METAPHOR AND ANALOGY IN SCIENCE EDUCATION

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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.

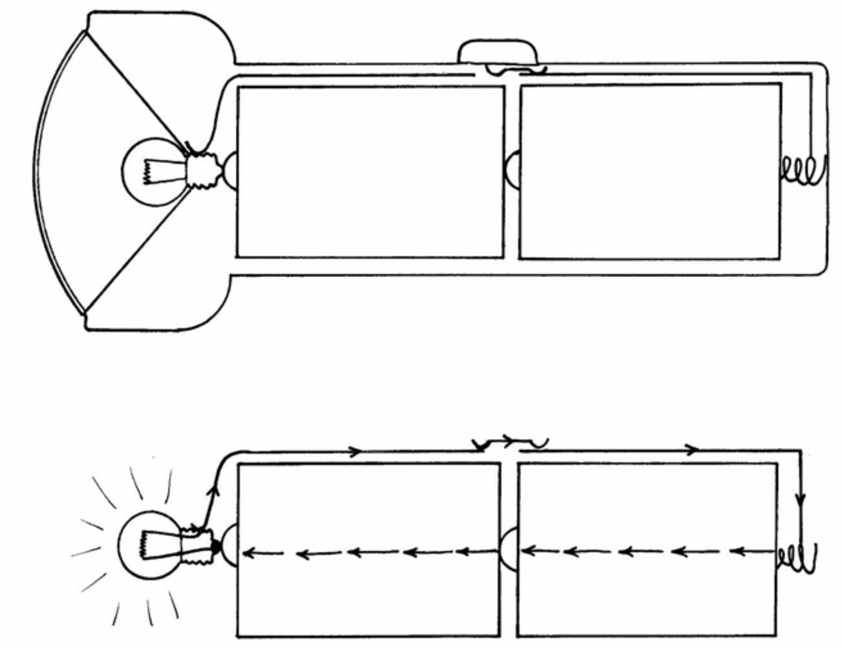

Figure 1a. Series circuit in a flashlight

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.

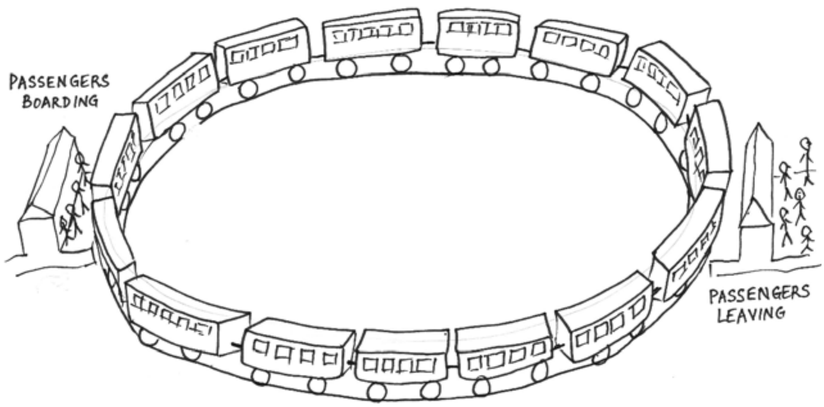

Figure 1b. Continuous train analogy shows that current is not consumed in a series circuit

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)