Analogical Transfer - Interest is Just as Important as Conceptual Potential

Allan G. Harrison

Central Queensland University

Rockhampton, Queensland

a.Harrison@cqu.edu.au

A paper presented at the annual meeting of the Australian Association for Research in Education, Brisbane 1-5 December 2002

Abstract

Analogies and models are frequently used in science and science teaching and much research is devoted to examining their effectiveness. Little research, however. has been conducted into their affective benefits and this paper reviews five studies by the author and his colleagues to find examples of interest enhancing cognition. The rolling wheels refraction analogy, a comparative study of a class that received the wheels analogy and one that did not, two teacher interview studies and the bursting-balloons analogy for molecular shapes are re-examined for instances of motivation and interest contributing to concept learning. The motivational literature insists that conceptual change learning will only proceed when students are interested and engaged. The re-examined analogies and teacher views support this claim. I recommend that a resource of interesting and effective analogies be compiled for teachers, that teachers are encouraged to systematically present their analogies in a model like the FAR guide, and that dedicated research be conducted into the affective aspect of analogy and model-based teaching.

Introduction

Questions of how people use analogies to acquire and create knowledge have occupied scientists, educators and psychologists for more than 40 years (e.g., Oppenheimer, 1956; Glynn, 1991; Gentner & Medina, 1998). The popular view of science is that it is a logical and rational process; therefore, it is understandable that scientific, empirical and cognitive methods should dominate science analogy research and discussions about the importance of analogy in discovery and learning (e.g., Clement, 1993, Dupin & Johsua, 1989; Gick & Holyoak, 1983). The rational approach (sometimes called the cold-rational view) has yielded significant benefits for teachers in the form of Glynn's Teaching-With-Analogies model and the FAR guide (Treagust, Harrison & Venville, 1998); however, rational research studies have little to say about the reasons why teachers and students are attracted to analogy in the first place. Thus, the affective dimension of analogy use is the subject of this paper.

The interest-generating power of analogies often is anecdotally reported by teachers but when interest is mentioned in analogy research, it is incidental and taken as a given rather than a focus of the study. Certain concepts like refraction can only be explained by analogy (Harrison, 1994) and analogies are widely accepted as conceptual change tools (Dagher, 1995a). The specific use of analogy to raise learners' interest levels is rarely reported.

Indeed, Pintrich, Marx and Boyle's (1993) review of the motivational literature on conceptual change showed that affective factors are largely ignored in conceptual learning studies. They argued that affective or "hot-irrational" issues are just as important in concept learning as cognitive issues because interest determines the level of student engagement with cognitive activities and explanations. I argue that the interest-dimension of analogy and model use should be scrutinised alongside their concept learning potential.

Theoretical Background

Two detailed reviews of analogy use in school science (Dagher, 1995b; Duit, 1991) concentrate on the conceptual growth potential of analogies and devote limited attention to their interest-generating power. In his review, Duit shows that analogies are effective conceptual change agents because they enhance understanding by making connections between scientific concepts and the students' life-world experiences, and by helping students visualise abstract ideas. He points 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 detail pertaining to interest and motivation is easily explained: few studies of analogy discuss this factor.

Motivation and interest are essential ingredients in effective learning. If students are not attracted to the concept or context, learning will be limited. Pintrich et al. (1993) explain that it is the student who decides whether or not to engage in concept learning. Students choose to be involved 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 learning psychology (van der Veer & Valsiner, 1991) helps us understand why social interaction is useful and 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 Glynn (1991) and Treagust et al. (1998) insist that analogs be familiar to the students (i.e., drawn from their life-world). If an analog is not familiar, it should not be used.

Analogical thinking extracts useful structural and relational information from a learner's repertoire of familiar instances or events (the *analog or source*) and maps it onto the unfamiliar science concept (which is called the *target*). The familiar teaches the student about the unfamiliar. Analogies are interesting and motivating for students when the teacher's analog can be enriched from the students' own experience. If, however, the analog is unknown to or poorly visualised by the student, then s/he will feel marginalised or frustrated and this will lower his or her interest in the analogical discussion. Interest and engagement are, therefore, crucial to learning - it is "important to begin to build 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 is an important determiner of learning outcomes. Gentner and Markman (1997) show that relational learning (as opposed to instrumental knowledge) is the desideratum of effective analogies; thus, the analogies discussed later in this paper are limited to ones that enhance relational understanding. For example, in the wheels analogy for the refraction of light (Figure 1), a pair of wheels rolls obliquely across the boundary from a hard surface (where they roll fast) onto a softer surface (where they roll slowly). The wheels' direction bends towards the normal because the wheel that first crossed onto the soft carpet slows down and covers less distance than the other wheel (still on the hard surface). A ray of light passing from air to glass also slows down on entering the glass. If the ray strikes the boundary at an angle, one side of the ray enters the glass first and slows before the other side of the ray. Because the slowed side is covering less distance than the other side, the light ray bends towards the normal. Students can explore this analogy by rolling wheels from card to carpet and carpet to card. If the wheels are coated with paint, the tracks are recorded and students see the similarity between the behaviour of the wheels and the refracted light ray. In our experience (Harrison & Treagust, 1993), students are fascinated by this phenomenon and enthusiastically apply it to other refraction problems.

Place Figure 1
about here

Investigating the affective dimension of such an analogy is facilitated by Pintrich et al.'s (1993) motivational and self-efficacy theories. This research program helps us understand the benefit of examples like the wheels-refraction analogy and Thagard (1989) also claims that motivational factors enhance conceptual change. For these reasons, I decided to review my own and joint studies to find instances of analogical affect on concept learning. The reviewed studies comprise Harrison (1992, 1997, 2001), Harrison & Treagust (1993, 2000, 2001), Treagust, Harrison, Venville & Dagher (1996), and Treagust et al. (1998).

Methodology

The method involved scrutinising published papers and unpublished theses to identify potential instances where interest and motivation influenced the learning outcomes of planned taught analogies. The concepts and their supporting analogies were taught by a range of experienced teachers including the author. The student ages cover Years 8-11 and the teaching took place in middle school science, chemistry and physics classes. As the cases already are reported in detail, their choice was a purposeful on the ground that they contained instances of analogical affect (Patton, 1990). Each case was chosen because the evidence showed that students found some part of it interesting. 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.

Issues of space also mean that the following vignettes are compressed and the reader is referred to the original articles should s/he desire more information regarding theory, method and interpretation. The intent of this paper is to revisit the cases to draw new sense and to generate research questions that will guide future study into the affective dimensions of science analogies and models.

Cases of Affective Analogical Teaching

The Wheels Analogy for the Refraction of Light (Harrison & Treagust, 1993)

The wheels analogy was first reported by Harrison (1992) and published by Harrison and Treagust (1993). The setting was a Year 10 physics class at an all-girls independent school and the girls were taught by Mrs Kay (pseudonym). Mrs Kay was identified by her colleagues as an expert physical science teacher and she was interviewed to identify the analogies she used in her lessons. In the interview she expressed a desire to trial Paul Hewitt's (1992) wheels analogy for the refraction of light (p.437). At the time, she was teaching optics to two Year 10 physics classes and one class had already studied refraction; thus, the analogy could only be used with the second class. The situation was fortuitous because both classes were of comparable ability and achievement enabling Treagust et al. (1998) to later study the conceptual change differences between the class taught with the analogy and the one without the analogy. A motivational event associated with the second study will be discussed later in this paper.

Teaching the wheels analogy. The lesson in which the wheels analogy was demonstrated was audio-taped. Mrs Kay was interviewed pre- and post-lesson and nine girls were individually interviewed post-lesson. The lesson and the interviews were transcribed and provide the comments that illustrate the students' interest.

The lesson. Mrs Kay, led her students through the analogy with considerable panache, First, she demonstrated how light bends towards the normal as it enters a perspex block and then bends away from the normal when it exits the perspex. The top diagram in Figure 1 depicts the set-up: a light box and a large rectangular perspex 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 showing the hard card butting up to the soft carpet, the wheels and some bright fluorescent paint. The students were attracted to the paint and wanted to know how it was to be used: "what if we spill it ...". Mrs Kay first conducted a 'dry-run': she rolled the wheels so that they obliquely crossed from the hard card to the soft carpet. She drew attention to the change in the wheels' direction as they slowed down. Then it was time for the paint. She invited a student to liberally coat a pair of 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 rolled across 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 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 interviews that followed, several students related the 'wheels slowing down and turning' to experiences they had of driving farm vehicles on sandy tracks and skateboards running off concrete paths and onto grass.

Discussion. This exchange is significant because the students' concept learning was enhanced by the spontaneous introduction of familiar experiences. This helps explain why some analogies are effective and others are not. When the students are able to make connections between the analog-target and their experiences, they are motivated to explore the analogy in deeper and more meaningful ways. In this case, I suggest that the student interest that 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). With the conversation focused on everyday matters, the students were excited and willingly sought connections and like 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.

Note. These vignettes are part of an extensive case. Should the reader need more theory, method and data, s/he is directed to Harrison and Treagust (1993). The point of the vignettes is to show that the wheels analogy was cognitively effective and affective because it captured the students' interest.

Analogy and Conceptual Change (Treagust, Harrison, Venville & Dagher, 1996)

The knowledge that one Year 10 class studied refraction with the analogy and the other without enabled a second study (of conceptual change effects of the analogy) to be conducted three months later by Treagust, Harrison, Venville and Dagher (1996). In this interview-about-instances study, 25 of the 29 students who were taught refraction with the wheels analogy were interviewed and 14 of the 25 who were taught by the same teacher but without an analogy also were interviewed (all with the same protocol). The explanation provided 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 forcing the ray to bend. End of the school year constraints made it difficult to integrate student and researcher availability, thus the maximum length of each interview was 15-20 minutes. Six students from the analogy class and 11 from the second class were absent or unavailable for interview.

This second study was an empirical study of cognitive change; however, motivation and interest appear to be important conceptual change learning factors. While this study was not searching for hot-emotive, interest-based events, one such case emerged during an interview with Dana. On her own admission, Dana was unable to explain refraction, insisted that she was "no good at science" and told how she had failed the optics test. I will argue that her lack of success in the optics topic is related to the type of questions that are asked of students like Dana

The interview protocol. The interview used a think-aloud protocol in which students were shown a set of refraction problems comprising activities they had completed in class and unique extension questions. For instance, the students were shown two striped pencils placed respectively in beakers of glycerine and water, and the students asked to explain why the pencils appeared to break at the liquid's surface. The protocol included three ray-tracing diagrams that the students were asked to complete (Figure 2 and a summary of the questions asked in relation to each diagram). Questions 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 (Hewson & Thorley, 1989).

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

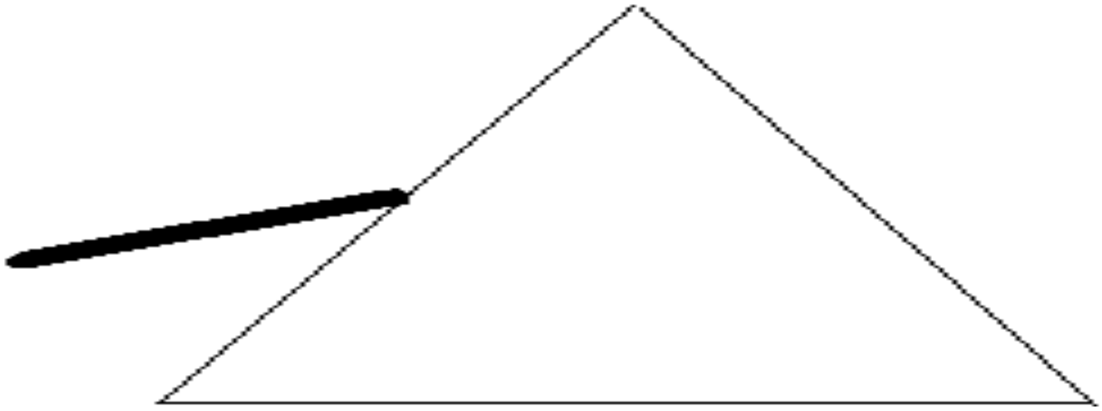
cardboard

AIR

WATER

source

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 used in the interviews.

Dana's Case study: 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 lighter 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.

Dana's sketch

cardboard

1 1

2

AIR

WATER

source

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

Dana provided no explanation for the interview-about-instances nor for the "bent" pencils in the tumblers of liquid. Therefore, the planned cues for reluctant were provided.

Interviewer OK, 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.

Interviewer 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.

Interviewer 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.

Interviewer So what happened to the wheel that got onto the paper first?

Dana It went faster so it turned.

Interviewer O.K. 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.

Interviewer O.K. So the direction of the wheels changed because the speed changed did it?

Dana Mmm.

Interviewer Does that fit in, in any way with light?

Dana Yes, because light changes faster in air than it does in water.

Interviewer Alright, let's come back to this one [Dana's sketch in Figure 5]. 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.

Interviewer 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. O.K. did the wheels help you work that out?

Dana Yes.

Interviewer Did you initially remember the wheels?

Dana No.

Dana then returned to the interviews-about-instances cards and the pencils problem and her revised answers were among the best we saw amongst the 39 students.

Listening to the tape-recording provides a perspective not evident in the interview 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 little evidence of understanding. Her aid-to-memory provided by the analogy, led to her becoming dissatisfied with the initial answer and she confidently changed her vague sketch into one resembling the desired response.

Discussion. Treagust et al. (1998) discuss in detail the nature of Dana's conceptual change once the analogy entered her thinking; however, the salient issue in this paper is the role of the analogy in arousing her interest and motivating her to become involved with the problems and talk about the problem. I suggest that there is a signal lesson here. Dana is not alone, she belongs to a large group of students for whom physics (and other sciences) lacks 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 select those students who are capable of tertiary science studies. Disinterested students cannot be ignored as "lacking in knowledge and/or ability". School science has a warrant to productively engage students in exploring the science knowledge that affects their lives. In their *Beyond 2000* report, Millar and Osborne (1999) ask "Who is school science education for?" They answer by insisting 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" (all p.2006).

So why are students like Dana not included in the successful processes of sense making about their life-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 argue that the curriculum and the culture of that science class, while so much better than many, still has a way to go before it includes all who are able to learn science. The cold-cognitive approach did not satisfy Dana's needs; but she could recalled 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 on the part of the testing regime to provide instances and events that encouraged her to show what she knew and could do. I claim that making science interesting for all students is achievable and one way to build and sustain motivating learning environments is through the use of imaginative and relevant analogies.

Teachers' Attitudes to Analogies (Harrison, 2001)

The dissemination of teaching-with-analogies models (Glynn, 1991; Duit, 1991) and the publication of cognitively beneficial analogies and models (Harrison & Treagust, 1993, 1994a, 1994b, 1998, 1999, 2000) has helped interested teachers motivate their students by providing them with effective analogies (Harrison, 2001). The following excerpts are taken from detailed interviews with experienced and expert secondary science teachers. First, we share the enthusiasm of Ian as he talks about a favourite analogy (Harrison, 2001) that he used to heighten interest and explain the principles of inheritance to his low achieving Year-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 [similar to one found in the *Australian Science Education Project* (1974)] to show how he used everyday knowledge to interest his students.

Discussion. It is important to share Ian's enthusiasm for these strategies because they are *his* purpose built analogies and models - analogies and models that work because he designed them with his students' learning needs in mind. Ian was particularly enthusiastic about his 'breeding' analogy because he believed that it was interesting, familiar, relevant 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 lacks motivation and therefore 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. This is the task of the teacher and interesting analogies and models make excellent motivators.

Neil's chemistry analogies. My second 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 the 10 analogies he discussed 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, and 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 (sic) 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's detailed analogies were of three types: the first and most common type is the provocative idea developed over subsequent lessons (four analogies). In type two, he uses motivational stories that illustrate and generate interest in big ideas (three analogies), and then he uses specific analogies for specific problems (three analogies). Neil appeared to have just three analogical-story contexts: boy-girl behaviour, cars, and sport. Remembering that these are analogies for Year 11-12, the contexts seem appropriate. Neil also believed that many of his story-analogies were successful because they were interactive; that is, he encouraged students to join in the story by adding comments and asking questions. This approach resembles Mrs Kay's discussion about cars running off the road. Neil's interview and the enthusiasm with which he retells his stories and describes 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 Pintrich et al.'s 'hot, irrational approach' to concept learning.

An attention-grabbing analogy for molecular shapes (Treagust et al., 1998)

Analogical models are frequently used in chemistry to enhance conceptual understanding. For example, ball-and-stick and space-filling molecular models often are invoked to illustrate covalent bonding and to explain molecular shapes. This is their cognitive purpose and students are left to 'accept" that bonding electrons repel each other to produce tetrahedral, pyramidal, triangular planar, and linear shapes. They are told that electrostatic repulsions "push" the bonds apart and that the negative bonding electrons are attracted to the positive nuclei. Able students create the desired mental models using "mind experiments" (Nersessian, 1992) but less imaginative students have trouble visualising the dynamic interplay of attraction and repulsion. One way to help these students is the balloon bursting analogy (students can repeat it themselves if they like)! I used this analogy with a senior chemistry classes with striking effect (Harrison, 1997). Teaching this analogy involves three phases - *Focus*, *Action* and *Reflection* [which we called the FAR guide for effective analogical teaching (Treagust et al., 1998)].

1. *Pre-lesson Focus.* Here, I scrutinise the difficult aspects of the concept to be taught (i.e., difficulties for the teacher and the students), whether or not the students already know

something about the molecular shapes concept (they have seen ball-and-stick organic molecules but not discussed reasons for their shapes), and whether the students are familiar with the analog (yes, they are familiar with balloons tied together and even Year-11 students like to play with balloons).

Theory states that the forces between nuclei and electrons in covalent bonds are purely electrostatic. The valence shell electron pair repulsion (VSEPR) theory uses the repulsion between electron pairs around a central nucleus to explain linear, triangular planar and tetrahedral molecules (e.g., ethyne, ethene and methane respectively). Students have difficulty visualising abstract repulsion between adjacent covalent bonds. They are, however, familiar with the elasticity of inflated balloons.

2. *In-class Action.* A simple way to demonstrate the repulsion between adjacent electron pairs is to take four strongly inflated elliptical balloons and tightly tie their necks together. The four joined balloons are then hung from the ceiling. The balloons represent single covalent bonds or one pair of shared electrons. The pneumatic pressure in the balloons (like the repelling bonds) forces them into a tetrahedral shape [Figure 4(a)]. The students see and can handle the model. Rotating the four balloons shows that the tetrahedron is symmetrical. If one balloon is suddenly burst, the remaining three pop into a triangularplanar shape [Figure 4(b)] and when another balloon is burst, the two remaining balloons become roughly linear [Figure 4(c)].

a. Four balloons forming a tetrahedron   *b. Three balloons forming a planar triangle.*

c. *Two balloons forming a linear shape*

Figure 4: Four balloons as analogies for chemical bonds and molecular shapes

The model's sudden change in shape as one balloon was unexpectedly burst was "attention-grabbing". This promoted interest and when later asked to explain their understanding of molecular shapes three students used the balloon "game" to explain the forces between four, three and two bonds respectively and the resultant shapes (Harrison, 1997).

During the class presentation, the teacher pays careful attention to the students' familiarity with the analog and identifies the Like attributes (i.e., those features held in common) and the Unlike attributes (i. e., those features not held in common) of the analog and the target. To achieve this, the features of the analog and target are socially negotiated with students, similarities are drawn between them, and ways that the analog and target are not alike are explicitly identified. This is the Action phase of analogical teaching and usually involves no more than three cognitive steps: (a) familiarity with the analog, (b) mapping of the shared attributes, and (c) discussing with the students where the analogy breaks down.

The common features of the science concept (chemical bonds and molecular shapes) and the analog (balloons) are summarised in Table 1. The features that the science concept (chemical bonds and molecular shapes) and the analog (balloons) do NOT have in common are summarised in Table 2.

Table 1: *Ways in which the analog and target are alike*

Science Concept (Bonding and molecular shape)	Analog (Balloons tied together)
One (or more) central atoms unites the molecule	The tied stems unite the balloons at a central point
A nucleus (or molecule or atom) is attached to each end of the bond	The inner and outer tip of the balloon is attached to the balloon
Bonding pair electrons are most likely found in the region between the two nuclei	A pressurised region exists between the stem and the balloon end
Electrostatic repulsion	Pneumatic pressure
Two bonds unite to form a double bond	One balloon is burst

Table 2: *Ways in which the analog and target are different*

Science Concept (Bonding and molecular shape)	Analog (Balloons tied together)
There are only 2, 4, or 6 electrons per bond region	The balloon contains a vast number of particles
The electron density is not uniform within the bond	The air density is uniform in the balloon
Electrostatic repulsion is non-contact	Pneumatic pressure between balloons involves contact

3. *Reflection.* Following the presentation of the analogy, the teacher reflects on the analogy's interest, clarity, usefulness and conclusions. Were the shared and unshared attributes clear and adequately discussed? How can the balloons analogy be improved to make it more interesting (do the students want to repeat it themselves?) and more cognitively effective? The Reflection may take place within the lesson itself or after the lesson when preparing for the next lesson. In practice, the three phases are not distinct but merge into one another. Because Reflection is a characteristic of all good teaching, competent teachers will likely implement this step

as a matter of course. Indeed, the FAR guide emerged from many pedagogical discussions with experienced teachers.

The pertinent question to ask here is, "do students enjoy this analogy" and, "do they use it to think about bonding and molecular shapes? Harrison and Treagust (2001) discuss the cases of Dan and Alex who told in independent interviews how they enjoyed the analogy and learned from it. Further, Harrison (1997) comprehensively report the responses of six students to this analogy and show that they found it exciting and a positive heuristic for explaining bonding. Two brief comments about the balloons analogy are provided:

> Dan: It shows you how the [bonds] are all evenly spaced out like if you put them two together they sort of bounce off so that's like the two electrons repelling each other at an equal distance from each other but it doesn't look like it, it just shows how they repel each other and how the shape ... like three dimensional pyramid ... it's electrical.... Just like ... methane ... where you can see it's three dimensional, you can see the actual spacing of ... Yea ... when he burst [one balloon], it became like, it became evenly spaced, like more on one, on one plane
>
> Alex: These ... are all models of molecules, the ball-and-stick method is too rigid and doesn't show that the atom is mobile, the balloon method is to[o] out of proportion, the hydrogens are huge compared to the carbon and the bonds. [Alex]

Conclusions and Recommendations

The examples featured in this paper - the wheels analogy, the interviews-about-instances study, the two teacher interviews and the balloons analogy show that familiar analogies have the capacity to interest and excite students. Not all analogies, however, are this effective. The Melbourne Cricket Ground analogy was used by Harrison (1997) to analogically model the spaciousness of an hydrogen atom; but too few students in the class were interested in football and cricket to enable them to access to the benefits of this analogy. Hence, a familiar alternative was needed. An effective analogy, based on the proximity of each student's home to the school and different sized sport balls was used to model the nucleus, electron and the space between them in a hydrogen atom.

This brief example highlights the needed teacher resources and strategies. Teachers need a resource containing interesting analogies and the creative imagination to construct a working analogy from the shared experiences of the students in their class. The other need is a systematic model 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 to check that the students realize where the analogy breaks down. This strategy is available in the FAR guide for effective analogy presentation (Treagust et al., 1998).

Three needs remain to be met: First, a book of effective analogies is needed so that teachers can choose from a range of familiar, tested and interesting analogies. The test of familiarity rests with the students and teachers should always ensure that the students share their account of the analogy. If the students do not readily visualize the analog, another should be chosen. There is an inherent strength in analogies like the wheels analogy for refraction: being an enacted analogy, familiarity is high. A book of analogies in preparation should help address this need. The second need is specific research into the affective benefits of popular analogies. It is important that we ascertain which analogies interest students, how and why students are interested in these analogies, and which concepts are effectively developed by these analogies. Third, this paper has shown that expert and creative teachers carefully plan their analogies and know well 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 expected type or depth when ad hoc analogies are used. I therefore recommend that only those tried analogies that can be presented in an effective way be used to explain abstract and difficult science concepts. But above all, let's choose interesting analogies - the learning of our students comes from motivating teaching!

References

Australian Science Education Project (1974). *Atoms.* Manuka, ACT: Author.

Clement, J. (1993) Using bridging analogies and anchoring intuitions to deal with students preconceptions in physics. *Journal of Research in Science Teaching, 30*, 1241-1258.

Dagher, Z. R. (1995a). Does the use of analogies contribute to conceptual change? *Science Education, 78,* 601-614.

Dagher, Z. R. (1995b). Analysis of analogies used by teachers. *Journal of Research in Science Education, 32*, 259-270.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education*, 75, 649-672.

Dupin, J. J., & Johsua, S. (1989). Analogies and "modelling analogies" in teaching. Some examples in basic electricity. *Science Education, 73,* 207-224.

Gentner, D. (1983). Structure mapping; a theoretical framework for analogy. *Cognitive Science, 7*, 155-170.

Gentner, D., & Markman, A.B. (1997). Structure mapping in analogy and similarity. *American Psychologist, 52*(1), 45-56.

Gentner, D., & Medina, J. (1998). Similarity and the development of rules *Cognition, 65,* 263-297)

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15,* 1-38.

Glynn, S. M. (1991). Explaining science concepts: A teaching-with-analogies model. In S. Glynn, R. Yeany and B. Britton (Eds.), *The psychology of learning science* (pp. 219-240). Hillsdale, NJ, Erlbaum.

Harrison A. G., & Treagust, D. F. (1993). Teaching with analogies: A case study in grade 10 optics. *Journal of Research in Science Teaching, 30*, 1291-1307.

Harrison, A. G. (1994). Is there a scientific explanation for refraction of light? - A review of textbook analogies. *Australian Science Teachers Journal. 40,*2, 30-35.

Harrison, A. G. (1997). *Conceptual change in secondary chemistry: The role of multiple analogical models of atoms and molecules.* Unpublished Ph.D. thesis, Curtin University of Technology, Perth, Western Australia.

Harrison, A. G. (2001). How do teachers and textbook writers model scientific ideas for students? *Research in Science Education*, 31, *401-436.*

Harrison, A. G., & Treagust, D. F. (1994a). Science analogies. *The Science Teacher, 61* (4), 40-43.

Harrison, A. G., & Treagust, D. F. (1994b). The three states of matter are like students at school. *Australian Science Teachers Journal. 40* (2), 20-23.

Harrison, A. G., & Treagust, D. F. (1998). Modelling in science lessons: Are there better ways to learn with models? *School Science and Mathematics, 98*(8), 420-430.

Harrison, A.G. (1992). *Evaluation of a model for teaching analogies in secondary science.* Unpublished master's thesis, Curtin University of Technology, Perth, Western Australia.

Harrison, A.G., & Treagust, D.F. (2000) Learning about atoms, molecules and chemical bonds: a case-study of multiple model use in grade-11 chemistry. *Science Education. 84*, 352-381.

Harrison, A.G., & Treagust, D.F. (2001) Conceptual change using multiple interpretive perspectives: Two cases in secondary school chemistry.*Instructional Science, 29*, 45-85.

Hewitt, P. G. (1992). *Conceptual physics.* Menlo Park, CA: Addison-Wesley Publishing Company, Inc.

Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education, 11,* Special Issue, 541-553.

Millar, R., & Osborne, J. (1998). *Beyond 2000.* London: Kings College.

Oppenheimer, R. (1956). Analogy in science*. American Psychologist, 11,* 127-135.

Nersessian, N. (1992). Constructing and instructing: The role of "abstraction techniques" in creating and learning physics. In R..A. Duschl & R. .J. Hamilton (eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 48-68). New York: State University of New York Press.

Patton, M. Q. (1990). *Qualitative evaluation and research methods.* Newbury Park, CA: Sage Publications.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63,* 2, 197-199.

Thagard, P. (1989). Scientific cognition: Hot or cold. In S. Fuller, M. de Mey and T. Shinn (Eds.) *The cognitive turn: Sociological and psychological perspectives on science* (pp. 71-82), Dordrecht: Kluwer Academic Publishers.

Thagard, P. (1992). Analogy, explanation and education. *Journal of Research in Science Teaching, 26,* 537-544.

Treagust, D. F., Harrison, A. G., Venville, G (1998). Teaching science effectively with analogies: An approach for pre-service and in-service teacher education. *Journal of Science Teacher Education. 9*(1), 85-101.

Treagust, D. F., Harrison, A. G., Venville, G., & Dagher, Z. (1996). Using an analogical teaching approach to engender conceptual change. *International Journal of Science Education, 18*. 213-229.

van der Veer, R., & Valsiner, J. (1991). *Understanding Vygotsky: A quest for synthesis.* Oxford: Blackwell.

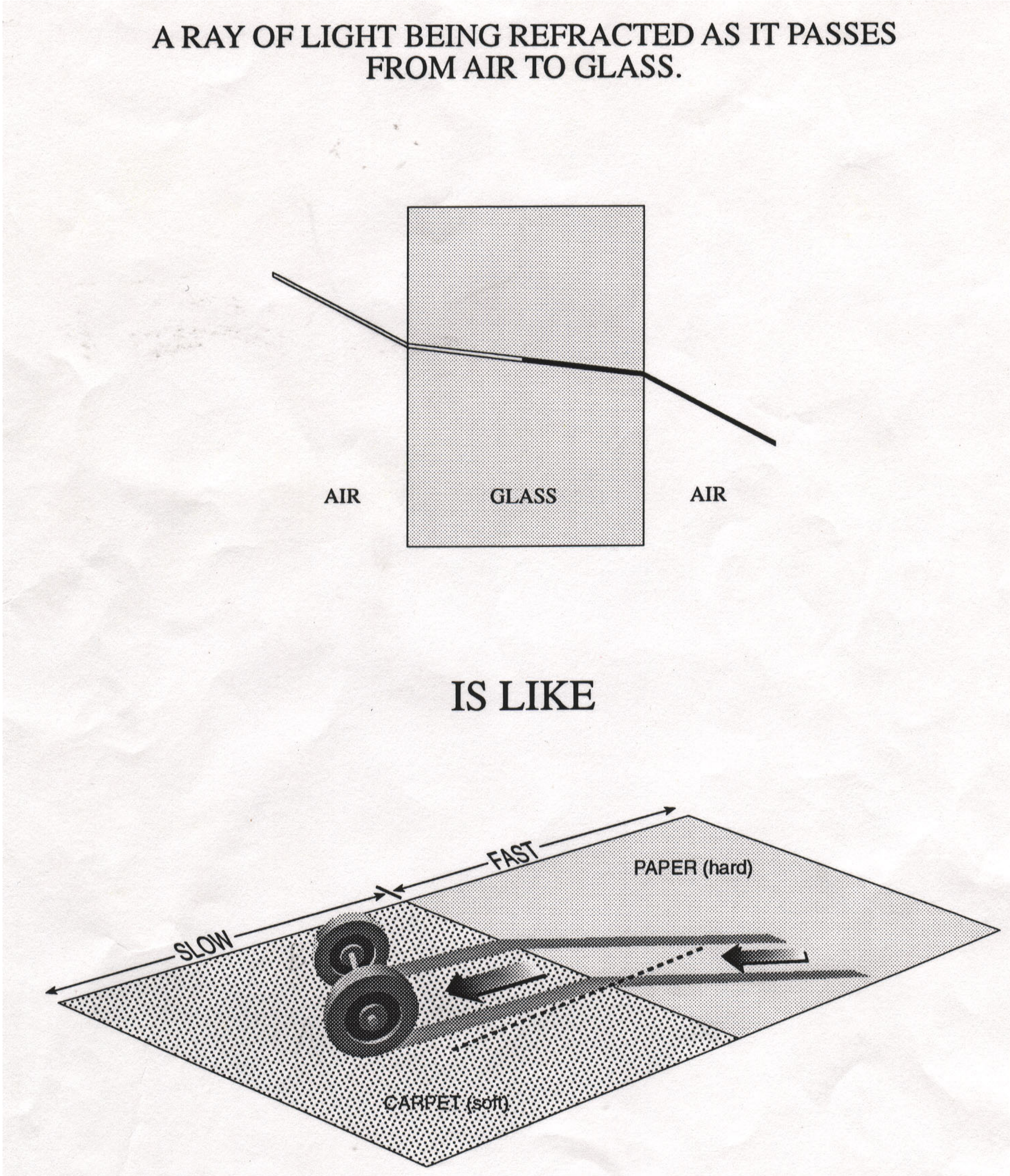


Figure 1: The wheels analogy for the refraction of light