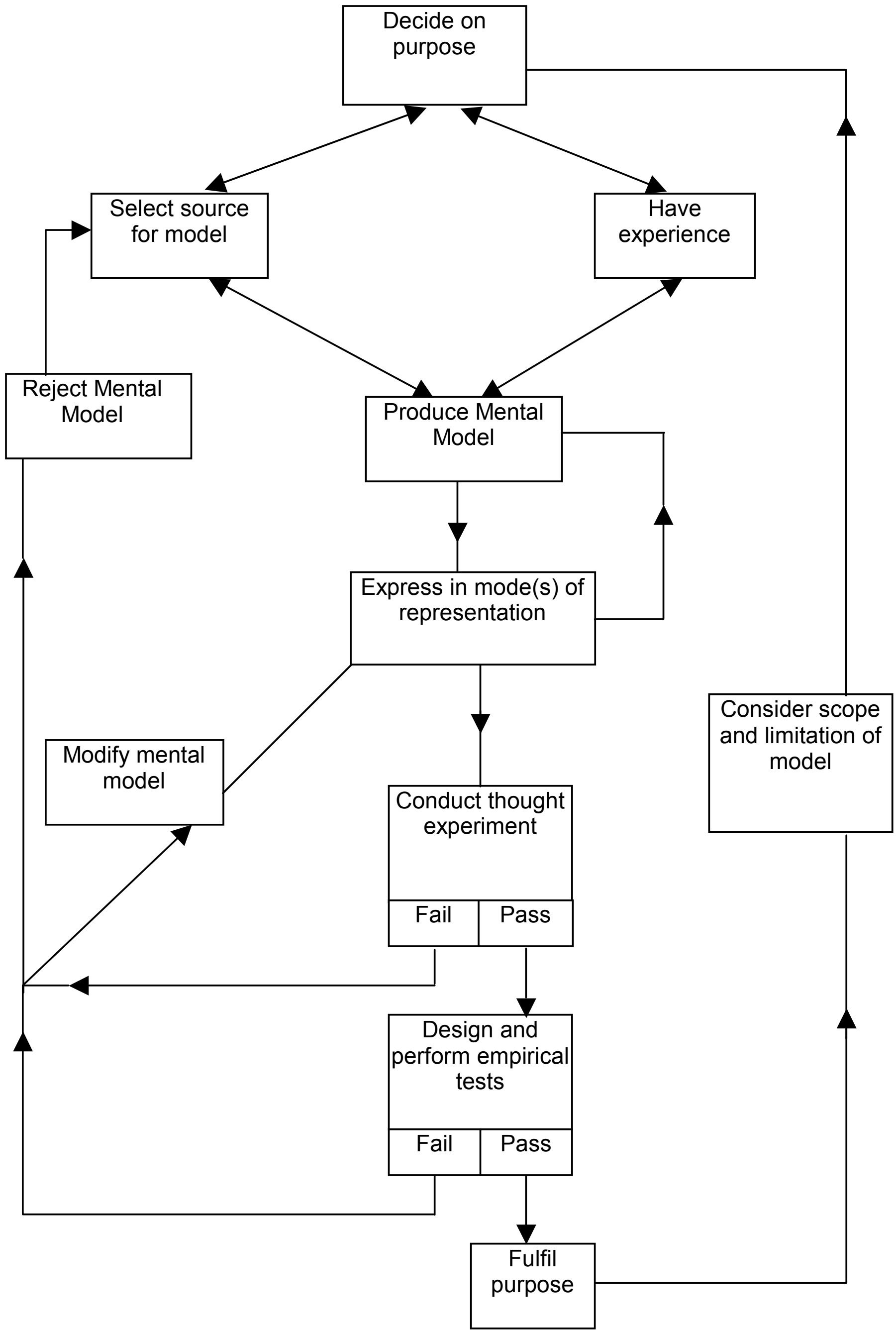


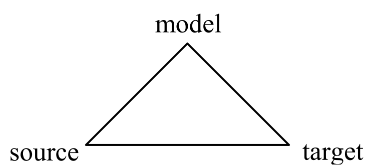
Figure 1. A "model of modelling" framework

This would be followed by a phase in which an attempt would be made to persuade others (peers and the teacher) of its value. During this process of advocacy, the *scope and limitations* of the model would become apparent, leading to a reconsideration of the earliest elements in the model-production cycle. If the sub-cycles of model modification and thought and/or empirical testing were repeatedly unsuccessful, then the model would have to be rejected. This would lead to a radical reconsideration of the earliest elements in the model-production cycle. The introduction of this framework to students implies both the development and use of several skills and knowledge. It should result in the achievement of the comprehensive understanding of chemistry previously discussed. This introduction could be conducted from different methodological perspectives in different educational contexts. We do not believe that the framework itself should be taught to students prior to the proposition of a modelling activity. The risk that they merely learn the framework rather than be able to use it in some way is too great. A much better use for the framework is to help teachers think about their classroom practices in general and how to change them so they become *generally* more model-based and modelling-oriented.

3. ANALOGIES AND MODELLING

An analogy, as emphasised in other chapters of this book, expresses a relation of equivalence or likeness. This means that when we say 'A' is analogous with 'B', we are saying that there are some aspects of 'A' that *are like* aspects of 'B'. Analogies are employed throughout the realm of language use because they are powerful tools in the understanding of new domains. This is so because, when an analogy involves a target that is unknown and a source that is known for someone, this is followed by the establishment of new relationships between them.

In one of his best-known papers, Duit asserted that: "It is the analogy relation that makes a model a model" (Duit, 1991, p.651). Such an assertion was made from the recognition that models, as analogies, "have to do with the structural mapping of different domains" (Duit, 1991, p.651). According to this view, we may represent the process of creation of a model through the diagram:



In this representation:

- "Target" is the aspect of reality that is being modelled. It may be an object, an event, a process or an idea.
- "Source" is some more familiar entity that is used to represent the target through the production of an analogy.

- "Model" is the result of this representation.

Historically, the building of analog models was very important in both the development and communication of scientific knowledge. The more detailed examples found in the literature come from physics. Nersessian (1999), for instance, after emphasising that analogical reasoning is a kind of modelling activity, explains how Maxwell constructed the visual model of "electromagnetic field" by the building of an analog model and from several tests on it to improve its scope of representation and capacity for generating predictions. Nersessian also comments about Maxwell's use of his model in communicating the knowledge he created and in trying to convince other scientists of its potential.

In chemistry there are also examples in which the building of an analogy had a pivotal role in the modelling process that resulted in the production of new knowledge. In identifying the historical models in the development of the field of chemical kinetics (Justi, 1997, Justi & Gilbert, 1999), we realised how the use of different analogies for the key concept of chemical reaction was vital in the evolution of explanations of "rate of reaction". Some of them are presented next.

In the seventeenth and eighteenth centuries, the gradual development of corpuscular views of matter meant that the concept of "affinity", introduced by the Greek philosophers from the attribution of the human qualities of love and hate to the elements, changed in character. Boyle, for instance, built a mechanical analogy according to which "affinity" was a result of corpuscles having appropriate shapes which permitted them to adhere together and which did not result from an attraction force. On the other hand, Newton, from an analogy with his studies in physics, thought "affinity" was a sort of force by which bodies tended toward one another, whatsoever was the cause (Duncan, 1996; Levere, 1971). This was the first time that the origin of a "force" that brings about a chemical reaction was seen to be related to the characteristics of particles as such or as originated from them. By being somewhat more precise about the forces operating between reacting substances, a model for chemical kinetics facilitated predictions about the likelihood and rate of a reaction. Within this model, the rate of the transformation was related to the different degrees of affinity between the particles and depended on its readiness to occur (Justi & Gilbert, 1999).

At the beginning of the last century, another powerful analogy was proposed for chemical reactions. Assuming the kinetic theory of gases, Trautz and Lewis, working separately, proposed that the behaviour of molecules was analogous to that of hard spheres. For them, the collision of the molecules produced a reaction only if it occurred with both sufficient energy and at an appropriate orientation such that specific bonds were broken and made. Then, from this overall view of how collisions occur, they also related the "frequency factor" – previously defined by Arrhenius – to the frequency of collisions between reacting molecules and calculated the magnitudes of frequency factors (Laidler & King, 1983). These examples show how the choice of a given source for an analogy led to the development of specific models for "reaction rate".

However, the analogies were not the only origin of such models. According to the framework presented in Figure 1, a mental model is produced as a result of integration between three steps that sometimes occur simultaneously: "decide on purpose", "have experience" and "select source for model". From the chemical kinetics perspective, we may say that the purpose in all the cases was the same: to explain reaction rate. But the selection of the analogies, as well as the way in which analog relationships were established between the source and the target, was determined by what could be empirically observed at the time.

This is the stage in the modelling process (Figure 1) where analogies are most evident. But they can also exert roles at other stages of this process. The next stages – "produce a mental model" and "express it in any mode of representation" – may also involve analogical reasoning. For example, in 1850, Wilhelmy studied the rate of inversion of sucrose by using a polarimeter to follow the decomposition of saccharose into two monosaccharides in the presence of an acid. The polarimeter did not disturb the conditions of the reacting system and he observed that the instantaneous rate of change of the sugar concentration was proportional to the concentration of both the reactants. Thus, from an analogy to the mathematical and physical theory of heat – that he had studied before – he proposed a mathematical differential equation to express and explain his ideas. This was the first time that the rate of a reaction was treated quantitatively (Laidler, 1995).

Finally, the stage of testing a model and its consequences – leading to either the modification or rejection of the model or to the consideration of its scope and limitations – can also make the role of analogies and analogical reasoning evident. As was said before, in the seventeenth and eighteenth centuries, two main analogical models for "affinity" were accepted. According to one of them, "affinity" was a result of corpuscles having appropriate shapes which permitted them to adhere together and which did not result from an attraction force. However, it also was at that time that empirical experimentation started to become essential for the acceptance of chemical ideas. It was exactly due to such an empiricist tradition that this analogical model for affinity decreased in importance. Aspects such as shapes, sizes, and mechanisms of particle adhesion, could not be tested experimentally (Duncan, 1996). Thus, as the main elements of the source of the analogy could not be transferred to the target in the testing phase of the model, such an analogical model could not fulfil its purpose and was soon rejected by the scientists working in that field. On the other hand, one of the followers of the Newton's analogical model – "affinity" was a sort of force by which bodies tended toward one another – Wenzel proposed an extension of this analogy that was able to increase the acceptability of the model. This was done not only by successfully testing the analog relationship itself but also by producing new knowledge from it. According to him, the magnitude of a force in mechanics was measured by its influence upon the motion of a body. If affinity between particles was a sort of force, it should be possible to determine the magnitude of this force – chemical affinity – by measuring its influence in the rate of the occurrence of reactions (Mellor, 1904). By empirically studying the rate of dissolution of a metal by an acid, he found out that such a rate depended not only upon the nature of the metal, but also upon the concentration of the acid. Therefore, he proposed that "a chemical action is proportional to the amount of substances taking part in the reaction".

In sum, the analysis of all the examples presented above corroborates the idea that analogies are very important, and may even be essential, in modelling chemical entities. As the source of the model is changed, so does the nature of the target that can be successfully explained. The “hard spheres” analogy enabled distributions of molecular energy to be represented and hence the availability of energy for bond breaking to be conceptualised. The “mathematical and physical theory of heat” analogy enabled differential equations to be used in constructing rate equations. The “chemical affinity as a force” analogy enabled the amount of substances involved in reactions to be represented.

4. ANALOGIES AND MODELLING IN CHEMISTRY TEACHING

The roles of modelling in chemistry and of analogies in modelling suggest a distinctive place for analogies in chemistry teaching and learning: their invaluable contribution to the understanding of the nature of models and modelling. Such a perspective may be analysed at different levels.

As previously emphasised, visualizable chemical knowledge at the macroscopic and sub-microscopic levels is based on models. This has been recognised as one of the factors that make understanding chemistry difficult for students at all educational levels (Gabel, 1999; Johnstone, 1993; Treagust & Chittleborough, 2001; Wu, Krajcik, & Soloway, 2001). This is because the major chemical explanations are derived from the use of models of sub-microscopic – thus abstract – entities. Moreover, such researchers assert that difficulties in chemistry learning do not only arise from the existence of these different levels, or even from the inherently abstract characteristic of chemical explanations, but also from the disconnected way in which they are often presented to students. Therefore, students are not able to integrate the two levels and to construct a comprehensive understanding of chemistry.

According to Gabel (1999), one of the ways to help students to establish relationships between these different levels is through work in the laboratory. However, this would not be so in the case of traditional practical work – that which can be characterised as the following of a recipe – the purpose of which is to illustrate something already known. Following Johnstone, Gabel asserts that “one reason why students find chemistry difficult is that in the laboratory, they make observations at the macroscopic level, but instructors expect them to interpret their findings at the microscopic level (Gabel, 1999, p.549). Therefore, what seems missing in the process is the provision for students of opportunities to *visualise* the sub-microscopic level in such a way that they can establish relevant relationships with the macroscopic level.

From both our belief in the central role of modelling in the development of scientific knowledge and the importance of analogies in the modelling process, we suggest that such visualization can only be achieved by the involvement of students in producing and using analog models. The production and/or understanding of a model based on an analogy with something that is familiar to students should result in a way to visualise the sub-microscopic level. This can then be the basis of an understanding of its role in explaining the given phenomenon at the macroscopic level. Such an approach is the main reason for the use of analog models in both science and science teaching.

In chemistry teaching, the analog systems most frequently used for such a purpose are molecular models, especially ball-and-stick models. In a ball-and-stick molecular model, atoms or ions are assumed to be hard spheres and the main bonds between them are represented by "sticks" in a way that the final model has a structure that is similar to the one that is believed to occur in the real substance. By building or using molecular models, students can visualise such a structure, thus becoming able to understand the properties and behaviour of substances (macroscopic aspects, those capable of being observed in nature or in practical work) that are explained from particularities of the structure of the substances. Moreover, by changing the analog model – for instance, by using space-filling instead of ball-and-stick models – the teacher can make clear to the students how the choice of the analogy influences the model produced and hence its explanatory power.

The use of analog models in teaching can also help students to understand the second stage of the modelling process – where mental models are produced and expressed in different modes of representation. In teaching how chemical reactions occur, the model proposed by Trautz and Lewis can be expressed in a range of modes of representation. This model proposed that collisions between molecules cause reactions if they occur with sufficient energy and with an appropriate orientation such that the necessary bonds are broken and made. The teacher can, for instance, draw particles showing all the substances involved in the reaction, both reactants and products. This is a very common way to express the model but very frequently results in students' misunderstandings. These are due to the absence in the representation of essential aspects of the model, mainly the movement of the particles and the presence of more than a few particles of each reactant. On the other hand, the teacher can use a computer simulation to express the analog models. Here the atoms that constitute each substance are represented as spheres of different colours and sizes, binding to each other to form many particles of each substance. Such sets of spheres move within the simulation in a way analogous to how it is believed that particles of given substances move at a specific temperature. Bonds are broken and made when the necessary conditions are satisfied. When a teacher presents both forms of the model to the students, it is possible to discuss the notion that the choice of mode of representation is important in expressing any one model. Where such a discussion follows an activity in which students build their own models for a given phenomenon, the teacher could also lead them to appreciate how their choice of a given mode of representation could have impacted on the process of the production of the model itself.

The testing of analog models can also help students to understand both specific aspects of the scientific model that they are learning and the importance of testing models as such. In addressing the properties of gaseous substances, teachers turn to the sub-microscopic level and deal with the behaviour of gaseous particles. In so doing, some of them introduce a dynamic analog model (in a gestural mode of representation) in which the students themselves take on the role of particles and move in a defined area at a given rate. By decreasing the area in which they walk, students can "feel" what happens when the volume of a gas is decreased. In another test, the area where they move is not changed, but they start running instead of walking. In this case, they can "feel" what happens in a gaseous system when the temperature is increased. Several other tests can be made by using this analog model. In all of them students become able to understand different aspects of the particulate model of matter. Moreover, students can also test their own ideas about such a model, a process that may result in either changing some previous ideas or refining the model. By using this analog model in this way and by discussing such use, students can also understand the nature of the stage of "empirically testing a model" and its possible consequences.

It is of pivotal importance that the scope and limitations of an analogy are discussed with students at the stage of the modelling process that is focused on its use. They must understand that only some of the elements of the analog model are transferable to the target. For example, ball-and-stick models imply that atoms are solid, that they are not in "contact", and that bonds have no significant width. Space-filling models do not clearly represent bond angles. From the modelling perspective, this discussion is of pivotal importance since it may help students to understand the essence of the nature of models: that they are partial representations.

5. ANALOG MODELS IN CHEMISTRY TEACHING – IMPLICATIONS FOR TEACHERS

An emphasis not only on a chemical phenomenon under discussion, but also on the nature of all the elements (target, analogy and model) and the processes (analogical reasoning and modelling) involved in representing it can, as we have argued, contribute to an improvement in chemistry teaching and learning in a variety of ways.

In addition to learning how to go about producing a model, students would also come to understand what a model is and what it can do and cannot do. This would provide an invaluable window into that most exotic of topics: the philosophy of chemistry. For the chemistry teacher and student, the gains would be both more immediate and very powerful: to be able to fluently link the macroscopic and sub-microscopic realms of chemical representation.

How to go about the introduction and sustained use of modelling activities at the classroom and laboratory level will present considerable challenges to teachers. The development of case studies of how this was done in history seems an obvious way forward. The fields of enquiry into "acid/base chemistry", "chemical periodicity", "chemical bonding" are sufficiently well documented to enable them to be used for this purpose. However, there will be no substitute for students actually modelling for themselves. This will entail the identification of chemical phenomena that are capable of effective address by students at a given level of overall knowledge and understanding of chemistry. It is especially important that they have "ownership" of the problem addressed, for it is only if they are committed to a task that they will exercise their full analogical imagination. Students will need adequately large blocks of time in which to tackle any chosen task. They will need access both to laboratories and to the full range of tools with which all the modes of representation can be expressed if they are to succeed. Most importantly of all, teachers will have to suspend the "show and tell" approach in favour of "discuss and guide". The rewards for such effort should be considerable.

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TOM RUSSELL AND MICHAEL HRYCENKO

THE ROLE OF METAPHOR IN A NEW SCIENCE TEACHER'S LEARNING FROM EXPERIENCE

1. INTRODUCTION

In this chapter, a teacher candidate and a teacher educator explore the role of analogy and metaphor in the development of a pre-service science teacher. The primary data source is an interactive electronic journal, spanning a 10-week teaching practicum, with the two authors exchanging comments at fortnightly intervals. Analysis continues through to the conclusion of the pre-service program, supplemented by further analysis of the practicum exchanges and the interaction of candidate and teacher educator during their work in chemistry and physics method courses. This chapter documents and interprets a teacher candidate's awareness of his early professional development and draws connections to recent literature about the role of perception in learning from experience.

2. THE CONTEXT FOR STUDYING METAPHORS IN LEARNING TO TEACH

Michael completed an eight-month Bachelor of Education program at Queen's University between September 2002 and April 2003; his teaching subjects were chemistry and physics. Initial data were collected in the period October to December 2002, when Michael completed a ten-week practicum placement in an eastern Ontario secondary school. (In early November, halfway through the practicum, he returned to Queen's for additional classes.) Metaphors appeared early and spontaneously in Michael's writing about his experiences. These metaphors quickly became the major focus of our conversations and a significant feature of Michael's professional development.

During the October-to-December period, Michael sent a practicum report file every two weeks to Tom, who inserted comments and returned the file to Michael. As we passed the file back and forth over the course of 12 weeks, we built a document that ran to more than 12,000 words. Why Michael uses metaphors often in

P. J. Aubusson et al. (eds.), Metaphor and Analogy in Science Education, 131-142.

writing about his professional learning is not something we can explain here. Our goal is to illustrate and interpret the metaphors and to explore their significance in Michael's professional learning as a science teacher.

3. METAPHORS IN THINKING AND WRITING ABOUT PRACTICE

We know little about *why* we use metaphors in our thinking, speaking and writing. The experience of seeing one thing as or like another seems far more spontaneous than deliberate. Thus it seems quite different from many of our teaching and learning experiences in schools, where deliberate, step-by-step learning seems the norm. In the literature on learning to teach, metaphor is mentioned frequently and is often seen as an element of reflective practice. Hoban (2000) asked preservice teachers to identify a metaphor to "conceptualise an optimal relationship between teaching and learning" (p.168), while Martinez, Sauleda, and Huber (2001) worked to "clarify the crucial role of metaphors in educational thinking" (p.966), concluding that "by disclosing the metaphorical bases of thinking about teaching and learning we hope to assist teachers in bridging the gap between their implicit and explicit knowledge" (p.973). Hunt (2001) used metaphor in a discussion of the facilitation of reflective practice in a programme for experienced educators, and Perry and Cooper (2001) used metaphor "as an educative tool for reflection" on "personal images of change" held by teacher educators (p.41). Cook-Sather (2001) proposed "that teacher educators use the metaphor of translation to illuminate the process of preparing to teach" (p.177) and came to the following conclusion:

> Learning to teach must be an ongoing, informed, deliberate, embodied process of discerning and rendering meanings that continually shift. The metaphor of translation illuminates the efforts, struggles, resistances, and epiphanies preservice teachers experience as they prepare to re-enter high school classrooms. It throws into relief the process of becoming a teacher—a process that is at once duplication, revision, and recreation, with meaning lost, preserved, and created anew. (p.189)

Michael's accounts of his practicum experiences and our conversations about them illuminate the role of metaphor in his process of learning to teach through his early efforts at reflective practice. The following selections from our original file illustrate the range of metaphors that Michael used.

Table 1. Excerpts from Michael's Practicum Notes, with Tom's Comments

Michael's comments on his practicum experiences	*Tom's comments in reply*
Weeks 1 – 2	
Prepared and delivered a lesson on projectile motion for the Grade 12 physics class. I was pretty excited about it: it had a good hook (monkey/ banana toss on overhead when they came in); review from the basics up with some good thought-examples; a little mini-lab; and a handout with a couple of problems which spelled it all out so explicitly. I knew it was something they were shaky in but had been exposed to, as I'd seen them stumble on rectangular components but finally achieve projectile motion problems. It was brilliant!	This 'episode' you describe could be a textbook classic—or should be! You make it so very clear how excited you were by the planning you had done, and then you quickly found yourself reminded that it's you+subject+students, not just

Michael's comments on his practicum experiences	*Tom's comments in reply*
Then I *delivered*. The monkey overhead sparked some interest, but *getting them to talk about different possibilities was like pulling teeth.* They all wound up agreeing on one answer, mostly because they were afraid to be wrong. I reassured them that it's just ideas, but *they played the part of torture victims*. So I left them hanging, promising that by the end of the class they'd know the answer, and why. In the review of rectangular components, they explained their ways of remembering when to use cos & sin, and I wrote them on the board. We talked about the exclusivity of perpendicular elements, and did a demo. I guess I should have had them do some simple, simple problems early on, because when I finally had them do what I thought was a simple problem, *they froze up and seemed to have never seen the stuff before!* I don't know. *I was so expecting some lights to go off.* Out of the six, two of them got it, but probably already had it. … I think: 1) I overestimated where they're at, 2) I overestimated the brilliance of the logic of my presentation, and 3) I presented things in a way sufficiently different from what they're used to that they froze up and forgot what they did know.	you and the subject (or you and the students). What's magical in your writing is your imagery! It adds a lot of clarity as well as interest.
Weeks 3–4–5 Time. It's the great enemy. At night, lesson planning. During the day, teaching. Throughout the year, trying to teach a curriculum. I love being with the kids, I love running a well-planned class. I have troubles getting excited about all the time it takes to do it. I'm tired. The Grade 12s are interesting to teach. There are only six of them, so it's a very casual atmosphere; management is simply not an issue. They all (save for one) have great work ethics and are keen to learn. But get excited? I haven't seen it yet. *They're like whipped horses*, obliging but *somehow lacking some life in them*. I struggle to find the spark for them. Humour goes a little ways, but isn't the catalyst it can be. Challenges are taken, but with a sense of WORK, as opposed to adventure. I'll get 'em yet, somehow.	Here's the image/analogy of the week (in italics). Your sense of persistence ('I'll get 'em yet') contrasts a bit with 'all the time it takes to do it.' As weeks go by, you are learning how to set priorities. Can you sense that some things are already getting a bit easier?
On-campus for two weeks between weeks 5 and 6 When I got to [my school] and met my associate, my impression was 'I'm sure I have lots to learn from him.' And I feel I have. I think I've integrated well into his class, format, and routine. I made most of my lessons from scratch, preparing the daily overhead notes, making up worksheets, tests, labs, etc. But looking back, I can't help but feel that I'm learning to be the teacher I don't want to be! It seems there's so much of my own vision that has been *obscured by some arbitrary harness and blinders I've willingly stepped in to.* While the routine is good for class management, and perhaps even the consistency some kids	Learning to be the teacher you don't want to be sounds pretty serious — perhaps you can focus some of your thoughts of the next five weeks on this issue. 'Arbitrary harness and blinders' — wonderful imagery again. I don't think we'll scare it away by noticing it!

need, I just know there's so much more I can do! So many different

Michael's comments on his practicum experiences	*Tom's comments in reply*
ways to be!	
On-campus for two weeks between weeks 5 and 6 I was so busy trying to figure out where the next good wave was coming in, and *paddling like mad to get there and heaving myself up onto the board and trying to balance and steer and not get scrubbed in the sand* below and . . . Wait a minute, breathe! What's the weather doing? Am I integrating with the waves or fighting them? Am I still in safe distance from the shore? Am I remembering the reason I'm out here? Couldn't see the ocean for the waves. Coming back to McArthur [for two weeks] was like a swim in to the beach, and checking in with a wizened old surfer cat blinking slowly and saying, 'Sure looks like you're working hard out there.'	You DO like the imagery and run well with it. What you say here seems very rich. You take the time to spin it out—something I often don't manage to do. I admit that I wondered if I qualify as a 'wizened old surfer cat'—I expect I do, even if I can't surf!
End of two weeks on campus I fear I've become a bit self-conscious of metaphor now. I have this fear of being contrived. Are there any ways in which you'd like us to steer this conversation? I appreciate your questions, and know there is a deeper well to reflect from than what I can necessarily see from my perspective.	I'm no longer worried that I've made you self-conscious—I think it comes to you fairly naturally!
Weeks 6 – 7 I'm amazed at how slowly some of the 11s hold on to even the simplest things, especially compared to the 9s! Most of the Grade 9s are *sponges who soak up information*, while the 11s are *suitcases, already full with sports, relationships, fitting in, etc., into which they sometimes find room to store coursework.*	Here we are—yet another image!! Sponges vs. suitcases. I wonder if the same contrast applies to teacher candidates? Some are real sponges? Some are suitcases with very fixed views on everything from subject area to how kids should behave? You strike me as a *sponge who's willing to consider throwing some of his stuff out of his suitcase?*
Weeks 8 – 10 They didn't always *take the bait* with demonstrations; I couldn't believe how underimpressed they were by making sound disappear by actually removing the air molecules [the bell is] vibrating! They were content to believe me in what's happening without needing to see (or hear) it for themselves. And the 'do we get marks for this?' question; I'm sure there must be more I can do to promote intrinsic motivation, but there seems to be *a culture that rebels against that,* almost feels threatened by it, and works to dismantle the small outposts of it that do exist. It's like I have to *'trick' them into being curious about something!* I need some more of those tricks.	I expect that evacuating a bell jar didn't get their attention because they've seen it several times before. Your comments here could lead to a book! As long as a teacher is 'tricking' students into curiosity, then the more fundamental intrinsic motivation issue is being ignored, and the tricks won't work. Yes, it's a culture, a culture of extrinsic motivation driven by well-meaning parents and teachers who hope that kids can be tricked into better marks and staying in school. Surely one of your own personal characteristics is that

Michael's comments on his practicum experiences	*Tom's comments in reply*
	you are intrinsically motivated.
Final comments about 10 weeks When you first asked (Weeks 6-7) whether I thought more on-campus time between practicums would be beneficial, I was unsure. I had a sense that more time could be beneficial, but not a clear idea of how, or why. I felt there was adequate time to digest the previous five weeks. Now, though, I can see it. They were an active two weeks on campus, especially on the subconscious level. *Digesting, backing the chair away from the table. Looking up from the enchanting plate before us and surveying the massive feast laid out on the table. Some exchanges with fellow diners, and the subtle influence of the chefs, ensuring we're enjoying the meal. Then, soon enough, the next course is served.*	Interesting that you says it's on the subconscious level—how could we make it otherwise? Notice the brilliant metaphor you use here—diners at a feast.
Not a bad approach. *But between those courses—full of the aroma, tastes, intoxication of the food—could be a very inspired time to head to the kitchen and prepare some variations on the dishes.* Now could be the best time to prepare some of the dishes we can imagine in this unique place and time we're experiencing! *Get up from the table, not only to share what's happened, but also to go to the kitchen and whip up a few inspired dishes!* Soon enough we'll be engaged in the next course, a little more experienced, but nonetheless fully engaged in all that's before us. All of which is a roundabout way of saying that more time could be effectively used to prepare some exemplary lesson plans.	And then you pursue it by suggesting that the diners themselves need to experience preparation of these new dishes, all with a view to preparing to actually using the intoxicating ideas being served up. So you suggest using the restaurant venue as a setting for that preparation—and indeed I've always felt that much of the purpose and potential power of the practicum, for secondary candidates, involves their returning to students and setting that have become quite familiar.

Ultimately, during our seven-month conversation, metaphors were in one sense the catalyst and in another sense only the tip of the iceberg. The metaphors in Michael's writing prompted us to continue these conversations in person and in further electronic entries. At the end of the eight-month program, Michael stayed in Kingston for several weeks and agreed to review all that he had written with a view to interpreting the metaphors he had used in his writing and to assessing their significance in his professional learning. His efforts were very productive, helping him to understand the many transitions he experienced during the learning-to-teach process.

4. NEW PERSPECTIVES ON THE DEVELOPMENT OF PROFESSIONAL KNOWLEDGE

4.1 Metacognition and Conceptual Change in Learning to Teach

Before reporting our further conversations about the metaphors in Michael's writing about his teaching experiences, we call attention to three recent contributions to the literature on teachers' development of professional knowledge. We begin with a case study of a student teacher named 'Barbara.' Bryan and Abell (1999) introduce the case by declaring their perspectives on the role of experience in learning to teach:

> The heart of knowing how to teach cannot be learned from coursework alone. The construction of professional knowledge requires experience…. Experience influences the frames that teachers employ in identifying problems of practice, in approaching those problems and implementing solutions, and in making sense of the outcomes of their actions. (pp.121-122)

The case begins with an account of what Barbara believed about science teaching and learning and moves on to describe her vision for teaching elementary science as well as the tensions within her thinking about her professional responsibilities. Of particular interest was Barbara's initial premise that a teacher should continue to teach a scientific concept until all children show that they understand it. As the process of reflection became apparent to her, "Barbara began to shift her perspective and reframe the tension between her vision and practice. Her professional experience provided feedback that forced her to confront the idea that in teaching science, teachers need to consider more than students getting it" (p.131). While this is only one case study, the implications for further study of learning from experience seem clear:

> Barbara's case implicitly underscores the fallacy of certain assumptions underlying traditional teacher education programs: (a) that propositional knowledge from course readings and lectures can be translated directly into practice, and (b) that prospective teachers develop professional knowledge before experience rather than in conjunction with experience.... Teacher educators are challenged to coach prospective teachers to purposefully and systematically inquire into their own practices, encouraging them to make such inquiry a habit... (p.136)

Bryan and Abell conclude that "the genesis of the process of developing professional knowledge should be seen as inherent in experience" (p.136). "A preeminent goal of science teacher education should be to help prospective teachers challenge and refine their ideas about teaching and learning science and learn how to learn from experience" (p.137). Our conversations about Michael's practicum experiences forced us both to re-think our assumptions about how people learn to teach.

4.2 Phronesis and Episteme

Kessels and Korthagen (1996) offered a novel perspective for reducing the "theory-practice problem" by drawing on the Greek distinction between *episteme* and *phronesis*, a distinction that can also be seen as the difference between scientific understanding and practical wisdom. While episteme is at the core of our experiences of schooling and thus quite familiar, phronesis calls attention to our perceptions and how they are influenced by experience.

> The ultimate appeal of phronesis is not to principles, rules, theorems, or any conceptual knowledge. *Ultimately the appeal is to perception.* For to be able to choose a form of behavior appropriate for the situation, *one must above all be able to perceive and*

> *discriminate the relevant details*. These cannot be transmitted in some general, abstract form…. This faculty of judgment and discrimination is concerned with *the perception or apprehension of concrete particulars,* rather than of principles or universals. (p.19, emphasis added)

Kessels and Korthagen extend their comments about the significance of phronesis for those learning to teach in words that extend those of Bryan and Abell and challenge the fundamental premises of many preservice teacher education programs:

> The point of phronesis is that the knowledge a student needs is perceptual rather than conceptual. Therefore it is necessarily internal to the student, it is in the student's experience instead of outside it in some external, conceptual form. It is thoroughly subjective…. And so there is nothing or little to transmit, only a great deal to explore. And the task of the teacher educator is to help the student teacher explore and refine his or her perceptions. This asks for well-organized arrangements in which student teachers get the opportunity to reflect systematically on the details of their practical experiences, under the guidance of the teacher educator—both in group seminars and in individual supervision. (p.21, emphasis added)

Acknowledging that we live in an educational world that relies extensively on episteme, we do not claim to have understood fully the meaning of phronesis. Yet phronesis seems intimately linked to metaphor within the experience of perception. Our focus here has not been on Michael's formal understanding of teaching but on his evolving perceptions, not only of the students he taught but also of his own learning to teach.

4.3 Spontaneous and Non-Deliberate Processing of Experience

Schön (1983) gave considerable impetus to the "teacher as reflective practitioner" movement with his distinction between problem-solving and problem-setting (pp.39-42). Reframing problems to develop and enact new approaches became an attractive image for teachers thinking professionally about their work. Working from a conceptual analysis based on the work of Iran-Nejad (1990), Oosterheert and Vermunt (2003) suggest that teacher educators have been trying to encourage reflection-in-action without acknowledging the differences between problem-solving, on the one hand, and reframing of problems, on the other. Suggesting that there are three sources of regulation in knowledge construction, Oosterheert and Vermunt (2003) distinguish between "external" and "internal" sources of regulation in constructing knowledge. External sources (including practicum teaching experiences) provide information from outside the learner (whether child or adult). Internal sources of regulation refer to the capacities of the brain "to process information and to reconstruct existing knowledge" (p. 159). Adding to the familiar idea of "active" internal sources of reflection, the authors offer the new category of "dynamic" internal sources of regulation and argue that these are essential in learning to teach. In doing so, they build on Iran-Nehad's (1990) challenge of the assumption that learning involves incremental internalisation in response to external sources. They contrast active and dynamic self-regulation in the following terms:

- Active processing is "slow," "deliberate," and "sequential," while dynamic processing is "rapid," "non-deliberate," and "simultaneous."
- Active self-regulation processes information that is "conceptual" and "important", while dynamic self-regulation processes information that is "sensorial" and "interesting."
- The learning experience of active self-regulation involves "internalisation," "knowing," and "effort," while the learning experience of dynamic self-regulation involves "reconceptualisation," "understanding," and "ease." (Oosterheert & Vermunt, 2003, p. 160)

Teacher educators who have employed reflective practice perspectives may quickly recognize these contrasts between "active" and "dynamic" as similar to Schön's contrast between *solving* problems and *reframing* problems. We are particularly interested in the implications of seeing internal sources of regulation as

- "Active" self-regulation appears to capture the familiar tasks of schooling, including note-taking, homework, reviewing, quizzes and tests. In contrast, "dynamic" self-regulation appears to lead to the conceptual changes that science teachers often take as goals and genuine indicators of their success in teaching. It also appears relevant to the conceptual changes that teacher educators seek to develop in helping new teachers understand and learn from practicum experiences.
- "Active" self-regulation appears to capture the familiar tasks of learning to teach, including class participation, preparing and presenting practicum lessons, and completing assigned work. In contrast, "dynamic" self-regulation appears to lead to the shifts of understanding and perspective that teacher educators often take as genuine indicators of their success in helping individuals learn to teach.

Key features of "dynamic" self-regulation, as presented by Oosterheert and Vermunt, include "rapid, spontaneous, non-deliberate, simultaneous" processing of "sensorial" information leading, with "ease" to "reconceptualisation" and "understanding" (p.160). These all seem to be characteristics of Michael's spontaneous use of metaphors in writing about his practicum experiences. He was not deliberately attempting to include metaphors; his metaphors were part of dynamic rather than active self-regulation.

Oosterheert and Vermunt provide a key conclusion that seems particularly relevant to Michael's writing:

> Dynamic sources only become effectively involved when existing knowledge is not taken for granted in the interpretation of classroom experiences. Teaching experiences fail to be educative when the desire to see something new is absent…. One cannot (start to) see things that one is not looking for. Without interest…. there is mere perception, based on existing prior knowledge. The perception of classroom life then tends towards self-confirmation. (Oosterheert & Vermunt, 2003, pp.165-166)

Thus the authors contend that learning to teach involves taking learning beyond activities in which students proceed "deliberately and intentionally" (p.170). In their view, professional learning also involves "non-deliberate processing strategies" (p.170).

5. THE SIGNIFICANCE OF METAPHORS IN MICHAEL'S PROFESSIONAL LEARNING

We return now to our account of Michael's learning. Table 2 reports an exchange between Michael and Tom over a seven-day period shortly after Michael completed the formal requirements of his B.Ed. program. Here Michael writes explicitly about opening up to his own learning, as he and Tom write back and forth with a view to exploring the significance of metaphors in Michael's professional learning. Metaphors, metacognition, and conceptual change are all apparent in this summary of what Michael feels he learned from this extended conversation about his learning from experience.

Table 2. Michael's Analysis of his Professional Learning

Michael on May 13	Tom on May 18	Michael on May 19
Looking back on my year of teacher training with an eye on the metaphors I used to describe my experiences has offered me a **fresh perspective on my own development process.**	Michael, I put the bold in yesterday, and the italics after reading today. Anything you can add in reply to my comments and questions would move us even further.	The fact that we're engaged in this right now is excellent continued learning. It would be easy for me not to unpack some of this stuff.
I came into the program *looking for tools to help make my job easier*. I hadn't particularly thought about *how I would acquire the tools,* beyond the obvious mix of theory and practice that lay ahead. **If pressed, I would likely have said that I would learn some skills and practices from my professors, then apply them in the classroom. Simple!** Like so many students, **I was hoping to be told how to teach**. Of course, this is hardly surprising – it's how I remember most of my own schooling.	I find 'looking for tools' fascinating—learning to teach is acquiring tools (perhaps skills?)—certainly not fresh perspectives!	Or so I saw it coming into the program. But *so much of what we need to learn is in fact about perspective:* understanding what it means to be a professional, for example, or what it means to have ADHD.
My approach to my own learning naturally shows up in my teaching, and my reflections about it. I am now both surprised and informed to see **how much of the imagery I invoked in my writing about my practicum experiences revealed a transmissive approach** – where I thought I was 'delivering the perfect lesson' and 'expecting	This is a very honest as well as impressive insight.	I think I was aware of this at the time of teaching, and this is a reason for my discontent and for the *shift* I felt I needed. *It's the realization that I have something I want to or need to learn that makes all the difference.*

lights to go off' for the kids.

Michael on May 13	Tom on May 18	Michael on May 19
Although **lacking a clear alternative** to this style of teaching, I became acutely aware that this was not the type of teaching to which I aspired. I stated that I saw senior students 'behaving like whipped horses,' and was fearful that I, too, was **stepping willingly** into the **'harness and blinders'** provided to me by my practicum situation. I did not feel that I was finding the type of modelling that I was hoping for in the classroom, and did not particularly expect that my professors could fill that role in the university classrooms. *Something had to shift for me*, and it did.	WHY did something have to shift? To deal with the frustration you were feeling?	Yes, I was frustrated and disappointed. I wasn't finding what I was hoping to find. So I had to change either what I was looking for, or how I was looking for it. I guess both eventually happened, but the rigidity of the program made the former more accessible than the latter.

We conclude this analysis of Michael's professional learning by stepping out of the table format and presenting Michael's concluding analysis, revealing active self-regulation, on May 13 and 19. On May 13, he wrote as follows:

> In fact, my shift as a student in a B.Ed. program became visible to me only in hindsight, and through an examination of the metaphors I used to describe my teaching and learning experiences. Although there were many contributing and reinforcing factors along the way, there was a point where I changed from expecting delivery from associate teachers and professors to recognising my own responsibility in learning what I felt I needed to learn. Perhaps characteristically, the deep learning came as an offshoot of another topic. Through discussions about rubrics, I realised the number of preconceptions, biases and assumptions I had about them, even though I had never actually used one! I was also amazed to realise 'how malleable' I was, and these revelations triggered for me an understanding of the importance of that term I had heard but not felt: metacognition. I described it as 'the distorting haze of my prior beliefs burn[ing] away,' and it was the point at which I 'bought in' to the teacher education program. I realised that I had much to learn about my own learning and teaching, and that the responsibility for both lay with myself. From this point on, there are some changes in the metaphors I used towards a more egalitarian conception of teaching and learning: references to being 'on the same team,' or on a wagon together.

On May 19, his final thoughts were these:

> 'Transmission' shows me how steeped I was in it and the tension I was feeling to get out of it. Two main things come to mind:
>
> 1. The surprising amount of 'transmissive teaching' imagery in my descriptions explains much of the dissatisfaction I felt during the practicum and reveals the fundamental tension that drives my own learning: the difference between the teacher I am by default, and the teacher I would like to be. I was looking for ways to learn how to be a different type of teacher—one more student-centred—and it was rarely obvious

> from my professors how to proceed. I didn't actually realise how steeped I was in a teacher-centred approach, but it explains a lot of the dissatisfaction with my own teaching that I felt, and what I was looking for. Of course, having a teacher-centred approach, I was looking to my professors for the answers, and was not always finding them.
>
> 2. The point at which I've referred to as having a shift is what I now see as the moment at which I came to understand what I needed to learn. I realised that I had significant unchecked assumptions that would influence the way I teach, perhaps more profoundly than any other single thing. When I realised this, I realised that I needed to take responsibility for my own learning. I began to get frustrated by classmates who stalled classes or complained about the program, because I now saw the role of my professors as giving me a forum for my learning, as opposed to giving me my learning. I had indeed 'bought in' to self-directed learning.
>
> Again, this shift in approach to my own education did not feel like a singular event at the time. While I was energized and aware of a changing perspective, it was only while looking back at the metaphors that I was able to single out this point and put it all together. I still maintain that I am highly malleable. That may be different from other students, but I bet that just as many feel they are blank slates and are not, they may also feel that they're not going to be influenced – but are. Whether or not they're influenced in a lasting way with measurable differences in a classroom is a different matter.
>
> I think I know what you mean about tangential and opportunistic learning. Nothing's better than a 'teachable moment', but I have a feeling that both are necessary, meaning the direct and deliberate also have a role to play in it. Once I saw the relevance of my own metacognition, I wanted to share it with my students; it's such an incredibly valuable tool for all students. And who in this world is living and not a student of something?

Our initial analysis focused on key features of *dynamic* self-regulation as we considered metaphors in his non-deliberate and spontaneous reflections. Michael's later analysis exhibited key features of *active* self-regulation. His later analysis was deliberate in that there was conscious reflection on how he came to learn to teach. It was sequential in that the data were presented and reviewed chronologically in the first instance; it was conceptual and important to Michael in that, for example, it contributed to his understanding of metacognition. Finally, there was internalisation in that Michael realised how identification and use of metaphor contributed to his learning.

6. CONCLUSIONS

Viewing Michael's learning in the context of the previously cited literature in which others have explored metaphors in professional learning extends our interest in the spontaneous and non-deliberate features of metaphors and in the value of documenting and analysing their significance. Tom did not teach Michael to use metaphors, nor did Michael attempt to create them. Realising that metaphors were appearing in his writing and then attending carefully to that insight encouraged and enriched Michael's awareness of his professional learning. Michael's willingness to pursue the conversation about metaphors after his practicum extended considerably his awareness of the changes occurring in his professional knowledge and in his understanding of how such knowledge develops. This account of Michael's professional learning illustrates the potential value of assisting new teachers in identifying and interpreting changes in their perceptions of themselves and of those they teach. It also illustrates the power of bringing careful and deliberate attention to bear on spontaneous and non-deliberate features of learning from experience.

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METAPHORS AND ANALOGIES IN TRANSITION

Beginning Teachers' Lived Experiences

1. CONNECTING WITH METAPHORS AND ANALOGIES

Typically beginning teachers sever their ties with university-based teacher educators upon graduation. As Howey and Zimpher (in Feiman-Nemser, 2001) noted: "Nowhere is the absence of a seamless continuum in teacher education more evident than in the early years of teaching" (p. 1037). Similarly, Feiman-Nemser (2001) observed: "There is no connective tissue holding things together within or across the different phases of learning to teach" (p. 1049). The need to maintain a partnership, within the context of a professional learning continuum, uniting initial teacher training, induction and continuing professional development was also recognised by beginning teachers. In a survey of 696 beginning teachers in Australia (Department of Education, Science & Training – DEST, 2002), 61.6% of respondents "believed Education faculties should play a continuing role in the professional development of their graduates, through involvement in induction" (p. 17). In this chapter we explore the potential power of sustaining conversations between university-based teacher educators and their recent graduates during the beginning years of their teaching careers by sharing and discussing the stories of three beginning teachers about their use of metaphors and analogies in science teaching.

1.1 Metaphors for Science Teaching

Teaching metaphors like the *teacher as provocateur* (Prawat, 1996), were used by Steve (first listed author) in his pre-service science education programs to help students imagine what teaching might be like from a social constructivist perspective. As well, some students (e.g., Marianne – the fourth listed author) were encouraged to develop a range of personally relevant teaching metaphors that might assist them teach in ways that were consistent with their beliefs. This practice was

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based in part on Steve's previous research with practicing teachers who deliberately changed their pedagogy to accord more closely with their understanding of constructivism. In one case study (Ritchie, 1994), the teacher called Bernice created the metaphor of *teacher as travel agent.* This metaphor proved to be a successful reflective tool for initiating and sustaining change in Bernice's classroom, even on topics that were considered outside of her field of expertise. Of course, several other researchers found personally created teaching metaphors helpful in conceptualising and enacting a wider range of pedagogical practices for experienced teachers (Nichols, Tippins, & Wieseman, 1997; Thomas & McRobbie, 1999; Tobin & Tippins, 1996). In pre-service teacher education, Bullough and Stokes (1994) and Volkmann and Anderson (1998) were strong advocates for student teachers to develop metaphors for teaching. For example, Volkmann and Anderson (1998) argued that metaphors taught in pre-service programs had the potential to clarify meaning in the complex and challenging first-year that awaited graduating chemistry teachers.

During her pre-service science education programs with Steve, Marianne developed a strong interest in personal teaching metaphors to guide her teaching practice. Three personally relevant metaphors that Marianne developed in her first year of teacher preparation were: *teacher as founding club leader*, *teacher as talent show coordinator*, and *teacher as toolbox*. Each metaphor created an image of a specific environment and the role she might play in that context. For example, as a talent show coordinator / teacher, Marianne recognised the need to set the general focus or theme for the show (or unit of work) before negotiating suitable acts or performances (i.e., activities and investigations) with her students. In this way, students learned science as they practised and performed their acts. Marianne's interest in metaphorical thinking extended to her second and final year of teacher preparation where analogies for learning scientific concepts became a topic in the curriculum.

1.2 Analogies in Science Teaching

Science metaphors and analogies can be effective tools to help students develop understanding of important concepts, especially those that are abstract or difficult to experience directly (e.g., Dagher, 1995; see also, Chapters 2, 3, 5, 6, & 7). Analogies can provide a conceptual bridge between existing and targeted knowledge (Glynn, 1994), as well as evoke emotion, interest and creative insight (Duit, 1991, Gilbert, 1989). Visual metaphorical images portrayed in some cartoons also might help to support the relational connections between vehicle or analog and target (Cameron, 2002). However, inappropriate use of analogies can lead to the formation of alternative conceptions when teachers do not intervene (Duit, 1991; Glynn, 1994). For example, in Yerrick, Doster, Nugent, Parke, and Crawley's study (2003) of pre-service teachers use of physics analogies within groups during inquiry projects, students demonstrated a strong tendency to overgeneralise analogies and map irrelevant features from the analogy to the target concept. Also, the students "engaged in the generation of their own analogies that emerged first as personal theories, many of which were poor conceptual matches for the target concept" (p. 458). In similar inquiry contexts, Yerrick et al. (2003) recommended that frequent questions and guidance from the teacher might be effective in averting reinforcement of alternative conceptions. In the stories below, we show how three beginning teachers interacted with and guided their students as analogies were introduced and critiqued.

2. STORYTELLING

Connelly and Clandinin (1994) argued that stories are central to teacher education because the telling and writing, retelling and rewriting of stories can lead to awakenings and to transformations in the practice of the teacher-storytellers. Telling stories of their use of analogies in this chapter serves a pedagogical purpose for the three teacher-participants. Through their narrative interactions with each other and Steve, the teachers constructed more sophisticated ways of acting, believing, perceiving, and evaluating classroom actions (Rex, Murnen, Hobbs, & McEachen, 2002). As Connelly and Clandinin (1994) argued, sustaining conversations with theory, research, different classroom conditions and contexts, it is possible for the teachers to create more mindful retellings of their stories. Such ongoing conversations involve a similar reflexive process advocated by Fenstermacher and Richardson (1993) who claimed that:

> Practical reasoning is improved by helping the … teacher frame increasingly more sophisticated and well grounded practical arguments, thereby enhancing the teacher's ability to think more deeply and powerfully about his (sic) action. (p. 104)

With the goal of sustaining professional conversations with his former students, Steve invited each of the three teacher-participants to write a brief account of their use of metaphors and analogies during their first year of teaching. These stories were edited by Steve and returned to each storyteller for checking. All three stories were then shared between the participants for further discussion and reflection. In this way, we hoped to establish a mini-learning community that provided a connection between the pre-service and teacher induction phases of teacher learning because:

> Novices need opportunities to talk with others about their teaching, to analyze their students' work, to examine problems, and to consider alternative explanations and actions. If novices learn to talk about specific practices in specific terms, if they ask for clarification, share uncertainties, and request help, they will be developing skills and dispositions that are critical in the ongoing improvement of teaching. (Feiman-Nemser, 2001, p. 1030)

Before discussing the perceived benefits of this process from our experience, edited versions of the original stories are re-presented.

3. BEGINNING TEACHERS' STORIES

In this section three second-year teachers each tell a personal story about their transition from pre-service teacher education to first-year teaching. Each story focuses on the use of metaphors and analogies in science teaching. All three teachers graduated from the same science education class taught by Steve at James Cook University. While Alberto (i.e., the second listed author) teaches in the same city as Steve, Heidi (i.e., the third listed author) and Marianne moved interstate where they coincidentally teach at the same school.

3.1 Alberto's Story

I have become conscious of several metaphors that characterize my teaching. These change depending on the class and conceptual difficulty of the work. Walking from my Year 11 Chemistry class to my Year 8 Science class I purposefully change my demeanour. It hurts to admit this, but I have to be a bit of a mongrel with my Year 8s otherwise they get out of control. So from *teacher as provocateur* in Year 11 where I increasingly invite students to critique the effectiveness of particular analogies to help explain difficult concepts, I become *teacher as police officer* in Year 8. I also use the *teacher as Steve Irwin* (you know, the Croc Man) metaphor in Year 11 when I use interactive historical vignettes or perform entertaining demonstrations. Even though students appear to like being entertained, I have come to the conclusion that my Steve Irwin metaphor can be counter productive if overused. Generally, I have found that as my understanding of metaphors for teaching grows it helps me to analyse and adjust my practice. This is especially evident in relation to the application of the *teacher as provocateur* metaphor when used with science analogies.

I first heard of the *teacher as provocateur* metaphor at university in discussions about teaching from a constructivist perspective. But my first observation of a teacher's use of analogies in Chemistry left me unconvinced of the merits of analogies. I remember observing a series of Chemistry lessons by my supervising teacher who seemed fond of using analogies. I came away thinking "what a mess". Her students pulled the analogies apart. I told myself I would avoid using analogies in my classroom at all costs because I was afraid of falling foul of a similar fate.

In my first year of teaching I was allocated two Chemistry classes. Concerned that students did not understand the concepts adequately, I turned to analogies in frustration. My first reference to a common textbook analogy was successful. This encouraged me to go further.

I invented an analogical model (see also Chapters 5 & 6) to help explain the structure of atoms following the "Rutherford gold leaf experiment". I first questioned the students about what they remembered about the structure of the atom. From these interactions, the question "how do we know this?" begged an answer. I continued:

> Imagine that we throw a sheet over our overhead projector. Now suppose we stand at the back of the room and fire an air rifle at the covered projector. If the air rifle pellet pierces the sheet and encounters empty space, it will pass straight through to the other side and leave a hole in the wall. If the pellet hits the solid form of the projector behind the sheet, it bounces straight back without hitting the wall. We fire many pellets at the

> sheet. In the end we have a series of holes where the pellets encountered little resistance and a pattern shape of the projector on the wall where the pellets did not penetrate.

At this point the students were silent. I was concerned that I had confused them. I asked: "What will we see on the wall after we finish shooting?" "The shape of the projector, its outline", some replied. I asked, "Will this shape be an exact copy of the projector?" "No", they replied. "How is it different?" I retorted. "It's the outline only, it's not 3D", they answered. More questions and answers followed:

"What information about the projector doesn't it give us?"

"Colour, what's it made of".

"So how is this information helpful?"

"It gives us an idea of what it looks like".

Now that I was convinced that the class recognized the limitations of this model, I discussed the Rutherford experiment in more detail.

My use of analogies has increased. I now use them whenever we come across a novel or abstract concept for which there is no physical way to describe it. Sometimes students cheer, clap or just smile widely when they first get it (i.e., understand the concept). I realise that these analogies provide a metalanguage with which we can talk about Chemistry before identifying the Chemistry concepts. For me, analogies have been one useful tool to help students' understanding.

3.2 Heidi's Story

"Are we doing a prac today Miss?" is often the first thing students say to me as they enter the science classroom. Practicals are popular with students, let's face it, "hands-on" is more fun than writing notes and listening. However, we all know that life teaching science cannot be all about practicals. I try to use alternative teaching strategies when students need to learn prescribed concepts. One strategy I have used that draws upon metaphorical representation is to select appropriately relevant and humorous cartoons to illustrate science concepts. I sometimes even invite my students to construct their own cartoons to illustrate their understanding of ideas for the benefit of fellow students.

I first tried out humour in my practical teaching in my Year 11 Biology classes. The allocated topic was concerned with the relationships between organisms. Rather than preparing an overhead transparency with the required definitions I searched through one of my Gary Larson cartoon books where I found a selection of single frame cartoons that illustrated predation, symbiotic relationships, mutualism, and so forth. I organised six cartoons onto overheads and proceeded with, what I felt was, a unique lesson. I placed the overhead up and asked the students to view the cartoon and tell me what they thought it was about. From this introduction I asked the students to work in groups to come up with a cartoon to illustrate the relationship they were given in a package I had prepared, and then present it to the class. Each package included: information on an organism's relationships, paper, and an overhead pen and transparency. The students took on the challenge and resulted in some interesting cartoons. A few weeks later, when we had a mini quiz, the students knew the vocabulary and some even drew little cartoons to help answer some of the questions. I felt that the lesson had been a success.

In my first year of teaching I was required to teach the Big Bang theory in my Year 8 Science class. I assigned a particular astronomical event to each student before inviting the class to take up relative positions around the room to form a time line. I then showed a video, which explained the events. I was disappointed to find that the majority of students could only remember events at the beginning and end of the sequence on the end-of-topic quiz, even after they had copied the sequence in their notebooks. I returned to the topic a week later with a different approach. I asked the students to look at the events they had written down. We watched the video again. Then, working in pairs, I asked the students to draw the events, in sequence, as a multiple frame cartoon; that is, to represent their understanding in the form of metaphorical images (cf. Cameron, 2002). Some looked excited while others looked concerned. Using crossed out watches to show that there was no time at the beginning and cute characters representing matter and anti-matter the students produced some creative pieces that represented the sequence accurately. When it came to the formal unit test, 26 of the 30 students were awarded 5 to 6 out of 6 for the Big Bang question. I feel this was a positive and encouraging result. I concluded that the variety of teaching strategies used for the topic had helped the students retain the information and understand this theory.

I have learned that cartoon humour, for me, can be a device to motivate students and aid them with their learning. It also shows them that science is all around them, even when they do not realise it!

3.3 Marianne's Story

The use of analogies and metaphors had interested me since pre-service teaching where I completed projects on developing personally constructed teaching metaphors (e.g., *teacher as talent show coordinator*) and analogies to help student understanding of the cell using "The general model of analogy teaching" (GMAT; Zeitoun, in Dagher, 1997). I was eager to implement and reflect on the use of analogies in the classroom in my first year of teaching. Despite this goal, the realities of day-to-day teaching overwhelmed me for the first term. Also, the out-of-class responsibilities of a teacher began to mount, including attending numerous meetings, induction, paper work for student reporting, excursions and experiments, and "actively participating in the life of the school". An additional difficulty was adapting to the school science program. The units were broader than what I had previously encountered and there was no set text for students. In the hands of experienced teachers this allowed the unit to be shaped to the class' needs and interests using their vast wealth of personal knowledge and resources. However, for a first year teacher used to structure and organisation it was like being placed at the wheel of a cruise boat, knowing where the ship is destined but having only a vague idea on how to sail there. I spent most of the first term just "treading water" and it was not till the first break that I had a chance to relax and reflect. My interest in investigating analogies in the classroom had paled in importance considering all the other demands of a new teacher. Nevertheless, I was able to encourage students to develop analogies in the classroom with mixed results.

Student generated analogies can be a powerful aid to teachers in the classroom. Although there are well known pitfalls with such analogies (see also Chapter 5), as I have experienced personally this year, they can also provide feedback on students' understanding of the prescribed concepts as well as providing an extremely effective tool in helping other students learn. I have learned that analogies lose effectiveness if students have limited familiarity with the analog, and it is a good idea to appraise student analogies before whole class discussion.

A student generated one successful analogy following my whole class discussion of the function of a neurone. The student had not started the diagram I had requested to be drawn and when prompted he explained he had been thinking and that a neurone was a lot like a power cord. He suggested that the axon was like the wire inside and the myelin was like the insulation on a power cord. Other students listening agreed and started expanding the analogy further by including dendrites and synapses. This developed into a class discussion on the analogy and how far you could take it. Students took the core idea and applied it while also realising its limits, namely, there was no corresponding cell body in a power cord so they started discussing computer networks and cabling. The discussion did require me to guide it back when ideas were getting confused or ridiculous and also to field questions including: "If myelin breaks down is it dangerous like if insulation is damaged on a power cord?" leading to discussion on diseases. In the end the class had a good understanding of the parts and function of the neurone, and demonstrated this on their overall achievement for this section of the exam.

4. DISCUSSION

The stories shared between the three beginning teachers became reflective devices to help each teacher reinforce or modify his/her teaching practices. Marianne was encouraged to continue her use of analogies in science teaching and, following the readings of each other's stories, Alberto has subsequently introduced pre- and post-testing to gauge students' understanding through analogies. Furthermore, Alberto declared: "the idea of getting the students to write their own analogy had occurred to me previously but it was not until I read Heidi's story that I was prompted to use it, in part because of the obvious benefits she had with student generated cartoons."

4.1 Making Connections with Students

A common thread between the three stories was the teachers' recognition that the metaphors and analogies created common ground between teacher and student, especially in relation to shared language (or images) linking analog and target concepts. In Marianne's story, the students actively used the language associated with power cords (analog) to explore the function of nerve tissue. Alberto added the following account of his more recent experience teaching stoichiometry through analogy, largely inspired by his interactions within our learning community:

> Reading Heidi and Marianne's stories reminded me of what good teaching involves. For instance, I found analogies useful in helping me to create a third space where students and I could discuss chemical concepts through a shared vocabulary. Heidi found this space with her cartoons, and I quote "…the students knew the vocabulary…" From reading Heidi's story I was also reminded that it is possible to assess students' understanding of a concept as a guide for further teaching. More specifically, in one of my chemistry classes I chose to start the instruction using an analogy (i.e., ham sandwich – B_2H which represents 1 slice of ham for 2 slices of bread) rather than with the chemical concepts, and then bring in the chemistry once students had gained confidence with the analogy. Two weeks after having used the analogy for the first time, I asked students to provide me with examples of their own analogies. After reading the analogies they had written I noticed that two students still did not understand one of the basic concepts pertaining to chemical equations. Using their analogies I was able to approach them individually and discuss the problem. What this in turn allowed for was that the students were able to self-correct once I pointed out there was a problem. The use of the analogy allowed us to share a common language where I was confident the student would understand me and be able to show their understanding. One of the students was able to self-correct and then provide an explanation of why what he/she had written was incorrect.

4.2 Monitoring Analogies

Alberto's account draws attention to another significant shared experience between the teachers, namely, the need to monitor students' use of analogies. All three teachers wisely checked student-generated analogies or extensions before whole class discussion so as to avoid the creation of alternative conceptions. Their supporting roles for student conceptual development was reinforced by Yerrick et al., (2003) who concluded:

> Our study is a reminder that teachers serve an important role in classrooms by guiding and scaffolding ways in which knowledge, particularly analogies, gets shaped, refuted, and promoted. Exemplary curricula alone are no substitute for the teacher's role as the primary driver for rules of discourse in collaborative settings. This kind of classroom interaction stands in sharp relief to the kinds of talking science that are found in more conventionally managed classrooms. (p. 460)

4.3 Learning Together

Heidi and Marianne were fortunate enough to start their teaching careers at the same school. Working together and sharing their stories of successes and failures meant that they could also learn together. As Marianne noted: "I have benefited from continued contact with Heidi as both underwent our first year of teaching. Watching Heidi's enthusiasm and success with humour and cartoons has inspired me to add this as an additional teaching strategy to my *toolbox*. Cartoons were a simple step for classes used to analogies, and it certainly added a motivational factor." Heidi also recognised the value of networking with Marianne and Alberto.

> Marianne and I continuously bounce ideas off one another and discuss what has worked and not worked in our classrooms. This has been extremely helpful in its own, not only for better teaching and better learning, but for personal development… Alberto and I had discussed his trials and successes with his analogies in the classroom, and I remember how he was pleased with the outcome his "ham sandwich" analogy had produced.

Finally, despite the obvious challenges and constraints experienced by beginning teachers, each teacher participated actively in our discussions and various iterations of this chapter. Marianne identified several impediments to realising her ideal image of teaching in her first year. Alberto's story appeared to come along at the right time because it encouraged Marianne to reflect on her own teaching practices with the view to refining her teaching metaphors. As she admitted: "Overall my personal metaphors are changing and refining to fit my increasing experience and teaching environment. But in addition, I am becoming more confident in my ability to shape slowly both my teaching and the school culture by still aiming at idealistic teacher metaphors." Alberto, Heidi and Marianne's contributions here not only show the value that each teacher placed on maintaining our community, but also that the process of writing and sharing their stories provided a motivational incentive to contribute worthwhile accounts for each other's learning and possibly the readers of this chapter.

5. CONCLUSIONS

Teacher educators recognise that the ongoing study and improvement of one's teaching is difficult to accomplish alone (Feiman-Nemser, 2001). In this study, three beginning teachers – former classmates – shared their stories with each other and reacted to their colleagues' accounts in ways that helped each to become more reflective and implement new ideas about science analogies in their own classrooms. Steve was their professional development broker in this case. He created the learning community by inviting each of the teachers to participate in this project – the incentive was to write about the experience for the purposes of this book. Even though each teacher was busy, he/she wrote his/her story and reacted to each other's accounts with some significant shared learning outcomes, as illustrated by Alberto's concluding comment:

> I believe that in order to change my teaching to improve student outcomes, I must remain flexible like a supple, well-stretched muscle. Reading the other teachers' personal accounts was like a warm up – the stretching exercises to help me reflect on and modify my practice. The personal narratives have been particularly helpful to me in identifying good practice. The shared experiences of other teachers furthers my experience without having to be in their situation. I think of this as a way of shortcutting my development to achieve my teaching goals.

From Steve's perspective (and possibly for other teacher educators), sustaining conversations with his former students has not only reinforced his appreciation of the constraints that beginning teachers face, but also it has helped him to re-conceptualise aspects of his pre-service programs. Not only is it important to discuss the role of metaphor and analogy in science teaching from the vast research literature base available, but also it is important to share the real-life stories of beginning teachers committed to better student learning outcomes. The latter strategy will now be added to subsequent programs taught by Steve. The deconstructed stories/dilemmas of experienced teachers' use of analogies presented in Wallace and Louden (2002) will now be supplemented by the stories told by Alberto, Heidi and Marianne, for discussion/deconstruction by Steve's pre-service teachers. These stories hopefully will resonate with current student teachers as well as inspire them to persevere – sometimes against the odds – and create exciting new learning opportunities for their future students.

As Government departments around the world consider the increasing demands for better induction programs for beginning teachers (e.g., DEST, 2002), one principle for effective induction stands out from our experience in this project – "Induction programs should be negotiated on the basis of individual needs and goals, rather than standardised content, and should recognise that teachers' needs change over time" (DEST, 2002, p. 114). Because our ongoing discussions extended our previous work together at university, our agenda was negotiated on the basis of individual and collective needs and goals. We shared an interest in metaphor and analogy, and through this interest we sustained further conversations about the three teachers' lived experiences applying metaphorical thinking in class over the course of their first year as science teachers.

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KENNETH TOBIN

WHY DO SCIENCE TEACHERS TEACH THE WAY THEY DO AND HOW CAN THEY IMPROVE PRACTICE?

Research on teaching, learning and learning to teach can provide needed guidance for teacher education and education policy. As a science teacher educator my practices have been shaped consistently by a program of classroom-based research that began in 1973 and has continued to the present; an approach that was characterised by a dialectical relationship between theory and empirical studies. Over time the theoretical lenses I used to describe, interpret and raise questions evolved to take account of the historical constitution of science education and the sociocultural embeddedness of teaching and learning. Within the context of an ongoing program of research, the issue of metaphor became salient in 1985 during a sabbatical leave at the University of Georgia. Having read Lakoff and Johnson's (1980) *Metaphors we live by* I began to explore how metaphors were involved in conceptualising the roles teachers considered to have significance to their teaching. For more than a decade I then studied teaching and learning to teach through the lenses of the metaphors teachers used in their talk about science teaching and as referents for teaching science.

1. METAPHOR AND SCIENCE TEACHING

During a study of the teaching and learning of science in grade 10 one of the science teachers involved used metaphors to describe his roles in two very different classroom environments (Tobin, 1990). Peter used the metaphors of captain of the ship and entertainer to depict radically different teaching roles that appeared to constrain his identity as a teacher and the manner in which he interacted with students. The metaphors seemed to organise a variety of beliefs, values and practices. For example, Peter frequently taught as captain of the ship in whole class interactive activities, in which the teacher was clearly in charge, and the rule structure was consistent with the teacher, as captain, giving the orders and the students, as crew, following them. If transgressions occurred, penalties were

P. J. Aubusson et al. (eds.), Metaphor and Analogy in Science Education, 155-164.

administered by the captain. As captain of the ship, Peter's teaching incorporated values associated with efficiency and the teacher knowing best what to do in order to get tasks accomplished well. There was little time for digression and a fast pace was maintained by the teacher, who had firm control of the class.

When Peter switched from being captain of the ship to entertainer, a different set of beliefs, values and practices were evident in his teaching. The entertainer also was a central resource for learning, but a more relaxed atmosphere and a flexible rule structure allowed students to use humor and digress from the topic. The focus was not on efficiency but on establishing a relaxed and comfortable atmosphere in the classroom. As an entertainer Peter was humorous and personable. However, patterns of inequity were evident in his interactions with students. Some students were advantaged, others were disadvantaged, and issues of gender equity emerged. For example, Peter was serious with some female students, appeared to flirt with others, and ignored some entirely.

I regarded a change of metaphors as similar to throwing a master switch – a change in the metaphor used to frame teaching radically changed the enacted curriculum and the constituent roles, rules, and division of labor among participants. This idea was the underpinning for research on how learning environments could be engineered by changing metaphors for salient teaching roles. For example, in a study of a middle school science teacher, we investigated why Marsha was unable to teach as she wanted (Tobin & LaMaster, 1995). We examined Marsha's teaching in relation to the metaphors she used to make sense of roles such as facilitating learning, classroom management, and assessment of learning. Because the students in her class were extremely disruptive Marsha's reflective journal and talk about teaching focused primarily on ways in which she might control her students. She used a metaphor, teacher as comedian, to represent her role as a manager of student behavior. Her primary belief was that if she used humor, her students would like her, be cooperative, and learn more science. However, when she taught using the comedian metaphor to frame her teaching, she was unsuccessful in effectively managing her students; dysfunctional learning environments emerged in which Marsha spent nearly all of the time and her emotional energy on unsuccessful efforts to control the behavior of her students. Despite her efforts to be liked because of her humor, the students used Marsha's wisecracks as opportunities to show their dislike and disrespect for her.

In response to her failure to control students Marsha created two metaphors as referents for her roles as a facilitator and an assessor of learning; both metaphors intended to be consistent with constructivism. As a facilitator of learning, Marsha argued that she would be more successful if she adopted the metaphor of social director, whose role was to invite students to a party for learning. The metaphor recognised that she did not have direct control over students' learning; all she could do was to manipulate the environment such that the party was appealing to students, who would want to come and be cordial to her and one another. Planning an appealing party (lesson) was central to the metaphor of social director, as was a reduced rule system in which students did not interfere with one another's learning and showed respect for the teacher and their peers. Embodied in this metaphor and its enactment, however, was the enforcement of rules. If students were disrespectful or interfered with one another's learning Marsha punished them. There was no provision for collective responsibility for adhering to the rules and Marsha's efforts to create an improved environment using the social director metaphor seemed to fail because of the punishments and associated student resentment and negative emotional energy.

Marsha's efforts to create social capital with her students were minimised because of students' perceptions that she was unfair especially in her assessment of science learning. Hence she needed to change her practices as an assessor of their learning and allow students to start again in the process of earning credit in the class. Consistent with constructivism, Marsha created a metaphor for assessment as a window into the mind, an opportunity for learners to show what they know. This metaphor was potentially revolutionary because it involved a transfer of power from the teacher to students who would make decisions about what they had learned, what to show teachers, and when to show it.

Over time the learning environments in Marsha's class improved and students began to cooperate with her; she earned the right to teach them, or perhaps more accurately, they showed a willingness to be learners in her class and adopted roles that led to increased participation and learning. Rather than spend most of her time and energy establishing control over students, Marsha demonstrated a willingness to cede autonomy for assessment to students, a field in which traditionally they had little control. Not only did Marsha's practices establish a fresh system of incentives to pass the course, but students also felt respected and were more likely to show Marsha respect and assist her to succeed.

2. PERSONAL USES OF METAPHOR

A key idea with significant implications for improving the quality of science teaching was that metaphors operated as a master switch and allowed sets of practices and associated beliefs and values to be enacted without consciously having to deal with each of them as a separate entity. For example, in earlier research I showed that teachers could increase the science achievement of students by incorporating an average wait time of more than three seconds into their teaching (Tobin, 1987). This was a simple strategy that teachers readily accepted as common sense. For as long as they concentrated on so doing, teachers could incorporate longer pauses into their teaching; however, as the lesson unfolded their practices usually reverted to their habitual use of shorter wait times, averaging about a half second. The research on metaphor raises the possibility that teachers planning to enact a long wait time could create a metaphor to take account of waiting and using time to improve the quality of learning. Perhaps a metaphor of the teacher as an attentive listener would encourage teachers to pause for longer, take account of what students said during an interaction, and encourage teaching practices that were synchronised with those of students. I found this idea appealing and created metaphors for my teaching.

As a college professor it was useful to conceptualise my teaching metaphorically. For example, when I taught graduate students I preferred to be a provocateur. Verbally I would prod and probe so that students would be disequilibrated and become uncomfortable with their understandings. Verbal jabs were intended to catalyse deep thinking and create a form of inquiry that I felt was appropriate in graduate science education courses. Although all students were not comfortable with this approach, it was graduate school and I expected them to accommodate to my approach and assume responsibility for their own learning.

During the mid 1990s my research focused on equity issues in science education in urban high schools. So that I could avoid studying others teaching and probably falling short of my expectations, I decided to study my own teaching in a large urban high school in which most students were African American from home circumstances of economic hardship (Tobin, 2000). I opted to teach and undertake research with students who were at greatest risk of dropping out of school. Approximately 200 students (i.e., about 10 percent of the school population) were organised as a school within a school, constituting the lowest academic track, intended for students who were unsuccessful and in danger of dropping out because of poor academic performance, repeated absence, and in some cases ongoing problems associated with the law, parenting, and poverty.

When I started to teach I felt confident that I would create productive learning environments that would become models for prospective and practicing teachers and serve as a site for my research. However, analyses of videotapes reveal that my teaching was out of synch with the practices of students (Tobin, in press). I was teaching in a reactive way and seemed unable to create and sustain a flow of activity. My students seemed to deny me the right to teach them. Even though I knew I had to earn their respect and build rapport with them; I could not do it. Furthermore, I was afraid that my efforts to teach them would create struggles for control and I had little confidence that I could deal with any physical conflicts that might arise. To my surprise and disappointment, my efforts to improve the quality of the learning environments were unsuccessful and most efforts to succeed ended in failure. The students did not appear to respect me and I was too deliberative in my efforts to teach them. Continuously I searched for solutions, especially by creating metaphors to serve as referents for my teaching in what I described as event full classrooms. The following excerpt from my field notes provides insights into my efforts to use metaphor to frame my teaching.

> I will be a cork on a stormy ocean on Monday. They will be the waves, the current, the wind, and the tide. At times I am certain to be pulled adrift and even under the surface. However, I will be resilient and bob on the surface, following their lead as I find my way toward a destination that is dynamic and probably never ending. I will have more metaphors by the time I arrive in class, but for now this is a reassuring way to think about my role. I will not be a counter puncher, no weapons, totally responsive; but also mediating whenever the waters are calm.

Analyses of my teaching reveal that in the first month or two I was constantly considering my options and making changes to accommodate to the unfolding circumstances of the classroom. My efforts did not appear to produce events as I anticipated and anxiety was written on my face as the curriculum unfolded. There was hardly any flow to my teaching and, in terms of emotional energy, the lessons were flat. Unlike Marsha's problems, which involved boisterous interruptions to her efforts to teach, the students in my class were often silent, did not appear enthusiastic, and there was evidence of peer to peer playing among females (Elmesky, in press), which I endeavored to quash. Usually my attempts to control playful interactions were ineffective and seemed to catalyse disruptive practices, evident in the tone, pace and emotional content of student outbursts. When I used the floating cork metaphor as a referent I tended to back off and I did not escalate conflicts with the students or among students.

Even though the use of the metaphor might be seen as working, it is an oversimplification to claim success in any absolute sense. Analyses of the videotapes reveal that my efforts to distribute the teacher resource among the students were not appreciated by them; they translated my presence at their groups as checking up and not trusting them. Similarly, proximity desists where I moved closer to students who were becoming restless often sparked outbursts of the sort I was trying to avoid. My efforts to teach were not welcomed by many of the students and as I revealed anxiety and sometimes frustration, some students seized the opportunity to disrespect me openly, possibly seeking to earn the respect of peers.

Although I was aware of the importance of showing and earning the respect of students, I was unaware that respect was analogous to a currency students could earn through accomplishments that were valued by peers. For example respect could be earned by being a good fighter, being physically attractive, wearing new sneakers, or pertinent to the problems I experienced, showing disrespect for a peer or an authority figure, like me. Also, it was considered important for students not to act in ways that would earn the disrespect of peers. Hence, students were generally unwilling to be too cooperative with a teacher and often they acted to disrespect me.

In two ways I learned about the centrality of respect, a form of symbolic capital and part of the schema that structured life within this youth culture. First, I learned from the student researchers from my class who I hired to advise me on "how to teach kids like them." As they experienced my teaching and reviewed it on video tape they consistently advised me to "back off man." "Get outta their faces!" "You gonna get hurt ol' head[2]. Let 'em come to you when they wanna learn." Ever so reluctantly I began to teach in accordance with such advice and endeavored to stop many habitual practices, such as my circulation around the class. Similarly, I consciously did not use proximity desists to quiet students who were becoming restless and nor did I ask students to raise their heads when they appeared to be taking a nap or ignoring me. Instead I decided that learning was the students' responsibility and, like Marsha, my chief role was to act in ways that would allow students to learn when they so desired. If the signs suggested that too few students were participating I had an obligation to enact changes to stimulate more of them to get involved. I endeavored consciously to create attractive learning environments and left it to students to get involved when and how they chose. This approach held students accountable for participation and allowed them to accept the consequences of the quality and quantity of their involvement. In adopting this stance I reduced the opportunities for students to "treat me like a ho[3]!" Since fewer students challenged my right to teach and there were fewer instances of disrespect, my comfort levels grew and it became easier to build social networks with students who wanted to learn from me (as distinct from trying to get involvement from those who were disinclined to participate). As I created social capital more students accepted me as their teacher, and an upward spiral occurred as social and symbolic capital interacted positively, allowing me to teach, build rapport with students, and attain status to support my identity as a "good" science teacher.

A second resource to teach me about the centrality of respect was the research of Elijah Anderson. An African American sociologist, Anderson studied the culture of African American youth, especially the culture of being in the streets of West Philadelphia (Anderson, 1999). Anderson pointed out that successful street life necessitated the following of a code; which was important for all those who had to navigate the streets in order to get to where they were going. His analyses showed that street practices would often involve earning and maintaining respect and that disrespecting others was part of street life. As soon as I read Anderson's book on street code I realised its relevance to my teaching and the power of using cultural lenses to interpret my teaching experiences.

In an effort to learn more I searched for graduate courses in my university that were relevant to what I needed to know. As part of a course on the psychology of the African American I studied an article by Wade Boykin concerning the dispositions that African Americans construct while living with other African Americans; learning from one another by being together in different fields of activity (Boykin, 1986). Among the dispositions identified by Boykin were several that were highly salient to teaching and learning of science; oral fluency, communalism rather than individualism, verve, movement and rhythm, adherence to social time rather then a linear time perspective, and spirituality. Since almost all of my students were African American I was challenged to consider that by being together in the field of the science classroom they might experience tendencies to act in accordance with the dispositions identified by Boykin. Furthermore, they might participate and learn more if I structured learning environments to encourage such practices. Since I regarded habitus (Bourdieu & Wacquant, 1992) as a form of cultural capital I was eager to plan and enact teaching so that students could use the dispositions identified by Boykin. I needed to adapt my teaching to recognise and build on these dispositions in ways that supported higher levels of student participation in science. I was determined not to inadvertently shut down practices associated with dispositions created in other fields, which might be foundations for higher levels of performance in science. More research was needed to guide practice since my shut downs and the students' dispositional practices might be enacted without awareness. Currently we are studying practices enacted in fields outside of science classrooms (e.g., streets, home, youth clubs, and sporting fields); hoping to identify those with the potential to provide a foundation for becoming fluent in science (Elmesky, 2003).

Longitudinal research on my teaching of urban high school youth shows clearly that my teaching has become adaptive to the practices of the students. Some of the changes were intended and I was conscious about them, and most just happened without me being aware of them. For example, my pace of speaking became much quicker, I was less repetitive, and I exhibited greater variation in intonation and pitch. If others were speaking when I began to speak I continued to speak rather than stop and permit the oral fluency of students to disrupt the flow of my teaching and the learning of others. I was teaching for those who wanted to learn from me. My classroom was no longer modeled on one person speaking at a time. I also used many more expressions that might be regarded as Australian idioms and used humor in my interactions with students. Like my students I became more playful in class. These changes are consistent with the oral traditions that Boykin attributed to African Americans. On the one hand I allowed students to participate orally if and when they felt it was appropriate and I demonstrated my own oral strengths, thereby earning symbolic capital as a fluent speaker who was quick witted. No longer did I talk slowly to make sure students understood what I was saying. I disregarded my earlier work on wait time and focused on fluency. In so doing I allowed overlapping speech and made conscious efforts to keep things moving.

I am a much more animated teacher and employ more body movement and verve when I teach; as if being with these students in a school that consisted almost entirely of African American students allowed me to create dispositions like those of these youth. Of significance, unless I undertook the research on teaching I would still have been unaware of these changes to my teaching. In my conscious efforts to allow students to be themselves I created environments in which I was able to build social and symbolic capital. Gradually I became accepted and respected and, instead of having to conform to the students' images of what a teacher had to be, I was able to be myself and still be accepted by them as a teacher. My teaching practices afforded those of the youths I was teaching and in that sense the structure of the field, which included my practices, created resources that could be picked up by students and used to meet their goals of learning science. My practices could be appropriated by students to learn science and my teaching minimised shut downs that would create negative emotional energy and feelings of not wanting to participate.

3. LOOKING AHEAD

One critical advance that has emerged from our studies on learning to teach in urban science classes has been associated with the use of coteaching and cogenerative dialogues (LaVan & Beers, in press). In coteaching we assign from two to four teachers to plan and teach a class together so that participants learn to teach by teaching with others. Such an approach permits each teacher to experience many ways of teaching by being with other teachers as they are teaching and to become like the other quite unconsciously (Tobin, Zurbano, Ford & Carambo, 2003). Of course not all changes are desirable and, through coteaching, teachers "pick up" good and bad habits. Cogenerative dialogues can help participants to become aware of their practices and arrive at collective decisions about what is and is not acceptable practice, and what is to happen in the future.

Cogenerative dialogues that involve students, teachers, researchers, and sometimes administrators in discussions over shared experiences of teaching and learning can address the extent to which teaching benefits learners, the roles of the teacher and students, what appears to work and what does not, and the associated divisions of labor and power relationships. We endeavor to convene as equals with the goal of identifying contradictions and patterns of coherence that occur in the practices so that we can reach collective understandings on how to resolve contradictions that are identified. Agreement can be reached on patterns that ought to be strengthened and others regarded as deleterious and in need of elimination. Similarly, environments can be enhanced by eliminating some contradictions and strengthening others; making patterns of coherence by increasing the frequency of contradictory practices. By actively involving students in cogenerative dialogues there is a potential to have them identify maladaptive practices that lead them to experience symbolic violence as dispositions to act are shut down unintentionally by teaching practices, and even to identify instances when adherence to rules or schema leads to the oppression of some students.

4. CODA

William Sewell (1999) described culture in terms of a dialectical relationship between practices and an associated system of schema. Hence any exploration of a field in which social life occurs can focus on the practices of participants and the schema as they are enacted in ways that are both structured and structuring. That is, the agency, or power to act, of any individual is always mediated by structure and in that sense no individual is free to act without experiencing the practices of others and other elements of structure (social, material and symbolic; Sewell, 1992). Hence, if as part of agency, an individual creates a metaphor that is to be a referent for his or her practices as a teacher, it is imperative to remember that whatever happens as teaching is enacted can only occur in the context of the dynamic structure of the field, which includes the practices and schema brought by others to the field. From Sewell's perspective on culture, metaphor is part of the schematic resources that can structure social life for individuals in a field (Sewell, 1999). If a metaphor becomes an object for discussion in cogenerative dialogue then the practices, beliefs, roles, power distributions and rules associated with the metaphor can be discussed in relation to all facets of a community and collective understandings can emerge on how the metaphor can structure social life in the field. In this sense, metaphors might be useful if they are constructed to be consistent with shared visions for social life in a field. Hence a metaphor might contrast in many ways with existing experiences and can be a mutual focus around which cogenerated agreements are constructed. Alternatively, metaphors can be constructed as explanations for experience and stand for that experience metonymically, providing an object for discussion and potential change. In this way the changed metaphor can be a referent for conscious actions as curricula are enacted and then for review in subsequent cogenerative dialogues.

I conclude this chapter with a sense of being at a rest stop on a long journey. The research I have experienced on metaphor has greatly shaped my practices as a teacher educator, teacher and researcher. As I have participated in a theoretical journey that has taken me from Piagetian roots through constructivism to embrace more social and cultural perspectives on social life, metaphor has been an integral part of my theorising. Within my current bricolage of theories, drawn from cultural sociology (e.g., Sewell, 1999), activity theory (e.g., Cole & Engeström, 1993) and the sociology of emotions (Collins, 2004), metaphor is still central and potentially valuable. However, any use of metaphor must be undertaken with the realisation that much of social life is beyond what is and can be captured metaphorically and discursively. Those parts of social life that are enacted by being with others in many fields of activity can be wonderful teachers and what is learned through the experience of enacting culture, without awareness and without conscious rationale are not only critical to productive social life, but may be the most useful constituents of becoming educated not only in science, but also for life in the modern world.

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5.1 Notes

[1] Ol' head is a colloquialism for old head which refers to an elder within a community; a person who is shown respect.

[2] Ho is a colloquialism for whore.

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CAN ANALOGY HELP IN SCIENCE EDUCATION RESEARCH?

1. INTRODUCTION

Analogy creates knowledge and a purpose of research is knowledge production. This chapter asserts that analogy provides a means of theory building, a meaningful way to understand our world. It proposes that analogy can and should be used to inform the analysis of findings in educational research in general and science education in particular. First the case for analogical mapping as a device for interpreting research findings is made by considering analogy as a thinking tool and by proposing the use of analogical mapping. Second, this process of analogical analysis is illustrated by its application to a case study of school science. Third, the limitations, strengths and weaknesses of analogical mapping are considered before the reader is invited to apply analogical mapping to other research findings. The sequence of steps involved in the analogical analysis is then summarised as an exemplar for application to other research.

Metaphors and analogies are valued thinking tools because they allow the unknown to be understood in terms of well known phenomena (Badcock, 1995). In science, analogical reasoning is a well respected way of thinking and abounds in the language of science (Dunbar 1997; Eisenberg, 1992; Gentner, Brem, Ferguson, Wolff, Markman, & Forbus, 1997; Kurtz, Gentner, & Gunn, 1999; Holyoak & Thagard,1995; Markman & Gentner, 1996; 1997). We all use metaphors when we speak, write and think because they are fundamental to communication and the nature of human intellect (Holyoak & Thagard, 1995). When we use analogy it is interpreted. The person who constructs the analogy does so by 'viewing' one thing and comparing it with another. When the analogy is shared the analogy is reinterpreted as attributes of the analogy are identified and compared. When used to communicate an idea clearly, the important attributes of an analogy are often identified to guide the reader's or listener's interpretation. For example, when A. A. Milne tells us about Christopher Robin's imaginary friend, he writes, "Binker's brave as tigers when we're lying in the Dark … He never, never cries... Except (like other people) when the soap gets in his eyes." Milne specifies the feature of the tiger possessed by Binker. Then Binker is readily interpreted to be brave but not striped

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and furry and the chance of misinterpretation is reduced. The context of the analogy also informs both the user and the receiver. If a teacher describes a class as 'animals' then both the class and teacher know it is not a classification exercise but a metaphor identifying certain attributes of the students' behaviour.

A key danger of analogy is that it can be misleading and distort ideas and information. As Morgan (1997) explains, it is paradoxical that analogy can create insights but at the same time risk distortion by both providing a way of 'seeing' and a way of 'not seeing'. All who share a particular analogy will not recognise the same attributes and create the same meaning. A good user of analogy can reduce the chance of distortion by clarifying the analogy – by identifying the relevant and irrelevant attributes and elaborating on these. Consider Huygens view of light. '(Light) spreads', he wrote, 'As sound does, by spherical surfaces and waves: for I call them waves from their resemblance to those which are seen to be formed on water when a stone is thrown into it' (cited in Eisenberg, 1992, p.144). Note that in this extract, the similarities between water waves and light are mapped one against the other identifying similarities. These mappings provide insight into the nature of light (the unknown) through the well known and well understood phenomena of water waves. If analogy is to provide a means of interpreting research findings then careful mapping of attributes is one way to establish rigour and reduce misunderstanding. In order to do this in research we must first consider the interpretation of analogy in depth.

2. ANALOGICAL INTERPRETATION

Analogy is made up of two parts, the target, which is the domain to be explained, and the analog, which is the domain that serves as a source of knowledge. If an analogy is used in producing knowledge, then the value of the analogy does not lie simply in the overall number of similarities between target and analog. The essential requirement is that "a relational structure that normally applies in one domain can be applied in another domain" (Gentner, 1983, p.156). Relational structures are attributes of the analog and target that suggest a similar causal relationship. They reveal similar ways of understanding the analog and target.

Analogies may also have literal attributes (Gentner, 1983). The difference between a literal and a relational attribute can be illustrated by example. Aubusson (2002) uses the analogy of the teacher as nomad to reflect on the way an observed community of science teachers operated, that is, like the nomads in some ways. The nomads served as the base and the teachers as the target. Consider the following two attributes of the analogy. The nomads, as described by Bronowski (1974), traverse six rivers and accept high losses in their goods and herds as part of the natural order of life. Similarly, the teachers studied 'herded' their classes through six years of schooling. Each year their students had to 'traverse exams' and the teachers tolerated high rates of attrition as inevitable. The six rivers could be considered an attribute similar to the six years of secondary schooling. The number of obstacles, however, is merely a match of literal features with no explanatory power. On the other hand, the acceptance of high culls of students who fail to succeed academically as well as the way in which each class is herded towards the same destination year after year can be explored as relational similarities. The attributes suggest a potentially causal relationship, based on the nomad analogy, about the nature of schooling. The literal analogy only provides a match of trivial similarity. The relational similarities provide a system of connected knowledge for comparison.

The exploration of relational similarities allows the process of reasoning to be inferred from one domain to another, to transfer causes and processes to a target. Relational structures provide access to an existing knowledge system in the analog. High-order mappings (Gentner, 1983) are those which generate deeper understanding of the target. Analogical mapping, it seems, may provide one way to shift to a higher level of qualitative research where interpretation of data may 'convey new meaning' or 'reveal something unknown' (Kearney, 2001, p. 148). Analogical mapping does this not by mapping an uncharted landscape but by viewing the landscape in another way. In analogical mapping, high-level interpretation is characterised by mapping relationships associated with reasoning and argument, not merely identifying similar attributes. Selecting a useful analogy is important. The selection of an appropriate analogy for mapping involves seeking a metaphor with extensive relational correspondence rather than simply many similarities. Hence when using analogy to build understanding in research the careful selection of analogy is crucial. The process is an iterative cycle where analogies are selected and mapped, often only to be rejected due to their mismatch or failure to generate insights and a new analogy is then sought. This can be a time consuming process. To make this more efficient and productive, the procedure recommended here proceeds through two stages, an initial mapping and a second more extensive mapping.

The purpose of the initial mapping is to confirm that an analog has potential to provide insight into the target domain. Initial mapping identifies general relational features of the episode under study. It then looks for a match (and mismatch) between the analog and target. When this is found, the well understood analog is elaborated in detail. This allows other similarities and differences in the analogy to be identified. These steps in analogical mapping are illustrated below. The example used here refers to a case study of a science department that was attempting to bring about a change, which was informed by their understanding of constructivist epistemology. (For a detailed explanation see Aubusson, 2002.)

2.1 Stage 1: Initial mapping

In the initial mapping, the general features of the phenomena under study, the school science system, were identified. These were:

1. Complexity – many interconnected factors influenced what teachers did as they attempted epistemological change.
2. Stasis – despite the attempt to radically change, there was little long term change evident in the school. This stasis appeared to result from dynamic resistance to change derived from the complex interconnectedness of the system.
3. Unpredictability and gradual subtle change (later described as evolution).

Using these features, analogs were sought which might provide insights into the science education system. These were then subjected to a first mapping seeking correspondence between the above features and the target case of school science. Some were tried and rejected. First analogs were sought in chemistry and physics. Inertia as a consequence of balanced forces, seemed a likely candidate but it lacked the complexity and dynamism of the school system. Le Chatelier's principle was also mapped. This provided insights about equilibrium but it did not explain the unpredictability identified in the case study. Neither seemed to deal with the impression that school science functioned like an organism rather than a mechanism. An analog was sought in biology because 'living systems are characterised by a remarkably *complex* organisation ... (with) a steady-state balance in spite of much input and output. This homeo*stasis* is made possible by elaborate feedback mechanisms, unknown in their precision in any inanimate system' (Mayr, 1988, p. 14, emphasis added).

An ecosystem was selected for initial mapping because it provides the ultimate level of biological organisation. This choice was validated by Miller's (1975) description of ecosystem, which identified the same features in ecosystems that had been identified in the science education case study: complexity, stasis, variation and, (paradoxically) gradual change.

> … everything is *connected* to everything; everything feeds back through the ecosystem on itself. The interconnectedness *preserves* the overall system. The natural tendency of any *complex* ... ecosystem is to maintain a *dynamic steady state despite* environmental stresses, changes and shocks. Even where stresses are too great ... a biotic community can *evolve* a new steady state in balance with changed environmental conditions (p. 77, emphasis added).

The initial mapping proposed a potentially productive relational match and suggested that the ecosystem analogy could be extended.

2.2 Stage 2: Extended mapping

The next stage required a more detailed interpretation by mapping the research case against a more extensive view of the analog. In the example being used in this chapter, a well understood ecosystem provided a basis from which to identify a variety of specific attributes of ecosystems. These were refined by eliminating literal attributes and clarifying causal relationships in the analog that might be used to understand the target. A few of the potentially productive features of the ecosystem are stated below:

- *Complexity* of interactions as there are many interrelationships among plants, animals and their surroundings.
- *Homeostasis* such as the ecosystem's capacity for self preservation and self perpetuation.
- *Opportunism* such as when the house mouse exploits the short term plentiful food and altered environment after fire resulting in a rapid growth in population.
- *Reproductive maturity* in that species. To survive, they had to live long enough to pass on genetic information to successive generations.

- *Fragility* when sudden changes (e.g., frequency of fire) can eliminate species.
- *Evolution* as organisms have evolved through natural selection of variations.
- *Purpose* in that the organisms function as if there is an unconscious purpose, the survival of the species (Plotkin, 1994), through such adaptations as the production of nectar ‘to’ attract animals ‘to’ pollinate its flowers.

This outline of an ecosystem emphasised biological ideas including adaptation and evolution as well as interactions among organisms and with their environment. These characteristics maintain robust stagnation but permit unpredictable change.

These attributes can then be mapped against the case study to identify the similarities, differences and ambiguities. It is important in analogical mapping that features that match well and features that do not match well are considered (Hesse,1966). Sometimes the thorough comparison of attributes that are ambiguous may be thought provoking. In this chapter, two mappings will be considered in brief. The attribute of complexity is a very similar relational attribute. The attribute of purpose illustrates the use of an ambiguous similarity, leading us to question the extent to which school science and ecosystems are driven by purposes and whether these purposes are similar? The examples have been chosen to show how a well-known analog (ecosystem) can provide an extensive knowledge base to interpret a target (school science).

2.2.1 Complexity

The school science system is complex. The complexity could be seen in many different interacting features of the school’s science education system. There were interactions among the following:

1. the teachers competing views of purposes, teaching and learning;
2. the different official curricula, taught and learned curricula;
3. aspects of conflicting teaching/learning paradigms such as behaviourism, views of constructivism, and inquiry as well as tensions between learning a set of science processes and knowledge acquisition; and
4. aspects of school, science department and teacher practices unsympathetic to constructivism – particularly assessment and reporting.

The interconnectedness of these produced a robust steady state.

2.2.2 Purpose

The teachers held many purposes for science education. These included that students learn to think, learn science facts, work things out for themselves, learn process skills, appreciate science, perform well in exams, etc. Different teachers in the school emphasised different purposes. One might emphasise student appropriation of science process skills while another the acquisition of science understanding. By contrast, the ecosystem functions as if it has a single purpose. The organisms function as if their purpose is survival of the species. This notion of purpose in evolution has been contentious among biologists, (Williams, 1993; Ayala, 1993). Yet, natural selection serves a purpose:

> ...the designation of something as the means or mechanism for a certain goal or function or purpose will imply that the machinery involved was fashioned by selection for the goal attributed to it ... This is a convention in general use already, perhaps unconsciously ... Thus I would say that reproduction and dispersal are the goals or functions or purposes of apples and that the apple is a means or mechanism by which such goals are realised by the apple trees. (Williams, 1993, p.182-183)

The organisms in the ecosystem survive because everything that happens serves this survival imperative. This singular purpose in the ecosystem seems dissimilar to the science education system where the purposes identified in the case study are many and intentional. In purpose, the relationship between the analog and this school science system seems inconclusive and requires further consideration. To explore the analogy further a more detailed consideration of purpose is required. In biology, three types of purpose have been identified (Ayala,1993, p.189-190).

1. Intended teleology, where the outcomes of actions or objects are consciously intended by an organism (e.g., a lion pack hunting antelope).
2. Artificial teleology, where objects result from purposeful behaviour (e.g., a bird's nest).
3. Natural teleology, in which features are the result of a natural process (the wings of birds have evolve 'for' flying).

Purpose seems in the school science system to be intended but in the ecosystem to be natural. Like the adaptations of organisms, however, the school science system is a natural teleology. If the purpose of education is to promote the survival of the human species through the transfer and development of knowledge across generations then science education is a natural teleology. Specifically, extended nurturing among humans has long been considered an adaptation and school science forms part of this nurturing. In purpose, there is an ambiguous similarity between the science education system and the ecosystem analog. In biology, natural selection, through courtship, has resulted in characteristics which are, other than in courtship, disadvantageous. Consider for example, the oversized tail feathers of the peacock and the excessive bulk of the male sea lion. Has schooling similarly gradually evolved through selection to develop characteristics fundamentally inimical to its teleological purpose? For example, have its testing regimes, rigid timetables and packed curriculum evolved for seemingly sound reasons, such as ensuring rigorous education but might they inhibit the teleological purpose of learning?

This analysis of the nature of purpose in an ecosystem contributes to an understanding of purpose in schooling. The apparent broad similarity of purpose, identified in the school science system, is an imperfect match with the ecosystem analogy. Nevertheless, it raises questions about how the school science system's fundamental 'natural' teleology (learning) may be distorted as a result of 'natural selection' and a focus on 'intentional' teleologies (e.g., teaching practices) which may give rise to counterproductive 'artificial' teleologies (e.g., an exam emphasising recall).

2.2.3 Mapping conclusion

Mapping the ecosystem analogy onto the school science system identifies relational similarities (e.g., complexity) and ambiguous features (e.g., purpose) and produced an ecological model of stasis and change in education (Aubusson, 2002). Some similarities identified in the analysis provided insights into the functioning of school science and had implications for research and its interpretations. In particular, the ecological notions of reproductive maturity, adaptation and fragility can explain the varied impacts of attempted innovation in school science. Specifically, a 'new' teaching approach might thrive for a short time in a trial school, if supported by sufficient energy or resources, but it is unlikely to survive in the long term. Analogically, a new teaching approach is an exotic species, which has not evolved in the school to which it is introduced. It is less well adapted to the existing environment than are the established 'species', practices and procedures. It rarely reaches reproductive maturity, a point at which the ideas and practices are dispersed among other teachers and in other schools. It may flourish briefly but it is fragile and usually dies.

3. IS ANALOGICAL MAPPING VALID?

Although well established as a way of thinking and interpreting the world, the formal application of analogical mapping in qualitative research in education is atypical. Therefore, an important consideration is how the trustworthiness and quality of analogical analysis may be judged. This is considered briefly here to promote discussion of this method of analysis.

A first step in establishing the worth of the analogical mapping depends on the same principles or criteria for collecting and analysing data outlined in the many articles and books on qualitative research (e.g., Drisko, 1997; Garratt & Hodkinson, 1998; Lincoln & Guba, 1985; Searle, 1999). In early sections of this chapter the principles guiding the selection and testing of analogy against data and findings were discussed. The reader is perhaps best placed to make a judgement on the value of the analysis reported briefly in this chapter and its relevance to other settings. Nevertheless, researchers should make explicit their reasons for their interpretive judgements and provide evidence that these judgements have been subjected to scrutiny (Garratt & Hodkinson, 1998). Here, I will limit the discussion to just two strategies related to judging the worth of the analogical mapping (by means other than testing for its consistency and inconsistency with research data and findings, which has already been discussed). These two strategies are peer review and application to other cases.

3.1 Peer review

Analogical mapping sets out to communicate ideas and render phenomena more understandable. It follows that 'good' analogical mapping should help others to make sense of the phenomena under study. One way to seek verification of the validity of an analogy is to ask others with expertise or experience in the field to confirm or disconfirm the proposed analogy and its detailed analysis. In the case study reported in this chapter, this scrutiny was sought by discussing data and the analysis with peers in a university research group, experts in science education and change, reporting the interpretation to the teachers involved in the study, and reporting the analytical interpretation to meetings of other science teachers and academics. This procedure provided a check on the interpretation by those with knowledge of the phenomena. Where criticisms were raised or alternative interpretations were suggested these were explored and tested against data and findings. The discussion of 'purpose' outlined in this chapter was the result of one such criticism; a criticism which had to be tested against the data by looking for confirming and contradictory instances. Thus, one test of 'goodness' is peer review both by experts and research participants as well as evidence that alternative interpretations and criticism have been examined in light of data and findings. It could also be argued that an analogy is valid when it works for the participants in their context raising good questions, providing insights or ways to move forward.

3.2 Application

Qualitative researchers are usually very sensitive to the context bound nature of their research and findings, often leaving it to the reader to judge their applicability to other contexts (Searle, 1999). Yet, transferability is often important to consumers of research who want to make use of grounded knowledge in other settings (Drisko, 1997). If an analogy is relevant beyond the circumstance where it is generated, it should be applicable to other related circumstances. Here, if the ecological interpretation is to be useful it needs to provide a reasonable interpretation of other cases. One of my concerns with the ecology analogy was that it was derived from a case characterised by stagnation and little change. Yet, the ecology analogy also provided a potential for radical change. In the ecological view proposed, organisms (particularly humans) and geological events sometimes change aspects of their environment. (Continents drift, beavers build dams and humans radically alter most ecosystems.) So far, this ecological interpretation might suggest that school and ecosystem only prevent change by selecting species/ideas that fit and maintain the existing system. However, the analog suggests that change does, has and will occur – sometimes quickly.

In the reported research, the analogy was tested by reinterpreting findings of two well known researched projects where significant change in the teaching of science had been reported, the Project to Enhance Effective Learning (e.g., Baird & Northfield, 1992) and the Learning in Science Project (e.g., Bell & Gilbert, 1996). The interpretation of these two cases is reported in detail in Aubusson (1998) and briefly in Aubusson and Cosgrove, (1997) where it was concluded that the ecosystem analogy, through introduced species and the application of energy and resources, could explain radical change as well as stagnation in a school system.

3.3 Limitations

There are many different ways of interpreting and reporting research. I do not assert that all research be analysed analogically. Indeed, all data and findings do not lend themselves to analogy. A well-understood analog may not be available as a source of established theory. "Scientists have generated powerful insights by studying light as a wave or a particle. But not as a grapefruit." (Morgan, 1997, p.350). Even where available an analog may prove unproductive. Note that in this research a number of unproductive analogs were tried. But even unsuccessful analogs can provide insight necessary to develop an analogy that works.

Analogical analysis follows an initial interpretation to provide an alternative way to view the phenomena under study. Where the researcher is satisfied with the explanation yielded by other methods and judges that the outcomes of the research are evident and readily communicated, then analogical analysis may be unnecessary. However, where a more parsimonious explanation is sought and grounded theory proves difficult to generate, analogical mapping is a way of bringing established knowledge to bear on the problem. It adds a layer to interpret, communicate and increase understanding of human contexts. Used without a thorough, initial interpretation of the data, it is just as likely to mislead as to provide insights. This caveat needs to be strongly made as an inappropriate analogy can mislead if too much credence is attributed to the analogical relationships.

4. A SEQUENCE FOR ANALOGICAL ANALYSIS IN RESEARCH

Analogical mapping provided a means of reinterpreting the findings in a qualitative study and gave rise to unexpected insights into the nature of school science. Although analogical mapping for research purposes need not rigidly follow a set of steps, a sequence of analysis is suggested below:

- The key features of the target are identified. Here, key features of the school case study included complexity, stasis, evolution.
- A well understood analog is sought. Analogy was sought in a range of disciplines including biology.
- The target and analog are compared to test for a match of the key relational features. This is called the initial mapping.
- The well understood analog, if judged suitable on the basis of the initial mapping, is extended to identify more of its potentially salient attributes.
- The analog is then used to reinterpret the target domain seeking similar, different and ambiguous relationships. Literal attributes are discarded. In this case, the detailed attributes of an ecosystem were tested for a match in the school case study. This provided new ways of thinking about or supplied a conceptual framework for theorising about the case under study.
- The analysis provides a conclusion. In short it answers the question, what do we now know about the case under study that we did not know before?

4.1 Trying analogical mapping

The use of analogy in research is commonplace but systematic detailed mapping is rare. Like many things, the strengths and weakness only become apparent when you apply the method yourself. The challenge then is to investigate such a mapping in a field of educational research in which you are familiar. I am tempted to provide examples but to do so will trivialise the process. The process and selection of analogies should come from a need to further explore specific research findings. Nevertheless, it could be productive, for example, to extend the ecology analogy to a consideration of teacher burnout, school leadership or professional development. It may be more engaging to explore science education using multiple analogies to provide varied insights. For example, we might map our understanding of disease against the 'pandemic' of science education; we could interpret the spread of science education by likening it to the spread of a disease, through personal interactions, to infect many school systems. We could consider how in some virulent forms school science may promote apathy towards learning and inhibit curiosity. Alternatively, we could contrast science education viewed as disease with it viewed as cure. Science education could equally be cast in the role of cure, alleviating the ills of poverty and a depressed economy by enabling people to embrace and to exploit scientific and technological opportunities. The attributes of cure and disease could be mapped to explore when, how and why school science might sometimes promote well being (learning and growth) while at other times lead to a debilitating, chronic lack of interest.

5. CONCLUSION

> "Midway between the unintelligible and the commonplace, it is a metaphor which most produces knowledge." (Aristotle, cited in Gardner, 1983. p. 34).

Analogy in research should not be so hackneyed that it reveals nothing new, so poorly known that there can be little confidence in the insights generated, or so obscure that it can only communicate ideas to a few. The merit of analogy in research lies not in any measure of the absoluteness of similarity between the target and analog. Rather, the worth of analogical analysis lies in the mental inquiry it promotes; the knowledge produced by this inquiry, the cognitive engagement of researcher and others, and the communication afforded. To be productive, the analogy should be contentious enough to provoke and challenge thinking but agreeable enough to resonate with others' experience of the phenomenon under study. It is a fine line but a fine line worth treading.

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STEPHEN M. RITCHIE

METAPHORS WE WRITE BY

1. INTRODUCTION

Academic writing has been likened to "an act of artistic creation, in which the real payoff is not the work itself, but instead in the creation of a new product" (Hourcade & Anderson, 1998, p. 276). Through the image generated by this artistic metaphor for writing, I "see" writing in a research project as a creative process in which I willingly participate to produce an artefact that documents the sense I make of the topic. It is through the writing that I become most aware of my feelings and understanding of a particular phenomenon; in this case, metaphors that guide and illuminate the process of research writing.

Recent discussions of research practices inform us that metaphors permeate research discourses (Brew, 2001) and that metaphors can guide our practice (Alvesson & Sköldberg, 2000). In fact, Alvesson and Sköldberg (2000) have argued the case for researchers to generate multiple metaphors to guide their practice:

> The point is that having access to several different metaphors facilitates offering various comprehensive images of research, thus reducing the risk of latching on to a one-sided favourite conception. Having a favourite metaphor is both (sic) natural, desirable and inevitable, but the trick is to have a certain distance in relation to it, that is, an ability to look at one's favourite position from an other angle. Metaphors should be chosen so as to stimulate reflection and movement between the levels of interpretation. (p. 284)

The extent to which this goal can be realised is yet to be fully tested empirically, if that were possible. As well, it is not known whether researchers will take up the suggestion to generate multiple metaphors to guide their research practice. What is possible in the context of this chapter is to offer descriptions of particular metaphors for writing, gleaned from my interviews with science education researchers about their research practices. Another purpose for this chapter is for me to begin to consider how I might adopt or generate particular writing metaphors in my research. Such writing might benefit novice researchers most because the practice of writing for publication can be a mysterious process, especially when traditional academic writing tends to be devoid of reflexive accounts of this practice (Brew, 2001; Roth & McGinn, 1998). Ultimately, through my research writing, I hope to come to know myself better, and as Brew (2001) asserted: "If in coming to know myself I also help

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others to know themselves or to know the world in which we live so much the better" (p. 184).

2. BACKGROUND TO THE STUDY

As part of a broader study of researcher practices with my long-term collaborator (Donna Rigano – see, Ritchie & Rigano, 2002), 24 science education researchers were asked questions relating to their writing practices. Each face-to-face interview focussed initially on the researcher's self-selected article involving qualitative research. As the interviews progressed, it was possible to interrogate researcher responses, often leading to the discussion of both similar and different writing experiences. In this way I was able to access a much wider set of experiences than those that were briefly articulated in the text of the focus articles. As well, most of these articles were artefacts of productive collaborations from long-standing research teams, giving me a chance to hear about a range of different writing styles and working practices, from the interviewee's perspective. Fortuitously, I was able to interview members of the same research teams on several occasions.

Thirteen Australian researchers from three major university sites comprised the original sample of informants. While all ranks (i.e., Lecturer, Senior Lecturer, Associate Professor, Professor) were represented in the sample, only three women were included – none at the rank of Professor. To redress this imbalance and to internationalise the sample, an additional 11 researchers from North America were interviewed. Once again, all ranks were represented (i.e., Assistant Professor, Associate Professor, Professor), but seven informants were women; two of these were full professors. Six researchers from the North American sample were selected from two well-known science education centres while the remaining five women worked at different sites. All researchers had published their work in international journals in science education and had presented conference papers at international conferences. Despite this, two of the researchers did not identify themselves as primarily science educators. One identified more with information technology education and the other was trained in literacy education. To ensure anonymity of researchers throughout this chapter, pseudonyms are used for interviewed researchers while letters (e.g., Researcher X) are assigned to those non-participating researchers who were named in interviews.

The transcripts of interviews were the primary data sources. These transcripts were returned to the researchers for checking. Informal conversations with the researchers pre- and post-interview, as well as follow-up email correspondence informed my interpretations. Consistent with the phenomenological stance adopted for this study, I borrowed "other people's experiences and their reflections on their experiences in order to better be able (sic) to come to an understanding of the deeper meaning or significance on an aspect of human experience" (van Manen, 1990, p. 62); in this case, writing for research publication. Lincoln and Guba (2000) best expressed the assumption underpinning my writing in this chapter, as follows:

> There is no single "truth" – that all truths are but partial truths; that the slippage between signifier and signified in linguistic and textual terms creates re-presentations

> that are only and always shadows of the actual people, events, and places; that identities are fluid rather than fixed. (p. 185)

3. METAPHORS FOR WRITING RESEARCH

Almost all of the researchers shared a commitment to, and enjoyment for, writing. Mirana, Carla, and Prue suggested that they each had something worthwhile to say through writing for publication. Perhaps more importantly, many researchers claimed that it was through their writing that they completed the analysis of data and came to a better understanding of the phenomenon under study. For example, Carla (a full Professor) said:

> I don't know that you can have the same learning experience without writing. The writing, I believe really strongly that you figure some of this out in the write. The write-up isn't post analysis; the write-up is part of the analysis. And so if you thought that you didn't have to publish then you wouldn't write and if you didn't write then you really wouldn't do the analysis… I like to write. I think it's grand fun to write, but I still have to push myself to do it. Definitely, you've got to do the writing.

Similarly, Martin explained: "I think this notion of writing as research is a very powerful idea. For me, more often than not, the ideas only come through the writing; [they] only come when I actually sit down to engage with the data."

Given that so many of the researchers endorsed the *writing as research* metaphor, it should not surprise that most of them considered the writing process a challenging activity. Even full professors admitted to being slow writers who intellectually struggled expressing their ideas. For Scott, a full professor, writing the first draft of a paper was "hell". He elaborated:

> I enjoy writing the [research] proposals; I have fun with the titles and the abstracts. Then when it actually comes to writing, it's [like] pulling teeth. I enjoy gathering the data and thinking about it and coming up with ideas, that kind of stuff, [but] sitting down and writing is hard work.

Only one of the researchers interviewed admitted to hating writing, though. For Anna, she wrote only because it was expected. She was much more comfortable with her teaching identity. Accordingly, she preferred conference presentations rather than writing refereed articles because, "I can present [just] as much information, but you have to be there." Yet for another researcher who strongly identified with his role as teacher, Frank has come to believe he has a responsibility to influence others by writing for publication. Frank asserted:

> My shift in understanding about writing and reading has been dramatic in the last decade. Once when I started, I didn't think I really understood what value there really is in writing. Now I'm a great believer, I still view myself as a teacher in that sense, that what I do in my class is important, but I now see myself as a researcher where what I learn has got to be made public. If I can share what I learn and I can research in ways that give strength to those claims, I must make that available to others, that's part of my academic role and people can decide if they want to pursue things this way, whether it's important, whether it will influence their practice. I can't accept any more that I could do a terrific job in my classes here and never do anything more. As an academic, that's not good enough. It is implicit in our job to go further than that… I don't accept any more that I'm too busy to research or write. If I'm an academic I have to find time to do

> those things because if the things I'm doing are helpful they've got to be helpful beyond me and my class, they've got to be helpful out in the world.

While a few of the researchers nominated sole-authored articles to discuss during the interviews, all researchers had collaborated with others on research projects. In fact, research collaboration has increased in recent times (Milem, Sherlin, & Irwin, 2001; Phelan, Anderson, & Bourke, 2000). Given this changing trend in conducting educational research, research collaboration became a focus area for discussion in my interviews with the researchers. Lincoln (2001) borrowed a physics metaphor of free molecules used by her spouse-collaborator to make the point that "collaborations represent self-other relationships that are unique, shape-shifting entities" (p. 53). She recounted:

> Researchers acting and writing alone… are like free molecules. They have enormous degrees of freedom but are sometimes characterized as moving in Brownian motion – a random pattern of movement determined largely by electrical charges on the molecules. Sometimes molecules with attractors manage to attract other molecules and become more stable as the attractor links them and they move in tandem. While molecules lose a degree of freedom in such attraction, new forms of movement and new linkages are created. (Lincoln, 2001, p. 53)

To help me describe the different ways that researchers write together in collaborative teams I call on principally two contrasting musical metaphors, namely: the "duelling banjos" and "piano duet" metaphors. My writing about these metaphors might evoke images of alternative writing (and researching) practices as well as create a climate for the reader to generate other possible images and metaphors. In addition to discussing how co-authors might write as if they were "duelling banjos", in the next section I identify related writing practices individuals adopted within research teams. This is followed by a discussion of interdependent writing practices that were best represented by the "piano duet" metaphor.

4. WRITING AS "DUELLING BANJOS"

In an effort to give voice to each researcher and make visible the trajectory of interpretive discussions with my collaborators, notably Donna Rigano, I once suggested that we write as if we were playing "duelling banjos" where the text would show a series of interchanges between us. Unlike the musical piece these interchanges would not be combative as the metaphor suggests, but nevertheless they would be constitutive by building on what was previously argued and represent our different positions where they existed. Our early attempts of using this metaphor translated into the inclusion of brief narrative accounts or stories by Donna, where my voice tended to be that of the narrator of the remaining academic text (e.g., Ritchie, Rigano, & Lowry, 2000). More recently, we have succeeded in including brief reflexive accounts written by each of us within sections of the paper yet without ongoing and interactive texts (see Ritchie & Rigano, 2002).

What I had in mind by generating the "duelling banjos" metaphor was later realised – without reference to the metaphor – when I co-authored a book with Michael Roth and Ken Tobin on teaching and learning science in elementary schools (i.e., Roth, Tobin, & Ritchie, 2001). Michael had been experimenting with what he called metalogue (and other interactive devices – see for example, Roth & McRobbie, 1999) in some of his academic writing and suggested that we generate metalogues throughout the book. To illustrate the interactive nature of such text, I include an abbreviated example of a metalogue from the introductory chapter of our book.

> S[teve]: Before we provide an overview of the book we should tell readers more about metalogues and why we use them in this book.
>
> **What is a Metalogue?**
>
> M[ichael]: As far as I know, it was Gregory Bateson [in 1972] who introduced metalogues. A metalogue is a conversation about some problematic subject. But it is not just a conversation. Rather, in the ideal case, the structure of the conversation in its entirety is also relevant to the subject; that is the metalogue exemplifies its subject matter in its form… Here we use metalogues in the way Mary Catherine Bateson constructed them, not as stand-alone texts but as conversations that occur in a context. Our metalogues are constructed as continuing conversations about elementary science…
>
> K[en]: In a sense, our metalogues also reflect our argument. Throughout the book, we suggest that for learning to occur, elementary children and their teachers need to engage in conversations around artefacts…
>
> S: But it is important to note that in both situations, we hope that the discourse will evolve to embody some of the best of scientific discourses in each domain. (Roth, Tobin, & Ritchie, 2001, pp. 10-11)

In this extract and elsewhere throughout the book we generated a log of interactive text that not only gave voice to each co-author, but also showed how each responded to the views expressed by others. Metalogues appeared at the end of each chapter to highlight the reflexive post-analysis of the main ideas argued, and these were frequently re-visited in later chapters. I enjoyed participating in the creation of these metalogues with Michael and Ken, but their impact on the reader didn't become clear to me until one of my graduate students suggested that I assign to students the task of reading only the metalogues (rather than the major text upon which the metalogues were based). This more personal genre appeared to appeal more to student teachers than more traditional academic text.

Although none of the researchers identified the "duelling banjos" metaphor in our conversations about writing practices, a related common practice for collaborators was turn-writing. Turn-writing was described as a "cooperative (as distinct from collaborative) division of labour" (Mirana) where contributors negotiate different sections or "chunks" (Scott) to write before someone (mostly the professor in research teams involving doctoral students, or the first listed author in other research teams) "glues" (or edits) it together by "gluing [or merging] different voices" (Kristin). Ryan, who predominantly writes in this way with his doctoral students, described this process as follows: "Once we got the structure mapped out, and that was through numerous meetings and sitting down with paper [and pen] just dividing up and saying, 'Okay, you take the lead on this section and I'll take the lead on this section.'" Similarly, Scott recounted a rushed effort to write a paper with his doctoral students the night before their scheduled conference presentation: "And we sat around a hotel room talking and I think we had several computers and we'd talk for a bit then we'd go off and write and we'd write different chunks and bring them back together and talk some more."

A more common writing practice in research teams was where one person would lead by taking responsibility for writing the first draft of a paper (i.e., lead-writing). The lead would then be rotated for subsequent papers on the project so that each team member would be listed first as an author. This seemed to be a well established "rule of thumb" for collaborators other than those involving doctoral students, where the student mostly was listed first, because "I just think it's their primary work so I've been quite happy to go second author… even if I do a fair bit of work on the writing" (Ryan). While several researchers recounted the same "rule of thumb" (even using this identical nomenclature), it was interesting to hear that one North American university had created a policy that formalised the practice to protect the interests of students: "There's even a document at my university about authorship that whoever writes the first draft should be the first author" (Mirana).

In two cases, the researchers expressed a slightly different perspective. Evan was a very experienced full Professor who no longer wanted or needed professional recognition frequently afforded to a first-listed author. While his contribution may not have been less than his collaborators, he deliberately promoted others ahead of himself in the list of authors, even on those projects for which he had won competitive grants. In the second case, Glen had collaborated mostly with his doctoral students. Initially he did not bid to be listed as a co-author and claims to have missed promotional opportunities as a result. But now he justifies the inclusion of his name as a co-author on publications with his students with reference to his understanding of the post-modern concept of intertextuality. From this perspective:

> There is no single privileged author to writing a paper. Even if it's me only on the keyboard, I'm still drawing from other texts… So we have this notion of intertextuality, that texts don't sit in isolation from other texts. There is a blurring of boundaries. So I've come [to] … a new understanding about what it means to be an author and a co-author… it is not clear, it is not simple, it is not black and white, it is quite complex. To find our way through that we need a strong sense of ethics about participation and about collaboration. (Glen)

In the metaphors described so far a common thread has been that researchers tend to make individual contributions to co-authored publications usually after a general direction has been mapped out within the collaborative team. In contrast, writing side-by-side with one's collaborator involved interdependent work undertaken together. Trina used the metaphor of writing as a "piano duet" to describe this practice. This metaphor and associated practices are now discussed.

5. WRITING AS A "PIANO DUET"

Trina has never written a sole-authored paper for publication. In almost all of her research collaborations she writes with her collaborator(s) side-by-side as in a piano duet. As she explained:

> Two of us would sit like you play a duet at the piano and one person would talk and the other person would be writing. And the other person would say, "wait, I've got an idea." So I'd move away from the keyboard and they would write. And that's how my collaborative writing has happened in three different instances, in different groups… It's sort of like the ideas that you have when you're thinking to yourself but you don't write them down, and you think "gosh, I should have captured those because they are rich". It was like journaling I guess. So we were taking our live conversation and then capturing it while it was fresh and exciting and then putting it together… I think that my co-writing [sessions] are extremely intense periods where there's no interruption of thought… It's like taking two paintbrushes and having a go at a canvas; it's extremely exciting to see something take shape.

Kristin was one of Trina's collaborators. Typically, the bulk of the writing with Trina would occur in two-week blocks for each paper at Trina's home. According to Kristin, much of the reading and some data analysis would be done before the writing sessions. So Kristin would travel to Trina's town prepared for the task and then they would "spend hours conceptualising and writing and writing and writing… We could sit and talk out loud and write at the computer" (Kristin).

Even though Trina and Kristin forged a very productive collaboration by writing together side-by-side up to five or six papers, they both acknowledged that not all researchers could work this way. When Kristin tried the same practice with another research team (i.e., with Wesley and Zac), they had to revert to turn-writing or lead-writing practices. It was Wesley who could not cope with this dynamic because he needed more time alone to think through the issues. As he explained: "What bothers me the most is there's a sense that you have to make decisions so quickly. [When] you're together there's pressure to perform or to get the job done and I feel that I need more time to work out ideas. Maybe it's just my own inability to think on my feet." This was the same reason offered by Trina for why the "piano duet" style of writing failed for some of her other collaborators. She continued:

> A few of them can't think that fast, [as in the case of Researcher X]. She found it difficult to be generative in terms of thinking on the spot. She needed a bigger chunk of reflective space to do it in. Whereas I think about these things quickly, so people with whom I write like this are also comfortable with spontaneous generation of ideas that emerge through conversation.

As I listened to three researchers talk about their experiences with writing side-by-side, I tried to imagine what I would feel in similar circumstances. Exposing oneself intellectually so intimately to another must involve a high degree of risk-taking and then there would be an interpersonal consciousness – an awareness of one's self and the other's close physical presence for extended periods of time – that might interfere with one's task-related thinking. I could empathise with Wesley's experience. Notwithstanding the logistical barriers to schedule large chunks of time for writing with my collaborators, the challenge of creating a manuscript with another, together is nevertheless tantalising.

After completing the first draft of this chapter I attempted writing side-by-side as a piano duet with Donna Rigano (Ritchie & Rigano, 2003). We found that writing side-by-side was a richly rewarding experience that extended our "interpretive zone" (Wasser & Bresler, 1996) through to the writing of our manuscript. However, the initial image of writing as in playing a piano duet was superseded by our descriptions of the impromptu jazz ensemble (i.e., an initial theme is developed and extemporized by all performers depending on their musical backgrounds) and think pad (i.e., the keyboard became an interactive thinking/writing device) metaphors. Rather than constraining our contributions by continued use of a single keyboard, our practices evolved to writing together (almost simultaneously) after networking our keyboards to a single hard drive and monitor. Writing in this way we achieved a synergistic connection where "the partners fuel one another, creating an energized dynamic" (Saltiel, 1998, p.8).

6. WRITING WITH HIGH PROFILE IDENTITIES

All of the researchers I interviewed were successful in that they had presented and published in international forums. However, my preceding discussions have centred on the writing practices of researchers either in equal status teams or from the perspective of the higher status researcher, especially in professor – graduate student relationships. Here, I briefly consider the different writing practices in collaborations involving differential status from the perspective of the lower ranking researcher. Only four of the researchers interviewed (i.e., Prue, Damien, Kate and Jodie) were involved in such collaborations.

Prue had only worked in two research collaborations, both with high profile researchers. Even though Prue has a different relationship with each identity, she respects them both dearly and admires their writing fluency. For example, talking about the writing style of her "sister mentor" Prue revealed:

> Do you know when Researcher Y writes, she'll have a yellow pad and her pen… The way she writes it, that's what is here in the journal. There's very little editing… [U]sually when it comes out of her head onto the piece of paper, that's the final. Me, I have to sit at the computer and I edit and I edit and it takes me half a day to write a paragraph… That's where the intimidation comes from because the only models I've seen are Researcher Z and Researcher Y and they're so prolific – it comes out right the first time… I have to make an outline for myself. I have to stick it on a sticky note, put it on the computer in front of me to remind me of my train of thought – don't diverge, don't write all over the place.

In both relationships, lead-writing was the practice adopted. In her collaboration with Researcher Y, Prue accepted that she brought several novel ideas into their work. This contribution was acknowledged by Researcher Y who readily encouraged Prue with positive comments about the quality of her lead-writing. Researcher Z also made encouraging comments, but these were restricted to one or two sentences that made Prue wonder, "What does that say about the rest of what I just wrote?" Prue generated the "dog and bone" metaphor to contrast writing styles with Researchers Y and Z, as follows:

> Researcher Z sort of tosses me a bone and I go take it and work with it. Researcher Y doesn't do that, she's going to gnaw on the other end of the bone with you. And you're going to be in the middle, teeth glaring all the way, but you'll get there and you'll both wag your tail and be happy in the end. With Researcher Z, I kind of chase this bone, and it was interesting learning for myself, but how much did Researcher Z and I really interact with each other?

The style of writing Prue did with Researcher Y was much more interactive than that with Researcher Z; almost like turn-writing. Perhaps the conscious use of writing metaphors could have altered the way Prue wrote in her collaborations with these researchers. For example, Prue's long-term relationship with Researcher Y might have been conducive to co-writing as per the "piano-duet" metaphor and the application of the "duelling banjos" metaphor in her collaboration with Researcher Z might have provided a more satisfying experience for her.

Like Wesley, Damien needed time "to think through things, and I might not look at stuff for a while then I'll come back to it… So in terms of sitting down and jointly writing the paper side by side [with Ben], this didn't happen". Damien welcomed his independence from his more senior co-researcher and they each appeared to take turns leading with only minimal interaction during and after writing, almost in the same way as Prue and Researcher Z, albeit without the bone to chase.

In contrast to Prue and Damien, Kate and Jodie worked within a large research team where, by necessity, meetings needed to be formally scheduled. Each researcher would bring ideas to the attention of others at these meetings, and while each turn-wrote in terms of contributing a section or two (cf. "chunking") to the group, one researcher usually took control of piecing the components together in a first draft. These formal and less formal meetings were extremely valuable for Kate in learning what others considered important in their study: "through the process of writing we came to question each other's understanding or what it might be important to write about. I think we shared a similar understanding." Through the process of sharing and critiquing together, research became a form of professional development for Kate, and indeed the other collaborators. As she explained:

> That's something interesting about this paper; it's a collaborative effort. I think where possible, … writing parts of the paper, being involved in the process of interviews, looking at the data; all those things really, really matter because research then becomes a form of professional development for those people involved… Ideally we'd see the process of research and professional development as intertwined.

7. REFLECTIONS

I began writing this chapter with the plan to write about two musical metaphors for writing research, namely, "duelling banjos" and "piano duet" that I had gleaned from my interviews with 24 internationally active researchers. I hadn't selected excerpts from the interviews nor particular supporting quotes from the literature. Through the writing process, however, I read and selected excerpts from both sources at different stages along the way. My reading from one source informed my reading of the other. And as I wrote, I decided that I needed to read more or find additional supporting or disconfirming evidence from the transcripts. For me, the metaphor, *writing as research*, matched what I had been doing.

Even though I cited references to support the practice of generating alternative metaphors to guide my research writing, I was not conscious of referring to any deliberately. My writing practice was historically and culturally embodied through my participation in communities of educational research (cf. Roth & McRobbie, 1999). Accordingly, I used particular conventions and developed a thesis that I perceived to be acceptable to my colleagues; that is, that the generation and application of alternative writing metaphors might guide researchers to take up new challenges in writing.

I do want to push the boundaries of my writing practice so I can learn more about writing and the issues about which I write. This is where the new musical metaphors might make a difference. I can recognise how I might build on my experience with turn-writing (and "duelling banjos") and look forward to further opportunities for writing as a piano duet or impromptu jazz ensemble with my collaborators. These new metaphors have the potential to create new realities for researchers. As Lakoff and Johnson (1980) argued:

> This can begin to happen when we start to comprehend our experience in terms of a metaphor, and it becomes a deeper reality when we begin to act in terms of it. If a new metaphor enters the conceptual system that we base our actions on, it will alter that conceptual system and the perceptions and actions that the system gives rise to. (p. 145)

While these metaphors were liberating for me, they also could be constraining for those researchers who feel the need to adhere to the image of a particular guiding metaphor.

My reflections of this writing experience are personally relevant. I hope that this account will alert researchers to both their preferred operating metaphors and alternative metaphors articulated by research colleagues. A function of research is to understand our worlds. According to Brew (2001), to achieve this we must first understand ourselves. The analysis of our research and writing metaphors can contribute to this understanding.

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STEPHEN M. RITCHIE, PETER J. AUBUSSON AND ALLAN, G. HARRISON

METAPHORICALLY THINKING

In our introductory chapter we proposed that metaphor and analogy pervades science education discourses and is central to the development of Western science. While the contributors to this volume also accepted this assumption, they expressed a broad range of views on the applications of these ways of thinking in science education, science teacher education and research. This concluding chapter canvasses ongoing discussions in science education communities about the future role for, and applications of metaphors and analogies. In so doing, we hope that readers will become more aware of their metaphorical thinking so that they can act in ways that enhance their students' learning. As Shön (1963) argued: "What we are inattentive to, we cannot deliberately change. The covertness of metaphor protects it from change" (p. 103).

Rather than develop a unified position and argue one thesis in a co-authored book, we see strength in the plurality of ideas about metaphor that have been teased out by the contributors. The chapters in this book were arranged in groups of related issues or themes. For convenience these same themes are used to organise our review of possible trends and questions for further research and application.

1. FOUNDATION PRINCIPLES

Several contributors acknowledged that metaphors and analogies are "two-edged swords" when used to understand and communicate scientific phenomena, but their recommended responses varied. Harrison and Treagust recommended the use of multiple analogies with appropriate support from the teacher to help learners map canonically acceptable connections between source and target concepts. They suggested reading the history of Western science and case studies of experienced teachers to glean alternative ways to use metaphors with students. Teachers who are comforted by instructional models might also find the FAR-Guide a helpful tool to enhance student learning. In contrast, Wilbers and Duit were critical of instructional models because such models ignore the role of non-propositional knowledge. Instead, they argued that the mode and outcomes of analogical production changes along with the learner's familiarity with the target concepts and this limits the usefulness of formal mapping exercises. From this position, the role of teachers in

P. J. Aubusson et al. (eds.), Metaphor and Analogy in Science Education, 189-195.

assisting learners is less clear and warrants further research. Ultimately, teachers can only access student thinking through communication, so perhaps there is a role here for multi-modal (e.g., drawings of models, gestures, speech) communication between teacher and student during spontaneously generated analogies (see Kress, Jewitt, Ogborn & Tsatsarelis, 2001). Alberto's story in Ritchie et al. also may help teachers make sense of in-class analogical reasoning.

The theorizing undertaken by Wilbers and Duit seems to provide an explanation for the challenges (described by Harrison and Treagust) facing students when they are asked to map analogies they did not construct for themselves. As Aubusson and Fogwill note later, student-generated analogies can provide multiple avenues for student learning. Yet, by apparently increasing the complexity of learning concepts by analogical mapping, it could be asked whether such mapping complicates rather than simplifies learning? Alternatively, it could be asked whether the mapping exercise enriches the learning experience, providing opportunities for deeper understanding of the concept?

While Harrison, Harrison and Treagust, and Wilbers and Duit focussed on the philosophical implications of metaphor for teaching and learning, Willison and Taylor extended metaphorical analysis to argue their controversial case to background theory in science education research. They argued that once perceived, competing theories (i.e., constructivism and objectivism) can be used metaphorically rather than literally to explore complex issues from multiple positions. Such an integral position has significant implications for both classroom practice and research. An integral classroom perspective has the potential to help students become more scientifically engaged while supporting evolving cultural identities, especially those that seem to be marginalized by Western science. Willison and Taylor also suggested there was a need to reappraise 'effective' teaching, a notion that in the late 20^{th} century often was located in a constructivist paradigm.

2. SCIENCE TEACHING AND LEARNING

The 'two-edged sword' metaphor recurred in the contributions that critiqued the use of analogies in biology, chemistry and physics. Following the lead of the conceptual change movement, we might expect researchers who study learning in the scientific disciplines to generate effective analogies and identify instructional strategies relevant to these disciplines. This has yet to happen and is a concern for both researchers and curriculum developers. Alternatively, effective pedagogical metaphors and analogies are hard to transfer because effective relational explanations are very personal and are not easily reconstructed (see Alberto's and Neil's stories – in Ritchie et al. and in Harrison).

Increasingly, science educators are recognising the significance of the quality of discourse and the importance of creating spaces where discourse flourishes in science classrooms (Moje, Collazo, Carrillo & Marx, 2001). Role-play, as an analogical model, is such a strategy and enhanced the discourse quality in Fogwill's class (Aubusson & Fogwill). Role-play elicited metaphorical thinking that could be translated into action and discourse in much the same way that Heidi used cartoons to enhance communication between herself and her students (Ritchie et al.). While teachers who try these strategies might find they enthuse their students, the tools (role-play and cartoons) used were a means to an end as they both encourage shared and meaningful discourse in science. Quality discussions decreased the likelihood of students being misled by poor mapping between source and target and to some extent address problems raised by many in the book (e.g., Wilbers & Duit). Openly discussing the merits of the metaphors and analogies used in class guides the teacher (who uses metaphor) and the writer (who communicates the experience). Discussion in Neil's class (Harrison) enhanced his students' interest in the 'busy highway' analogy and deepened their engagement and understanding. Interest through discourse (this time one-on-one) transformed Dana's experience from failure (her perception) to enthusiasm and mastery of the refraction phenomena. Interest and productive discourse seem to be inextricably linked and this strengthens the case for pre-planned, tried and tested metaphors and analogies.

From a research perspective, long-term studies of discourse involving analogical teaching and reasoning are needed to explicate the relationship between the classroom dialogue and learning that occurs. In a sense a 'bad' model/metaphor/analogy may be an excellent learning or teaching tool if it is used to highlight and challenge alternative conceptions (see Aubusson & Fogwill). In science, a 'perfect model' may be desirable but in teaching it may not be the ideal vehicle for learning. In fact, the 'perfect model' may be an oxymoron because a model always exaggerates and/or simplifies one or more of the target's attributes. Furthermore, a model is a cultural artefact so it is difficult for those who do not share the same cultural field to access the embedded meaning. A 'perfect model' may suit a realist but it sits uncomfortably with constructivists and relativists (see Coll and Harrison & Treagust). Important questions for researchers comprise: What criteria should be used to judge the quality of discourse? How do the analogies and strategies contribute to this discourse? How can operational warrants for non-verbal actions like gestures and non-propositional knowledge be expressed through models and drawings?

Willison and Taylor identified three student metaphors gleaned from the literature on scientific literacy that were observed in Grade 9 science. While the student-as-recruit metaphor was observed most frequently, they argued that enactment of alternative metaphors like student-as-judge and student-as-scientist might have led to a better appreciation of scientific work. Perhaps bringing such metaphors to the consciousness of the students might have resulted in a successful shift in student practice within these classrooms. Taking this position, Thomas invited students to select personally salient entailments of the metaphor 'learning is constructing'. He helped chemistry students make their tacit conceptions of teaching and learning more explicit thus enhancing the communication between students and teacher. The metaphor became a tool that encouraged students to talk about their learning and gave the class a shared focus. Thomas' research could be extended by exploring ways that mutual foci might lead to positive emotional energy (see Tobin) and solidarity (a concept used by Collins [2004] to refer to a feeling of membership or belonging to a group of interlocutors). Research to date has emphasised what researchers (often the teacher) learn from teacher or student metaphors about teaching and learning. There is a need for research where teacher educators use analogy themselves to explore their own roles as researchers and teachers. As illustrated in the next section, action research cycles seem well suited to this enterprise.

3. TEACHER AS LEARNER

Learning to teach science does not end with graduation from university; teacher learning is a career-long phenomenon. Designing 'connective tissue' that provides a more seamless continuum in teacher education is likely to occupy the research agendas of teacher educators for many years to come. Metaphor was a focus in each of the chapters in this section and sampled each phase in teacher education (i.e., teacher preparation, teacher induction, ongoing professional development). Another significant thread was the practice of teacher educators *working with* their students and colleagues. The practice of working with student teachers was extended to co-teaching (Tobin) and is nicely captured by the metaphor: *working at the elbow of another* (see Roth & Tobin, 2002).

Metaphoric communication between teacher educator and student teacher was at the crux of Russell and Hrycenko's chapter. By interacting in Michael Hrycenko's practicum, both were forced to re-think how they learn to teach. Perceptual knowledge about teaching experiences expressed through metaphor was the source for metacognitive reflection and subsequent action. Identifying and differentiating the metaphors in Michael's language was a helpful technique that opened communication channels about learning how to teach.

Sharing stories about their use of metaphor and analogy in their first-year science classes also benefited Alberto, Heidi and Marianne's evolving professional practices and identities (Ritchie et al.). While their former teacher educator engineered the small professional community, interactions between the teachers about their personal experiences with metaphors and analogies drove the project to success. Van Driel and Beijaard (2003) noted the importance of experienced-based collegial interactions more generally:

> Telling these ideas to colleagues, who listen and respond to them, are the most important ingredients of these kinds of interactions. Telling demands that a teacher structures his or her ideas; listening and responding to those ideas may help restructure the ideas of the person who told them. Moreover, teachers can be stimulated by the ideas of colleagues to change their own ideas. (p. 104)

It appears that engaging their former student teachers in ongoing professional interactions is a fruitful practice for teacher educators to pursue. Two studies (Ritchie et al., Russell & Hrycenko) involved small groups making them easy to manage. The challenge now is to devise large-scale networks that offer ongoing support for beginning teachers from teacher preparation through teacher induction to the establishment phase. Collaborative professional networks built on a culture of collective responsibility for sustaining teacher learning is a desirable goal. Based on the experiences of these researchers, metaphor and analogy could be an agenda item for discussion in these networks.

Tobin's personal account of his changing teaching practices illustrated the career-long enterprise of teacher learning. Like Wilbers and Duit, Tobin cautioned that much of social life (e.g., teaching) could not be captured metaphorically and discursively. For this reason, Tobin's teaching and research practices have evolved from an emphasis on personal metaphors – that was influential in the 1990s – to a more socio-cultural orientation to teacher learning. Nevertheless, Tobin continues to acknowledge the potential power of focusing on metaphors as objects for discussion and potential change. It is through reflection and metacognition that we begin to recognize the socio-cultural metaphors that structure our practice. This might best take place during co-generative dialogues between co-teachers and students or even between teacher educators, supervising teachers, student teachers and students. There seems to be scope for further research in the role that co-generative dialogues might play, not only in teacher learning but also in forging stronger partnerships between school and university staff.

4. METAPHOR AND ANALOGY AS RESEARCH TOOLS

While we readily accept the power of metaphor to convey meaning about teaching and learning in science and doing science in laboratories through storied (or interpretive) research reports, such practices rarely infiltrate personal accounts of doing educational research. If stories about teaching help storytellers and teacher-readers alike, this practice may apply equally well to expert and novice education researchers. Chapters 14 and 15 begin a trend we hope will flourish.

Aubusson used an ecological metaphor to help unravel the complex dynamics within a science department undergoing change. Even though the ecosystem analogy held up when applied to other cases of change, it was the story of how the mapping process was undertaken that provided the greatest insight for other researchers faced with different complex problems. As other contributors have noted, the social world in which we practice as teachers and researchers is complex and metaphor can help us make better sense of such complexities. As Dickmeyer (1989) argued:

> We must admire the complexity of our social world and strive to grasp increasing numbers of dimensions and interactions. To do this we must use multiple lenses to help examine the world with models [and metaphors] to make us ever more sophisticated observers. In the end, however, we require another process, often called intuition, to integrate the many views we have seen in our examination. (p. 159)

The use of multiple lenses, in science education research was the basis of Willison and Taylor's thesis for an integral approach to the learning-teaching relationship. They argued the need to bring together traditionally oppositional referents to dialectically examine complex phenomena. It will be interesting to follow how well this practice is accepted by journal editors.

Many contributors have noted that metaphor and analogy can focus our attention and even direct subsequent action. There is, nevertheless, part of our social world that cannot be articulated. This was also true for Ritchie in his account of research writing. While such metaphors as the piano duet and impromptu jazz ensemble helped to direct attention to alternative collaborative writing styles, unwritten practices helped in the construction of the chapter. Bourdieu (1990) referred to socially constituted dispositions or mental structures that constrain actions as 'habitus'. Working collaboratively with more experienced researchers might help novice researchers develop an effective research writing habitus. Also, perhaps with further practice at articulating one's writing practice metaphorically, it might be possible not only to become more conscious of our writing processes, but also help novice researchers imagine new possibilities.

5. CONCLUSION

When considering the nature and use of metaphor Black (1962) commented:

> It is especially noteworthy that there are, in general, no standard rules for the degree of *weight* or *emphasis* to be attached to a particular use of an expression. To know how "seriously" he [sic] treats the metaphorical focus. (Would he be just as content to have some rough synonym, or would only *that* word serve. Are we to take the word lightly, attending only to its most obvious implications – or should we dwell upon its less immediate associations?) … This somewhat elusive "weight" of a … metaphor is of great practical importance in exegesis. (pp. 29-30)

Research on metaphor and analogy in science education has propelled us along the journey of understanding metaphor and analogy by answering some of these questions but there is still much to do and understand. A tentative conclusion of what has been done is that if metaphor and analogy are to be used effectively, then their 'weight' needs to be made explicit: that relevant attributes of analogies should be identified and explored; that the experiences of those relating the source and target are as important to the interpretation as the meaning they generate. The journey needs to be considered because, as Achinstein (1983) pointed out, in science education the process (journey) is as important as the product (the knowledge gained). To achieve such understandings, rich and varied discourse is essential. As we seek new knowledge, we must not only attend to 'the most obvious implications' of analogy but to 'its less immediate associations', for it is in these less obvious relationships between target and source that extraordinary insights may be found.

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Michael Hrycenko worked as an environmental engineer, field biologist, backcountry guide, outdoor educator and English teacher before attending teachers college. He is currently teaching high school science at the American School Foundation in Monterrey, Mexico. He characterized his first year of teaching as an adrenaline-filled game of tag up the down escalator, and he calls teaching a high form of creative art. In case moving to a new country and beginning teaching were not stimulating enough, Michael also took up rock climbing, got married and began work on a masters degree.

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Stephen M. Ritchie (Editor) is now an Associate Professor in Science Education at Queensland University of Technology, Brisbane, Australia after working at James Cook University for 15 years. Steve's research has focussed mostly on classroom issues that relate to teaching and learning science, including metaphors for teaching science. He was co-author of *Re/Constructing elementary science* (2001 – Peter Lang) with Wolff-Michael Roth and Ken Tobin. His more recent research projects are concerned with leadership dynamics within high school science departments, research collaboration, and student science learning through writing children's fictional books.

Tom Russell began teaching in 1963 as an untrained volunteer teacher in Nigeria, where his students taught him many alternative ways of viewing events explained by science. After graduate studies in Boston and Toronto, he worked with teachers and principals in Ottawa before moving to Queen's University in 1977. He teaches a graduate course on action research, works with preservice candidates in secondary science, and supervises a 10-week practicum. His interest in metaphor relates to the significance of reframing events in a reflective practice perspective. His research interests focus on how individuals learn to teach.

Peter C. Taylor is Associate Professor of Transformative Education at the Science and Mathematics Education Centre, Curtin University of Technology, Australia. He is a member of the Culture Studies in Science Education Network and has a passionate interest in transforming education so that teaching and learning are morally empowering and culturally inclusive. His transformative research approach is fuelled by an integral worldview, and involves life-history writing and literary genres to produce imaginative, poetic and emotionally thoughtful insights into teacher practice. He co-edited the book *Transforming Undergraduate Science Teaching: Social Constructivist Perspectives* (Taylor, Gilmer & Tobin, Eds., 2002, Peter Lang Publishers).

Gregory P. Thomas is the Head of the Science Department at the Hong Kong Institute of Education. His interest in the use of metaphor and analogy stems from his doctoral work on the use of metaphor to develop students' metacognition. Currently, his research interests include the areas of metacognition, science education, learning environments, and the use of information technology in science classrooms. He is active in staff development in Hong Kong schools and is a frequent visitor to China where he teaches and conducts research.

Kenneth Tobin is Presidential Professor of Urban Education at the Graduate Center of City College. In 2004 Tobin was recognized by the National Science Foundation as a *Distinguished Teaching Scholar* and by the Association for the Education of Teachers of Science as *Outstanding Science Teacher Educator of the Year.* Prior to commencing a career as a teacher educator, Tobin taught high school science and mathematics in Australia and was involved in curriculum design. His research interests are focused on the teaching and learning of science in urban schools, which involve mainly African American students living in conditions of poverty. A parallel program of research focuses on coteaching as a way of learning to teach in urban high schools. Tobin has just completed an edited volume on urban science education (with Rowhea Elmesky and Gale Seiler) and another on coteaching (with Wolff-Michael Roth). In 2002 Tobin's book with Wolff-Michael Roth, *At the elbows of another: Learning to teach through coteaching,* received the Choice award in the category of *Outstanding Academic Titles.*

David Treagust is Professor of Science Education in the Science and Mathematics Education Centre at Curtin University in Perth, Western Australia and teaches courses in campus-based and international programs related to teaching and learning science. His research interests are related to understanding students' ideas about science concepts, and how these ideas contribute to conceptual change and can be used to enhance the design of curricula and teachers' classroom practice. Professor Treagust was President of the National Association for Research in Science Teaching (USA) (1999-2001), and is currently Managing Director of the Australasian Science Education Research Association.

Grady Venville is an Associate Professor of Science and Technology Education at Edith Cowan University, Australia. She has taught science, English as a second language and science education in primary, secondary and tertiary institutions in Australia, England and Japan. She also has been involved with several large education research projects in Australia at Curtin University and England at King's College London. Grady has published widely in international and national journals on conceptual change, students' learning in genetics, cognitive acceleration and the integration of science, mathematics and technology curricula. She recently was a co-editor, with Vaille Dawson, of a science education textbook titled, The Art of Teaching Science (2004, Allen and Unwin).

Marianne Wearmouth obtained a degree in Biomedical Science and a subsequent Graduate Bachelor of Education degree from James Cook University, Townsville, Australia. Upon graduation, Marianne moved to Canberra where she taught science for two and a half years. Looking for an international adventure, Marianne commenced her European "working holiday" in 2004. She currently has a teaching position in the UK.

Jens Wilbers is a lecturer of physics education in the Department of Physics Education at Dortmund University, Germany. After qualifying as a high school teacher from Bremen University, he worked at the IPN in Kiel and taught Physics and Mathematics in Hannover and Göttingen for four years. His interests gradually moved from teaching practice to research in science education. For a couple of years he was involved in research and development work in the field of deterministic chaos in Reinders Duit's research team. Since then his research interests and commitments have included cognitive science and analogical reasoning and is currently engaged in establishing a research project on the professional development of science teachers.

John W. Willison is a Lecturer at the University of Adelaide, where he is implementing a new Graduate Certificate in Higher Education. He has previously lectured in science education, and has taught high school science and gifted and talented students in primary school. Being involved in teaching such a range of students-from Year 1 to university lecturers-has stimulated his research interest in the notion of continuums of Scientific Literacy and Information Literacy. He has found fruitful the adoption of 'conceptual metaphor' as a dynamic theoretical framework for undertaking such research.

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