Teaching with Analogies: A Case Study in Grade-10 Optics

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Abstract

Analogies have long been tools of discovery in science and are often used as explanatory devices in the classroom. However, research has shown that analogies can engender alternative conceptions because some students visualize the analog in a different manner than the teacher and/or invalid analog–target transfers are left unchallenged. This case study describes one teacher’s implementation of a modified version of Clynn’s Teaching-With-Analogies (TWA) model with a Grade-10 optics class on refraction of light. The analogy likened a ray of light as it passes from air into glass to a pair of wheels that changed direction as they rolled obliquely from a hard onto a soft surface. The study indicates that a competent teacher can integrate this systematic approach into a teaching repertoire resulting in student conceptual understanding of the phenomena as expected at this level of science education. For analogies to be effective, it appears essential that the analogy be familiar to as many students as possible, that shared attributes be precisely identified by the teacher and/or students, and that the unshared attributes should be explicitly identified. The discussion concludes with recommendations for teaching and future research and discusses some limitations of this approach to analogical instruction.

Since the beginning of recorded history, analogies have been used as concept-building tools for children and for adults. Metaphors, similes, analogies, and parables plus mental and physical models are common devices in spoken, acted, and written communication. Metaphors and analogies are woven into children’s stories, for example, with people represented by animals. Both fiction and nonfiction authors use analogies as descriptive tools, and they are especially ubiquitous in religious writings. Each of these literary devices are collectively considered to be analogies (Duit, 1991) because of their potential to compare one object or situation to another, and in the process, transfer either details, relational information, or both. Analogies are used because they have the power to evoke rich, almost instantaneous, mental pictures that serve to challenge the hearer to transfer knowledge from a familiar to an unfamiliar domain. Furthermore, analogies ensure that a person’s mental imagery is concrete, as in, for example, the analog of hard balls in a container representing gas molecules in a closed container.

Analogies can also be tools of discovery. Johannes Kepler developed his concept of planetary motion from the workings of a clock (Bronowski, 1973) and Huygens used water wave motion to understand light phenomena (Duit, 1991). Perhaps the best described use of analogies in scientific discovery is Maxwell’s mathematical description of Faraday’s electric lines of force (Gee, 1978).
What works for the investigative scientist may be of value to other learners. For example, Cosgrove (1991) described how 14-year-old boys discovered a valid model for an electric current using their own analogies and Wong (1993) asked teacher education students to create their own analogies to explain three air-pressure phenomena. The question raised by these and other studies is whether students can economically and repeatedly employ analogue reasoning skills in the same way as experienced scientists: Emulating the analogue reasoning of scientists and philosophers may be too much to expect of unsophisticated thinkers. However, research has shown that the effectiveness of analogue instruction can be improved by training students in analogy reasoning (Friedel, Gabel, & Samuel, 1990; Gentner, 1980; Klauer, 1989).

Nevertheless, a significant body of research suggests that although analogies are commonplace in human communication, they are not as effective in the classroom as might be expected (Duit, 1991). Uncritical use of analogies may generate misconceptions (Champagne, Gunstone, & Klopfer, 1985), and this is especially so when unshared attributes are treated as valid (Cosgrove & Osborne, 1985; Curtis & Reigeluth, 1984), or where the learners are unfamiliar with the analogy (Gentner & Gentner, 1983; Nagel, 1961). Indeed, in using any analogy, care needs to be taken to ensure that an impression is not conveyed that the analog is a true description of the target concept.

The consensus amongst most investigators is that analogies enhance student learning through a constructivist pathway (Duit, 1991) whereby learners attempt to integrate new ideas into what may be preconceptions or alternative frameworks (Driver & Erickson, 1983; Dupin & Johsua, 1989). Three decades ago, Ausubel (1968) pointed out that these “preconceptions (are) amazingly tenacious and resilient to extinction.” Research since that time has shown that a student’s own concepts are so strongly held that in some instances, as seen from the teacher’s perspective, they will be preserved in the face of obvious and contradictory evidence (Driver, 1989; Johsua & Dupin, 1987). Many students accept the teacher’s science for the duration of the topic being studied, but revert to their intuitive views following instruction (Osborne & Freyberg, 1985). In other instances, students construct alternative schema to accommodate the lesson content without altering their preconceived views (Gunstone, 1988).

If these natural conceptions that Dupin and Johsua (1989, p. 118) call “epistemological obstacles” are to be successfully challenged, then a carefully planned pedagogy is called for. Such a classroom pedagogy should be designed so that the analogies used are relevant to as many students as possible. In attempting to redress this problem, a number of models or teaching approaches for valid and reliable use of analogies in classroom instruction have been produced. Four particular models are the Brown and Clement (1989) bridging-analogies, the Dupin and Johsua (1989) analogy teaching model, Glynn’s (1991) Teaching-With-Analogies (TWA) model, and Zeitoun’s (1984) general model of analogy teaching (GMAT). Although not a specific teaching model for analogy use, the Cosgrove and Osborne (1985) four phase conceptual change model highlights the value of analogies by suggesting their inclusion during “the challenge phase.”

A Systematic Approach for Teaching With Analogies

Although the use of an analogy to improve student’s understanding of a concept can be useful, the analogy itself must be used economically and in a valid and reliable way. An analogy enables valid concepts from a familiar domain to be used to challenge the student’s alternative conceptions with the result that the learner may be stimulated to reconstruct his or her knowledge (Sutula & Krajcik, 1988). Evaluation of a systematic model for analogical instruction can highlight the dangers inherent in the haphazard, uncritical use of analogies in the
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science classroom and may provide science teachers with an efficient model for improving their teaching.

To date there is little empirical evidence available regarding teachers' use of analogies in the classroom (Treagust, Duit, Joslin, & Lindauer, 1992; Thiele & Treagust, in press). A need exists for research to examine whether any of the above models can systematize teacher use of analogies and enhance student understanding of scientific concepts during analogical instruction. A review of the four models described above (Treagust, Thiele, & Venville, 1991) indicated that Glynn's model, which was developed from an analysis of science textbooks, would be most adaptable to classroom teaching. Consequently, this study evaluated the efficacy of the modified Teaching-With-Analogies (TWA) model in secondary physical science classes spanning grades 8 to 10 with 13–15-year-old students. This article describes one episode from research (Harrison, 1992) on the Teachers use of analogies project (Treagust, 1990). The following summary describes the systematic approach used in this research, which is a modification of Glynn's TWA model:

1. Introduce the target concept to be learned.
2. Cue the students' memory of the analogous situation.
3. Identify the relevant features of the analog.
4. Map the similarities between the analog and the target concepts.
5. Draw conclusions about the target concepts.
6. Identify the comparisons for which the analogy breaks down.

Glynn's TWA model (1991) had Steps 5 and 6 above reversed. However, early trials of Glynn's model showed that teachers tended to introduce the shared and unshared attributes side by side, resulting in their adjacent positions in the modified TWA model. We reasoned that if the conclusions of Step 5 were drawn before the unshared attributes were identified, then alternative student conceptions would arise more often than when these invalid comparisons were identified before the concluding summary. Subsequently, the aim of the research was to evaluate how well this systematic approach to analogical instruction could be implemented and to gauge the facility of this approach for student learning.

Method

Because analogies are devices of human communication, it is important to determine the analogy's meaning for the teacher and the students. To ascertain these meanings, the study employed classroom observations and audiotaped recordings in combination with teacher and student interviews. Each episode was transcribed verbatim and analyzed to yield data for interpretive analysis. The nature of the research, without any controlled treatment and investigating how the analogical teaching approach was implemented and how effective it was for student understanding of the phenomenon, ensured that the research mode was that of a qualitative case study that used some quantitative data (Merriam, 1988). The emphasis throughout the study was upon producing constructivist interpretations that were trustworthy; that is, they were credible (comparable to internal validity), transferable (external validity), and dependable (reliability) (Guba & Lincoln, 1989). Put another way, the aim was for outcomes that were plausible, viable, and possessed face validity (Patton, 1990).

Sample

In our research we are working with six science teachers and have so far analyzed a total of 12 different analogies using the modified TWA model. Four analogies used by one teacher, who
will be called Mrs. Kay,¹ are reported in Harrison (1992). Mrs. Kay derived the wave nature of light from water wave characteristics, the conduction of heat through a solid was likened to the domino effect, the slowing of light and its refraction as it passes from air into glass was demonstrated using a pair of wheels rolling from a hard surface onto a soft surface, and the mole concept was taught using three short analogies in which the particles of a mole were likened to dollars, oranges, and rice grains. For this article, the third lesson taught by Mrs. Kay is discussed.

The criterion employed for school and teacher selection was purposeful sampling, about which Patton (1990) points out that “[t]he logic and power of purposeful sampling lies in selecting information-rich cases for study in depth” (p. 169). Mrs. Kay was purposefully chosen because she is an experienced physical science teacher, is highly regarded in her school as an innovative teacher, often uses analogies, was cooperative and was teaching in her area of expertise; furthermore her contribution to science education has been acknowledged by the Australian Science Teachers' Association. The Grade 10 class that was studied consisted of 29 average-ability students attending a private school and students were chosen for interview on the basis of the extensiveness of their responses on a postlesson worksheet. Thus, this study does not claim to be fully representative of the local educational environment and for this reason the constructivist notions of rigor are particularly useful.

Mrs. Kay received in-service information from the researchers about the systematic approach for use of analogies in teaching both prior to the commencement of analogical instruction and before and after each lesson for the four observed lessons. Each postlesson discussion provided an opportunity for Mrs. Kay and the researchers to reflect upon the lesson just completed and to prepare for the next implementation of the model for incorporating analogies in her teaching. The teaching episode described in the following represents the third observed lesson taught by Mrs. Kay in which a class of Grade 10 girls was studying optics. The written objective for this lesson was: “Draw ray diagrams to show what happens when light enters glass along a normal or obliquely to a normal.” The analogy used to teach refraction during this lesson was chosen by Mrs. Kay and is described in the next section of the article. The lesson itself was audiotaped, as were both the postlesson teacher interview and the subsequent student interviews, after which the audiotapes were transcribed verbatim. Each student who heard the analogy completed an analogy mapping worksheet at the commencement of the lesson immediately following the presentation of the analogy (Olivera & Cachupuz, 1992). This worksheet examined both the shared and the unshared attributes of the refraction analogy and these responses were then used to select the subjects for interview. Students were interviewed if they had completed all or most of the attribute matches on the worksheet irrespective of whether those responses were correct or not. The selection criterion again was purposeful sampling with the reasoning that students who provided lengthy written comments were likely to provide insightful comments during the interview.

*Teaching about Light in Secondary School Science*

The lesson on refraction took place during the third week of a four-week optics unit. The topic’s first two lessons were devoted to revising wave motion coupled with the development of a theory of light in which the wavelike nature of light was dominant (Harrison, 1992). Within this unit of study, photons were mentioned but this aspect of the nature of light was not pursued. Students do have some familiarity with light bending when it passes from one transparent substance into another and the phenomenon of refraction is easy to demonstrate in the classroom. What then, constitutes a satisfactory explanation of refraction for Grade 10 students?
Figure 1. Refraction of light as it passes from air into glass is like a pair of wheels slowing down as it rolls obliquely from paper onto carpet.

As examination of 38 physics textbooks suitable for Grades 9–12 (Harrison, in press) revealed that 10 writers described refraction in detail but offered no explanation for the phenomenon. Of the 28 authors who offered an explanation for refraction, all employed one or more analogies. Twenty-six authors compared water-wave fronts to lightwave fronts, four used a car (or wheels) rolling from a hard surface onto sand or mud, four compared light to a line of soldiers marching from concrete onto sand, and 10 used a Newtonian inclined plane model (in which light was considered to be particles). Fourteen authors used two analogies in their explanation and two employed three analogies. No student textbook was found that offered a pure physics explanation for refraction—there was either no explanation or it was analogical. One of the student texts, Hewitt (1987), which was available to Mrs. Kay, modeled refraction using a pair of wheels rolling from a smooth to a rough surface. Mrs. Kay analogically demonstrated refraction by rolling a pair of Lego® wheels coated with paint obliquely across the interface between a smooth surface (paper) and a rough surface (carpet) as illustrated in Figure 1. This pair-of-wheels analogy for refraction of a ray of light appears to be typical of how refraction is taught to 15-year-old students.

Nine university textbooks also were surveyed and, in contrast to the secondary school physics books, in each instance the Huygens principle (wave front analogy) was used. Halliday,
Resnick, and Krane (1992) provide a detailed wave front analogy and Starling and Woodall (1955) state that “the wave theory of light was naturally first developed by analogy” (p. 430) and that “direct experimental tests . . . were decisively in favour of the Wave Theory” (p. 429). Only Serway (1990) used a second analogy, namely, wheels. When the wheels, being analogous to a light beam, were rolled by a student from the paper onto the carpet so that both wheels crossed the interface simultaneously (angle of incidence = 0°) no bending occurred. However, when the wheels were made to cross the interface obliquely (angle of incidence = about 30°) the wheels changed direction in a manner comparable to the refraction of a beam of light passing obliquely from air into glass.

Analysis of the Teaching Approach

The lesson notes and the lesson transcript were analyzed for evidence of how Mrs. Kay implemented the six steps of the modified TWA model, each of which is discussed below. During the lesson, Mrs. Kay initially referred to the light path as a beam but later called it a ray; for this reason “ray” has been used throughout to maintain compatibility with the transcripts.

1. Introduce the Target Concept to be Learned

Refraction of light was introduced by showing the students that a ray of light changes direction when it passes from air into glass. The demonstration using a glass block (Figure 1) precipitated the question, why do light rays bend when they pass obliquely from one transparent medium into another?

2. Cue the Students’ Memory to the Analogous Situation

Because many of the students would not have had direct experience of the analog, it was established by demonstration using the apparatus illustrated in Figure 1. Being simple and visual, the analog became familiar to the students as it would remind many of them of Lego® wheels. This led Mrs. Kay to state the analogy:

Let me show you a little analogy to illustrate this. This is what all the paint’s for, now to represent the ray of light, I’m going to use this pair of wheels here coated in this nice fluoro paint (Figure 1) . . . this is meant to represent the ray of light. I’m going to use this pair of wheels here coated in this nice fluoro paint. Now I’m going to do two demonstrations . . . our wheels going forward are meant to represent the ray [of light].

3. Identify the Relevant Features of the Analog

On the two previous occasions that Mrs. Kay used the modified TWA model, she employed the six steps in a simple sequential manner. This third instance suggested that she was more confident in the use of the model because she altered the order of the steps to suit her explanation and the class’s needs. The feature of the analog that was most important at this juncture was:

[the wheels are] really like the two edges of the ray of light as it starts off . . . it’s wider and it’s deliberately wider because it’s a little bit hard to see the reason for its bending when it’s as narrow as this (points to light ray). When it’s wider it’s a little bit easier to see the reason [for bending].
The wheels were rolled by a student from the paper onto the carpet twice; once at an angle of incidence of 0° and then at an angle of incidence of about 30°.

4. Map the Similarities Between the Analog and the Target Concepts

In explaining refraction of light by comparing it to wheels that slow down as they roll from a smooth surface onto a rough surface, Mrs. Kay utilized six propositions as the shared attributes of the analogy: (a) the two wheels represent the edges of a the light ray; (b) a ray that strikes the glass at 90° is not bent; (c) a ray that strikes the glass at an angle is bent; (d) the ray bends because it slows down; (e) when the ray strikes the glass at an angle, it bends toward the normal; and (f) the light slows down because the glass is denser than air. Nine students were interviewed on the day after the lesson immediately following their completion of the worksheet and these students’ relevant responses to the above six propositions follow.

(a) The Two Wheels Represent the Edges of the Light Ray. This proposition was introduced when Mrs. Kay said that “[the wheels are] really like the two edges of the ray of light.” On the worksheets, only 10 of the 29 students recalled this proposition in its correct form, with 19 students responding that each wheel is like a ray of light. This response may be a simplification rather than an error of understanding because all but one of the nine girls interviewed talked about the wheels being analogous to the edge of the ray. Matching named worksheets to the interviews, four girls wrote that each wheel was like a ray of light but then talked about the wheels representing the edges or sides of the ray of light. One girl, Cath, both wrote and said that the wheels represented separate light rays. Other student comments were typified by the following two remarks:

Jane: . . . one edge of the ray would hit the glass first . . . one edge gets there first . . . like the wheels do . . .

Cath: Well slowing down one side of it so that one side’s at a different speed to the other . . .

(b) A Ray that Strikes the Glass at 90° is not Bent. This propositional statement was derived from Mrs. Kay’s comments,

[The wheels are] like the ray of light going through the block along the normal . . . just push it straight . . . both [wheels] slow down at the same time so that they both would be moving slower, but it doesn’t change direction. It’s the same with a light ray, if the light ray goes through at right angles, it slows down but it doesn’t change direction.

Each girl explained during her interview that when the light ray struck the new medium at right angles (that is, parallel to the normal) it did not bend. Most could explain this in terms of both sides of the ray slowing down simultaneously. In response to the question “Does a ray of light always change its direction when it passes from one transparent medium into another one?”, Jane stated . . . “not if it enters it at right angles into the medium . . . it doesn’t change direction.” Similarly, Kay responded “. . . no it doesn’t if the light ray was on the normal because if they hit the medium at the same time . . . traveling perpendicular, then it wouldn’t bend because they both slow down at the same time.”
(c) A Ray of Light that Strikes the Glass at an Angle is Bent. Discussion during the lesson about the wheels crossing the paper/carpet joint obliquely highlighted this propositional statement:

Mrs. Kay: . . . it has bent and that light did more or less the same thing didn’t it? When we passed the light through our block at an angle, light also bent. Why does it bend when it approaches like that?

Sally: When the wheel is on a smooth surface it’s going faster . . .

Mrs. Kay: It’s to do with speed. That’s exactly the point I wanted to make . . . its speed. When we move it here, which wheel is going to slow down first?

Fiona: The one on the carpet.

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

Beth: Yes, yes . . .

Mrs. Kay: In exactly the same way with light, one edge of the ray slowed down slightly before the other, so this wheel that hits the carpet first, is slowing down first, so that’s covering less distance for a time, and obviously, once this one hits the carpet as well, they then become parallel again . . . so it bends because the wheels and the light ray travel more slowly in a dense medium, or in this case, on a rougher medium.

As for proposition (b), each student interviewed provided an intelligible response indicating that she knew that a ray striking the new medium at an angle would bend. Two of the nine stated that the ray bent away from the normal, though this was reversed later in the interview by Kay who said

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

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

Similarly, Cath stated that “. . . the part of the ray that goes in first, that’s going slower than the other half so it changes direction.”

(d) The Ray of Light Bends Because it Slows Down. This propositional statement, based on the final comment made by Mrs. Kay in the account reproduced in (c) above, was identified in eight of the nine student interview transcripts. Two of these student statements, which are representative of the overall sample, are

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

(e) When the Ray Strikes the Glass at an Angle, the Ray Bends Toward the Normal. This propositional statement arose following Mrs. Kay’s question, “. . . which way will the light bend? Is it bent towards the normal?” to which Emma replied, “It goes towards it.” Mrs. Kay continued probing—“It’s bent towards the normal isn’t it? Just look at the light rays and tell me if that does the same thing, does the light ray also bend towards the normal? Dani responded, “Mmm . . . Yes.” As already indicated, eight of the nine girls stated that the ray was bent towards the normal when light passed from a less dense to a more dense medium. When the interviewer asked, “From a less dense, like air, to a more dense medium like glass, which way will it bend? Jen, Sue, and Cath all replied with, “towards the normal.”

(f) The Light Slows Down Because the Glass is Denser than Air. On this occasion, Mrs. Kay asked the class “Why is light bent when it travels from one transparent medium to another?” after which she stated “. . . it’s to do with speed. So we can say that light travels more slowly in a denser medium.” This proposition that refraction was a consequence of the light changing speed was mentioned by the girls in each interview. The demonstration of the wheels slowing down going from paper to carpet, coupled with the “car wheels in the gravel” analogy (added by Mrs. Kay), made this idea intelligible to most of the students as illustrated by two quotations from the student interviews.

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

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

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

When a ray of light passes from a more dense to a less dense medium, it is bent away from the normal. Six girls were asked this question because it involved extrapolating from the concept and would thus be an indicator of whether or not the students understood refraction following the use of the analogy. However, the students may have just guessed, by saying the opposite to the previous case, but an ability to explain why would favor extrapolation over guessing. In responding to the question “when light passes from a dense to a less dense medium, which way will it bend?”, Jane and Sue simply stated that the ray would bend away from the normal but Kay explained it thus:

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.
Due to time limitations in the interviews, three girls were not asked this question. However, all six who were asked gave an answer similar to that above, with four students explaining why the ray bends away from the normal using an argument similar to Kay’s.

5. Identify the Comparisons for which the Analogy Breaks Down

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

*The pair of wheels were considerably wider than the light ray.* Mrs. Kay’s comment that highlighted this unshared attribute was:

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

This issue was examined during the student interviews and resulted in the following four responses to the question, “. . . but the two wheels were much wider than the ray of light?”

Jane: No, I just think it exaggerated it and so made it clearer.

Sue: Um, it is just sort of enlarged, just thought of it as enlarging the ray of light, magnified.

Kay: No, no, I don’t think that would really matter if I think the wheels were skinny and there were two wheels joined by an axle, it would still go the same. It was like, similar, but you still had your doubts that your light would be different until she said this is like a version of the light ray. . . . If she just got out the wheels and said this is a light ray, I would have questioned that.

Jen: It was more obvious, more extreme so you could sort of really see . . . if I hadn’t seen that wheel, I probably wouldn’t have understood the beam of light because it’s so narrow, it’s hard to believe it’s got little edges.

*There were two wheels but there was only one ray.* This unshared attribute was recognized by all the students who were interviewed; two typical responses were as follows:

Int: The two wheels were joined together with an axle, are the light rays in a beam joined together like that?

Kay: No they are individual, but they’re very close together.

Int: Are the light rays in a beam joined together [like the wheels]?

Cath: . . . I wouldn’t say they were joined together, I’d more say they’re all going in the same direction, do you know what I mean? They’re not joined together by an axle so that they can diverge if they wanted to.

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

*Friction slowing the wheels is like friction slowing the light.* During the lesson, friction was given as the reason the wheels slowed down. A minority of the students interviewed
recognized this as an unshared attribute. It is apparent that many of the students transferred friction as an explanation for the slowing down of light in denser media. For many, this was probably a misconception. In response to the question, “do you think there’s friction between the light and the glass?” four students answered in the affirmative and two of their responses were

Jane: I don’t think there is friction between light and air . . . I think there would be between light and glass.

Jan: If the medium’s different, because of friction, it’s a denser medium, then it’s friction.

The two wheels being joined is like light rays being joined. Of the 29 students who filled in the worksheet, 24 recognized this unshared attribute. This level of response may be a function of the fact that this was one of the two invalid mappings where half the statement was provided for the students on the worksheet. The response rate for this semicomplete proposition was far higher than for all but one other partial statement. That nearly all members of the class recognized this link as invalid is indicative of the usefulness of this teaching method.

One misconception emerged during the student interviews. Sue revealed that she thought the ray bent toward the normal because this provided a shorter route through the glass block. If the ray slowed down, it took a more direct (shorter) route. She was the only student who held this idea and in response to the question, “can you link the slowing down with the reason why it bends?” she replied, “Um, it is easier, to make the path shorter to get through the block.”

6. Draw Conclusions About the Target Concepts

The ideas derived from the analogy were then transformed by Mrs. Kay into a summary that provided the students with a statement of the concept of the refraction of light. “At all angles, [light] slows down . . . if it enters another denser medium. If it enters at an angle, it changes direction.” The probable value of this step rests in the identification and integration of the key ideas derived from the analogy into a conception that was intelligible, plausible, and fruitful for the students.

Discussion

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

This integration of the modified TWA model into the fabric of the lesson probably indicated that this teacher was now comfortable with the model for incorporating analogies into her teaching. To say that she was delighted with the lesson’s outcome is evident from Mrs. Kay’s evaluative comments relating to the analogy and the manner in which she expressed them.

I thought that was the best I’ve ever taught that . . . refraction from the point of the students understanding it. They seemed to just say, Oh yea, no worries, at the end, and that’s what I like about it. It’s certainly something I’d certainly do again.
Credence has been ascribed to an experienced teacher's qualitative assessment of the lesson's effectiveness in respect to student cognition. Mrs. Kay gave her assessment of the analogy's effect during the postlesson interview:

I was really pleased with [the analogy] actually, [refraction] was something I've always found hard to explain, and I don't know that the kids find it easy, but I thought, doing it that way, clarified it a lot. . . . I felt at the end of the lesson they seemed to have a good understanding of it. Something I noticed was that sheet that I gave them at the end of the lesson, I said does it bend towards or away from the normal, they had no problem with that today. . . . They all seemed to say towards it, where normally they will say, what on earth do you mean . . . they seemed to have a better understanding than usual, I felt. I was really happy with it.

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

During unrecorded conversation following the interview, Mrs. Kay expressed her delight at the consistent manner with which the students could predict the direction of bending. A look back at the lesson transcript shows that Gemma, at the point where the wheels changed direction, spontaneously exclaimed, “Isn't that because the wheels will move faster on the [paper]?” to which Mrs. Kay replied “Yes. Exactly, yes . . .” From their viewpoint, the students believed that the analogy helped them understand refraction. A sample of their comments are:

Jan: The wheels, I thought it was a good idea, it really explained it well, I understood that.

Kay: I think it was helpful because you could actually see the tracks of paint from the wheels . . . it was helpful to understand the light rays bending. But you just have to know what are different and that.

Cath: It wouldn't have been easy to understand if she had just put it on the board in a diagram, it just wouldn't have gone in, do you know what I mean . . . by demonstrating it, it actually registers, but otherwise it probably wouldn't have. . . . it was a good way of explaining . . .

By this third episode, Mrs. Kay had developed a high level of proficiency in the use of this model and it appeared that the model had become subservient to her own needs and those of the students. Interviews with a sample of the students focused upon each student’s understanding of the concepts presented via the analogy. When the student worksheet and interview data were combined with Mrs. Kay's personal perceptions of the students' understanding of the concepts presented, it was concluded that the students' conceptual understanding of the refraction phenomenon was compatible with the expectations of the teacher and comparable with what was expected at this level of schooling.
The fruitfulness of the students' extrapolations and their curiosity suggests that some students were willing to reconstruct their prior conceptions. Nevertheless, without prelesson interviews or survey data to define individual student's prior conceptual status, such conclusions must be limited to saying that there was credible and dependable evidence of an acceptable understanding of refraction shown by the students interviewed.

Recommendations for Teaching and Further Research

The approach taken by Mrs. Kay in teaching this pair of wheels analog of a ray of light bending as it passes from one medium to another at an oblique angle was to use only one analogy. Such an approach to help students understand difficult concepts was compatible with her general teaching approach. Additionally, as shown by the textbook analysis, her analogical approach is consistent with how refraction of light is taught to students at this grade level. As discussed below, we claim that this systematic approach to teaching analogies was viable for this teacher with this class. However, there are other aspects of analogy teaching that were not explored in this case study and these are discussed as limitations of this systematic approach to teaching with analogies, rather than of the lesson taught by Mrs. Kay.

The Modified TWA Model Can Be Implemented by an Experienced Teacher with Practice and Collegial Support

Based on the data collected over four lessons, the third one of which has been described in detail, it is asserted that in this instance, with this teacher, a systematic approach like the modified TWA model is a practical and achievable means for improving the use of analogies in science classrooms. The implementation of the modified TWA model requires both practice and collegial support in the form of constructive feedback (Wallace & Louden, in press). Indeed, practice and constructive feedback, coupled with reflection on practice, was required before Mrs. Kay, an experienced teacher, became proficient with implementing the modified TWA model. At the conclusion of three episodes during which Mrs. Kay used the modified TWA model, she appeared to be competent and fluent in its use and the students responded positively to the resultant analogical instruction. As shown by the data, there was a consistently high level of understanding encountered during the interviews. In the described lesson, Mrs. Kay felt that the students had understood refraction better than on any previous occasion that she had taught this concept. Based on our studies with this teacher and five other teachers, it is predicted that the majority of practicing teachers would require extended practice combined with critical feedback in order to integrate the modified TWA model into their pedagogical repertoire. Three applications may well be a minimum number of trials in order to achieve proficiency in this or another appropriate model. Additionally, research involving teaching innovations suggests that teachers will probably adapt the model to suit their personal teaching style.

When Analogies Are Presented Systematically, Student Understanding Is Enhanced

The student responses collected from the worksheets and the subsequent interviews provided extensive documentation that student understanding of refraction was achieved at the level at which it was taught. Using the constructivist criteria of credibility, transferability, and dependability, it is probable that the modified TWA model did, through some mechanism, enhance student conceptual understanding of refraction. There is a need for caution in this assertion because the degree of conceptual understanding that would have resulted without the model or
without the analogy is unknown. However, the data suggest that there was a high level of student reflective understanding achieved throughout this lesson. Indeed, Mrs. Kay repeatedly stated that these students understood this concept better than on previous occasions in her teaching and, being an exemplary teacher, her evaluations should be deemed to possess credibility and dependability.

**Analog Familiarity to the Students Should Be Established**

The second step of the modified TWA model involved establishing that the analog was truly familiar to the students; in the lesson on refraction, the analog was well grounded through an actual demonstration. Whenever there is vagueness or uncertainty in the minds of the students, the credibility (validity) of their analogical mappings should be queried. If the teacher’s concept of the analog is markedly different to that of the students, alternative conceptions will probably follow. Student understanding will be maximized whenever sufficient time is invested by the teacher in ensuring that the students visualize the analog in the same way that he or she understands the analog. However obvious this recommendation may sound, the literature contains abundant evidence on alternative conceptions confirming this assertion that novices often visualize phenomena in a different way than experts, and that these differences are often ignored by teachers.

**Unshared Attributes Should Always Be Discussed**

The fifth step of the model involved examining for credibility each of the apparent analog–target mappings. All the propositional statements that emerge from any analogy need to be tested for compatibility with the science concept being taught. Mrs. Kay was impressed with this process following her first use of the modified TWA model and she stated that she had never before thought to do this, even though she had been using analogies in her teaching for about 20 years. The student responses support the generalization that this is an essential step whenever analogies are used in instruction. The value to student cognition inherent in examining the unshared attributes clearly outweighed the time cost involved in this exercise. In each of the four lessons studied with this teacher, it was evident that the students did want to know which features of the analog–target mappings were valid and which ones were not. A student commented, “otherwise you would have thought they were pretty much the same thing . . . but really they do different things as well.”

**Limitations of the Approach Taken in this Research**

Many concepts may be best taught using multiple analogies (Gentner & Gentner, 1983) and one limitation of this study is that only one analogy was presented to the students. Certainly, there is a case for recommending that multiple analogies could be used, though in itself, this recommendation needs to be presented with some caution as is illustrated by the research of Garnett and Treagust (1992, p. 140), where multiple models for oxidation-reduction created many problems for Grade 11 and 12 students. In the textbooks reviewed by Harrison (in press), 17 authors employed multiple analogies for refraction of light and in seven of these instances the multiple analogies were complementary. However, in 10 texts the second analogy was, at best, neutral, and at worst, contradictory. Research is needed to investigate the efficacy of learning from multiple analogies from both textbooks and classroom discourse.

It is likely that with different, complementary analogies, different students could develop an
enhanced understanding of the phenomenon. Gentner and Gentner (1983) recommend that a concept be separated into its constituent parts and that the analogy best suited to each of the parts be employed to teach that idea. However, as the textbook example illustrates, multiple analogies do not necessarily lead to safety in numbers because a poorly chosen second analogy could undo the benefit of the first and vice versa. Conversely, nonantagonistic multiple analogies may cater for the diversity of background knowledge present in most classes, especially gender and ethnic differences. Nevertheless, as shown by the study of 47 textbooks and their explanations for refraction at secondary and college levels, it is not likely that a scientific explanation of refraction of light will be offered or made whether one or many analogies are used.

Conclusion

This study has shown that a competent teacher can systematically integrate analogies into her classroom practice. This finding should be transferable to other teachers, provided adequate in-service education is given, there is an opportunity for collegial support, and time is available for reflective feedback. An ample body of evidence has been collected from four teaching episodes, one of which has been reported in this article, which support the premise that student understanding is enhanced when analogies are used in a systematic manner. Selected student responses have been cited endowing this claim with credibility, transferability and dependability. The modified TWA model or, for that matter, any appropriate model for the systematic teaching of analogies, appears to contain three essential elements. First, there is a need to consider the students' background so that the chosen analogy is familiar to as many students as possible. Second, the shared attributes should be precisely identified by the teacher and/or the students, and third, where the analogy breaks down should be explicitly identified. Finally, where necessary, multiple, complementary analogies may prove to be superior to a single analogy in developing understanding in science.

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Note

1The names used throughout this article are fictitious and are not intended to refer to any known person.

References


Treagust, D.F. (1990). *Teachers' use of analogies to enhance students' conceptual understanding in science*. Research project funded by the Australian Research Council, Curtin University of Technology, Perth.


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