Should Different Types of Analogies Be Treated Differently in Instruction? Observations from a Middle-School Life Science Curriculum*

Mary Jane Else
John Clement

Mathematics and Science Education Concentration,
School of Education and
Scientific Reasoning Research Institute
University of Massachusetts at Amherst
Amherst, MA

Mary Anne Ramirez
Hampshire College
Amherst, MA

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ABSTRACT

This study is a formative evaluation of analogies as one of multiple tools used to help middle-school students understand cellular respiration and the body systems associated with it. In a curriculum trial that was conducted in three schools, analogies were used to help students develop understandings in areas that may be inaccessible through student reasoning, prior knowledge, or direct experience. We propose that students may process and understand analogies differently based on features of the analogy such as familiarity of the base, complexity (number of mappable elements) of the analogy, goal of the analogy (to illustrate structural or functional features), "nearness" or "farness" of the analogy, and position of the analogy in the instructional sequence. We explore evidence that there are different types of "pitfalls" in analogies based upon the criteria above using evidence from our trials, and suggest curriculum revisions and teaching methods that may help address these difficulties.

INTRODUCTION

The *Energy in the Human Body* curriculum uses multiple teaching and learning methods such as analogies, small- and large-group discussions, and learning-by-drawing to help middle-school students understand cellular respiration and the body systems associated with it (Rea-Ramirez 1998). Cellular respiration is the biochemical system in nearly all living things in which the chemical energy contained in the glucose molecule is transferred to molecules which serve to store and transport energy so it can be used in the cell's functions. The body's digestive, pulmonary, and circulatory systems supply cells with the oxygen and glucose needed in the process and dispose of the by-products created in cellular respiration reactions. The curriculum approach is from a mental models framework, in which learning is viewed as occurring through processes of generation, evaluation, and revision of a series of visualizable models. The curriculum provides an array of learning experiences that help students move toward a developmentally-appropriate "target model."

In the *Energy in the Human Body* curriculum, analogies are used to help students build initial models in areas in which they are not expected to be able to generate models themselves and to make model features more salient in content areas which are critical to understanding. For example, the middle-school students we work with generally have little prior knowledge of cell organelles. The curriculum uses an analogy in which school parts and their functions are compared with cell parts and their functions to help students build an initial cell model. This model is later revised with the aid of visuals of cell structure, student small-group work, and an in-depth exploration of mitochondrial function. An analogy used at the end of instruction is one in which a car's need for gas in compared to the body's need for food. In this case, the analogy is used to deepen understanding in a conceptually-difficult area.

This paper shares the results of a case study of analogy use that was conducted as part of our formative assessment of the curriculum. The study was conducted in one of the participating schools in the third year of curriculum trials. In this paper, we examine analogies as one of the learning tools used in the curriculum, assessing both the successes and difficulties associated with four of the curriculum's analogies. In addition, we look at the range of analogies used in the curriculum and attempt to identify both analogy features that influence students' degree of success with them and the types of errors we see as students attempt to learn through analogy. Lastly, we suggest curriculum revisions and teaching methods that may alleviate some of the difficulties encountered with different types of analogies.

LITERATURE REVIEW

<u>Analogy in reasoning and learning</u>. According to Gentner (1999), an analogy is a similarity in which the same relations hold between different domains or systems. Others (Duit 1991, Dagher

1994) consider analogy more broadly as the transfer of elements, structures, or relations between different domains.

A number of mechanisms have been proposed as being involved in learning through analogy. Duit (1990) sees analogies as being important in the generation of schemata during learning. A related view holds that analogies are important in helping students develop initial models which they can later improve (Glynn 1995, 1997). Analogies can allow the learner to build on relationships already in prior knowledge rather than starting a model from scratch. Some of these relationships may be represented in concrete images or simulations. (Clement and Steinberg 2002). On the other hand, when learning is about abstract concepts for which both analogs serve as examples, analogies may act as “abstraction tools,” allowing learners to see higher-order relations (Gick and Holyoak, 1983) However, this "abstract transfer" and model construction are seen as different processes by Brown and Clement (1989), who suggested that analogies may be used to enrich the target rather than to distill it to its abstract properties.

An important question about analogies concerns the degree of cognitive change that can be gained through their use. Stavy's (1991) research suggested that analogy can be useful in conceptual change, countering a misconception of difference between phenomena that are actually identical. Brown and Clement (1989) were able to overcome a strongly-held misconception via the use of analogies but found that the process required multiple analogies to help the subject see analogical connections, with no single analogy providing a conceptual breakthrough. Dagher (1994) suggested that analogies can contribute to conceptual change but are more likely to produce gradual change in conceptions than the sudden "ontological shift" of early conceptual change theory. Treagust and Venville (1995) also see it as important to look at the role of analogies in “everyday” learning as opposed to radical conceptual change.

It has also been proposed that analogies serve functions other than extension of knowledge to an unfamiliar domain. Duit (1990), for example, suggests that analogies serve to activate visual imagery. Other possible effects include increasing the memorability of new knowledge (Wong 1993), influencing motivational and affective aspects of learning (Dagher 1994, Gowan 1993, cited in Duit 1990), and activating learners' creativity (Dagher 1994). Dagher (1994) has also suggested that learning through analogies may help students understand the processes of inquiry and model building in science. Treagust and Venville (1995) see some analogies as “transformers,” tools that help learners change concepts from “things” to processes.

Terminology. A number of different terms have been used to describe analogy components. We will use the term base for the part of the analogy that is used as the source of new knowledge and target for the knowledge to be acquired, as in Glynn’s work (1995, 1997). We use the word mapping to describe the process by which transfer from base is made. We also adopt Gentner’s (1989) idea that analogs share both elemental and relational similarities, and so will use the term element to describe single pieces of the base that can be mapped to the target, and relations to describe interactions or functions involving these elements. For example, the familiar analogy in which an eye is compared to a camera contains both the elemental similarities of a circular opening and a surface on which an image is projected and relational similarity in that light enters the opening and forms the projected image.

Instructional analogies - characteristics and effectiveness. This paper will concern instructional analogies, non- spontaneous analogies used by a teacher in a formal educational setting. Delivery methods for instructional analogies include text, pictures or drawings, oral explanations and/or discussion, or some combination of these (Curtis and Riegeluth 1987). Studies of instructional analogies have tended to concentrate on those delivered in the form of text, perhaps because of the complications in studying complex delivery methods noted by Yanowitz (2001).

Instructional analogies have been characterized by features that may influence learning. Thiele and Traegust (1995) noted that analogies differ in their “extent of mapping.” Curtis and Riegeluth (1987) studied more than 200 analogies in science textbooks, classifying them according to presentation format, whether they communicate structural or functional features of the target, simplicity/complexity, position in text, concreteness/abstractness, and level of explication or "enrichment." Another way of characterizing analogies is by the degree of similarity of the analogs, with those that share many features being described as "near" and those which share few being described as "far" (Gentner, 1989). Both Gentner and Curtis and Riegeluth have suggested that some analogy features are associated with greater analogy effectiveness. Gentner, for example, considers far analogies to be more likely to result in learning because learners attend to them better. Others state a clear preference for analogies in which the base is already familiar to students (Goswami 1992) or is made familiar by explanation or experience (Stavy 1991). Curtis and Riegeluth (1987) rated their text analogies in a three-level hierarchy according to whether they shared "structural" similarities, functional attributes, or both. Although some of the psychological work on analogies has provided evidence to support the idea that some analogy characteristics make them function better than others as learning tools, the above discussion on analogy types identifies a number of different ways in which analogies vary.

FRAMEWORK

In this study, we analyze a subset of the analogies in the *Energy in the Human Body* curriculum for features that characterize them. The features we chose to look at were near vs far, simple vs complex, familiar vs unfamiliar, and visual /structural vs functional. These will be defined more fully in the following section. We also look at analogy position, where each analogy comes in relation to other methods in a unit. We then analyze evidence of student learning following the use of analogies to determine analogy success and to characterize the types of errors made by students in their attempts to learn by analogy. Finally, we attempt to infer connections between analogy features and the types of difficulties students show in learning by analogy, and develop curriculum revision recommendations and suggested teaching strategies.

METHODS

The *Energy in the Human Body* curriculum was developed through a series of tutoring interviews and a small-group teaching trial. It is now in its third year of trials in seventh-grade classrooms in western New England. A total of five teachers have participated in the trials. Two of the participating teachers have participated in the study for all three years. Trials have been located in urban, suburban, and rural areas and in towns varying in income and other socioeconomic indicators. This study will be focused primarily on data from one of the schools, a regional middle school in a rural area of western Massachusetts

. Students come primarily from poor and working-class families. The school is an inclusion school with the proportion of special education students varying from class to class and sometimes reaching as high as 30%. Students are approximately 90% white. Slightly over 30% of the students come from families with incomes qualifying them to receive free or reduced price school lunches. Approximately 35% of high school graduates in the district plan to attend a four-year college, as opposed to approximately 54% statewide (Massachusetts Department of Education, 2003). The teacher in the classroom has more than ten years of teaching experience and has participated in the trials since their inception. Teacher training included yearly four-day summer workshops, a one-day meeting during the school year, an extensive teachers' manual, and occasional discussions with research staff.

Data sources for this study include classroom observations, informal discussions with teachers and students, formative assessments, student interviews, and analysis of students' classroom work. Classroom observations were recorded in the form of notes and occasional video- and audio-taping. Formative assessments include pre- and post-analogy assessments, student homework, and quizzes. In addition, we administered one assessment that was designed to elicit students' ideas about analogies.

Approximately a dozen analogies are included in the curriculum. Key mappings and general goals of eight of these are summarized in Table 1. Table 2 shows our analysis of these according to five features that characterize them and which we believe may be important in learning. Although we have not attempted to define with precision exactly where each analogy falls along our spectra or dimensions, we see all but the visual vs functional dimension as a continuum. Our spectra are defined as follows.

Near vs. far: Analogies which share more object and/or relational similarities in Gentner's (1989) sense are "near," analogies which are dissimilar are "far."

Simple vs. complex: base to target comparisons in which only one or two elements or relations map to the target are simple analogies. Complex analogies are more elaborate analogies, with a number of elements and/or relations transferred.

Familiar vs. unfamiliar: Analogies may differ in the extent to which students are familiar with the elements of the base that are intended to map to the target.

Visual vs. functional: Some analogies are meant to help students understand what a target looks like, possibly including geometric structure, while others are meant to illustrate what it does or how its elements relate to each other. Some analogies serve both purposes.

Position: Analogies may be presented at the very beginning of a new topic or after other types of experiences. In addition, the curriculum sometimes uses multiple analogies in conjunction with each other.

In this study, we assessed four of our analogies for effectiveness by examining both error type and frequency and student understanding of specific target content areas. The analogies represent a range of types on our spectra. Two linked analogies for the structure and function of blood vessels, the river delta analogy and the water pipes analogy, will be used as a primary case study and examined in detail. Three other analogies, the ear of corn analogy, the school analogy, and the fire analogy will be discussed more briefly. We have both pre and post data for the circulatory and ear of corn analogies. We were able to give only post-analogy assessments for the remaining analogies, but generally find that students have little knowledge of the topics featured in these analogies before receiving instruction. Student number varies depending on the assessment and ranges from 28 to 78. Content understanding was assessed through open-response questions or drawings, and error types and frequency were assessed by asking

Table 1. Examples of analogies used in the "Energy in the Human Body" curriculum

Analogy	Primary mapping (s)	Summary
Car analogy	Fluids added to car repeatedly → things that people need continuously	We need food for energy in the same way that cars need gas for energy. We also need sleep, water, and exercise, but we do not need them for energy. This is similar to a car, which needs oil and water for other things but not for energy.
Ear of corn analogy	Kernels in ear of corn → cells in body	The arrangement of kernels in an ear of corn is like the arrangement of cells in the body - both are patterned with little space in between.
School analogy	School parts → cell parts	The functions of some school parts are similar to the functions of some cell parts. For example, the nucleus controls the cell in a way similar to the way the office controls a school.
Popper analogy	Energy contained in party popper → energy contained in ATP	A party popper contains energy which can later be released in the same way that ATP/mitochondria contain energy that can be released
Fire analogy	Fire inputs and outputs → mitochondria inputs and outputs	A fire consumes O_2 and fuel and releases energy, CO_2 and water. Mitochondria obtain energy from glucose using O_2, with CO_2 and water as wastes.
River delta analogy	River delta branches → artery branches	A river branches into many smaller branches in a way that is similar to the way blood vessels branch into smaller vessels after leaving the heart
Water/sewer pipes analogy	Water pipes and wastewater pipes → vessels going to cell with needed elements and taking wastes away	Branching water pipes in a city bring water to houses. Wastewater leaves through different pipes. Blood brings needed elements to cells through branching vessels, and waste is taken away by different vessels.
Grape analogy	Grapes in a bunch → clusters of alveoli in the lungs	The arrangement of grapes and their stems is similar to the arrangement of alveoli and bronchial tubes in the lungs

Table 2. Characteristics of principle analogies used in the *Energy in the Human Body* curriculum.

Analogy	Near vs far	Simple vs complex	Familiar vs unfamiliar	Visual vs functional	Position
Car analogy	Intermediate (some shared attributes)	intermediate	Intermediate (unfamiliar elements of familiar base)	Functional	Near end of instructional sequence
Ear of corn analogy	far	simple	Becomes familiar through hands-on examination	Visual	Near beginning
School analogy	far	complex	familiar	Functional	Near beginning
Fire analogy	Near/intermediate	complex	Unfamiliar elements of familiar base	Functional	Intermediate
Popper analogy	far	intermediate	Becomes somewhat familiar	Functional	Intermediate
River delta analogy	Intermediate	Simple	Intermediate	Primarily visual, some functional	Intemediate
Water/sewer pipes analogy	Intermediate	Intermediate →complex	Intermediat	Visual and functional	Intermediate
Grape analogy	Far	Simple	Familiar	Visual	Intermediate

students to map the analogies and to describe similarities and dissimilarities between base and target. Errors were classified as follows:

1. "Overmapping" – Transfer of a feature (element or relation) from the base to the target that is not a feature of the target.. For example, students generated a large number of features of the ear of corn such as color, hardness, and attachment to a base that they listed as similarities to the cell.
2. "Mismapping" – Incorrect or inappropriate transfer. This may occur when a base feature is mapped to a target feature other than the intended one. For example, in the school analogy students appeared to have been mixed up about which organelle mapped to which base feature. Numerous confusions appeared to occur in students attempting to understand the fire analogy. Some students, for example, thought that oxygen is both consumed and produced by a fire and the cell. Others seemed to confuse inputs and outputs, seeing carbon dioxide as something that is used rather than produced by the cell and the fire. In a particularly striking mismap, a student in one of the schools cried out during processing of the fire analogy: "I know why they need the water! To put out the fire!" This student appeared to have understood the fire analogy as meaning that a miniature fire is present in the cell, and had inferred that the water produce by the cell in cellular respiration had a purpose.
3. Failure to map – We see failure to map as the lack of transfer of a mappable base feature. For example, the majority of students failed to transfer water produced by the fire to the mitochondria. These students thus could not name water as a product of cellular respiration.
4. Retention of a base feature – Sometimes students seem to retain base features or relations when they draw or describe targets. For example, we have had students describe the endoplasmic reticulum of the cells as the "hallways" rather than naming the function they both share – a place for movement of things from one place to another. In another example, teachers sometimes used other analogies spontaneously in explaining organelle functions to students. One teacher described the mitochondria variously as the cafeteria (our analogy), and as like pizza. We found that a number of students retained pizza as their image of what the mitochondria actually looked like. While we are not certain that students actually believe that there are pizza or hallways in cells, we do believe that their confusion is real. They have not transitioned from the base analog to the desired feature of the target.

FINDINGS

The analysis of each analogy will be comprised of:
- A description of the analogy, its instructional goals, and a rationale for the placement of each analogy along the spectra summarized in Table 2
- A brief discussion of the place of the analogy in the curriculum and the classroom presentation of the analogy(-ies).
- Qualitative and, when possible, quantitative data on the understandings gained by students as a result of the analogy and accompanying activities
- An analysis of the types of errors made by students

Primary Case Study: River Delta and Water Pipes Analogies for the Structure and Function of the Circulatory System

<u>Description of analogies, location in curriculum, and placement on spectra</u>: The river delta analogy helps students build a model of the vessels leaving the heart as branching into smaller and smaller vessels in the same way that a river divides into smaller and smaller channels as it reaches the sea. The water pipes analogy asks students to develop an idea of how water gets from a reservoir to their house, through the streets and to each room. Students are also asked how wastewater from cooking, washing, etc., gets away from their house. This analogy reinforces the idea of branching and also helps students visualize a "way back" to the heart. The river delta and water pipes analogies are two analogies presented in succession fairly near the beginning of the unit on the structure and function of the vessels of the circulatory system. These analogies

follow students' initial drawings of their ideas of how the glucose and oxygen get to a cell in the big toe, their discussions of these drawings in small and large group, comparisons of their own veins and arteries, and viewing of animations that shows the circulatory system in action. The purpose of the analogies was to firm up and deepen the understandings that some of the students may have gained from the video and to make certain that students who had not followed the fairly dense and fast-paced animation also gained these three important understandings.

The river delta analogy is simple and visual in that it is meant to give students an image of large branches leading to successively smaller branches that they can transfer to develop an image of arteries that branch to smaller and smaller vessels as they leave the heart and go toward the cells. We have classified it as intermediate on the near → far spectrum because it has some of what Gentner might call "surface similarities" to blood vessels, in that liquids are carried by both branching rivers and branching vessels.

The water pipes analogy is presented immediately after the river delta analogy. It is much richer than the river delta analogy, building on the visual image transferred from the river delta and supplementing it with other structural images and with information about circulatory system function. In this analogy student groups were asked to draw a group model of how water would get from a central reservoir to an individual house and to the rooms in that house. They were also asked to draw the way wastewater would leave the house. Understandings we identified that students might be able to transfer from this analogy included:

- Both water pipes and arteries bring something needed to a location (room in house or cell)
- Wastewater pipes and veins bring waste away
- Vessels branch, and they branch from big to small. This is so they can get from a large main source to many small specific locations. This reinforces river delta analogy and adds functional and relational components to it.
- Pipes/vessels that carry "good" and "bad" material are separate because otherwise waste and needed elements would mix

As students drew their models in small group, it was noted that all groups visited developed the first three concepts listed above but only a few had developed the fourth, the idea that pipes carrying the different types of water would have to be separated. A few groups in each class were asked what would happen if the wastewater went out into the same pipe as the clean water coming in so that this understanding would be part of the whole-class discussion. These groups immediately changed their models and explained this feature in their presentation to the whole class. Thus the base required development in this analogy and the students participated actively in this development.

Two activities followed the sharing of group water pipe models and preceded the post test. First, student groups used pasta of different sizes (from manicotti to angel hair!) to build small group models of what they think the vessels look like as they go from the heart to an extremity – hand or foot. Observations suggested that the water pipes analogy had been partially but not completely successful, in that all student groups showed some branching but only approximately half of the groups had a gradual progression from large, to medium, to smaller and smaller sizes Groups that did not have a gradual transition in size went from large pasta to small pieces that branched out to occupy the extremity. In most cases these groups also had some small branches that left the large vessel as it traveled from the heart to the extremity, but they had failed to transfer the understanding that most groups had seemed to display so readily when they worked together to draw water pipes – that large pipes would carry large volumes, and smaller pipes would branch off of these to streets, and still smaller to houses and rooms in houses.

A second pasta model differed even more significantly from the water pipes and river delta analogies and from the understanding that we wished the students to gain. In their model, students placed alternated large pieces with small throughout the body, placing the larger sizes where, apparently, they believed that more branching would occur to supply other parts of the body. When questioned as to how this model was similar to the water pipes analogy, the students seemed puzzled. They were then asked what would happen to a small vessel that was next to a large vessel that came straight from the heart, one of the students immediately replied “it would blow up!”

Teachers began the next class period with the understanding that students had not all successfully mapped all relevant elements of the water pipes and river delta to the vessels leaving the heart. In this class, teachers followed this activity by asking students to compare the three pasta models, represented as actual vessels, that are described above - the target model with a gradual transition and the two alternative models. The models were drawn and described for the students and then students were asked to vote on the models. Between 80 and 92% of students, depending on the class, voted for the “correct” model. The teacher then asked students to critique the model with large and small pasta alternating. Students contributed ideas such as the idea that the volume of blood going from the large to the succeeding small vessel would be too much for the small vessel, and that when another large vessel followed there would not be enough blood to fill it. Others suggested that there would be a problem with speed – the blood would slow down so much in the first set of small vessels that it would not be able to make it through the entire body. With prompting from the teacher, students in two of the three classes also seemed to be able to see that pressure would also be a problem – that pressure on the walls of the first small vessels would cause them to burst if they were too close to the powerful heart. As will be described below, this activity seemed to produce an active discussion indicating some important increases in learning. A considerable portion of the understanding students gained thus came from exploring the target through reasoning and dialogue rather than through analogical transfer.

What went wrong with the analogies, and why was the correction described above necessary? Teachers described both the river delta and the water pipes analogies explicitly to students, explaining carefully that both went from large, to smaller, to very small; and then adding that in the human body the smallest branches are so small that we need a microscope to see them. We think it is possible that transfer might have been greater if teachers and students had explicitly mapped the portions of both analogies that provide explanatory power, a functional basis for the structures observed. This could have been done by asking students to vote on and discuss ill-designed alternatives to the standard water pipe model, in the same way this was done for the blood stream. This relationship could then have been mapped explicitly from base to target. Our formative observations suggests that explicitly mapping the relations in the pipes analogy – the ways in which water flows through the pipes – rather than just the elements, the pipes themselves, would have been helpful.

Pre/post assessment results: An assessment given to each student followed the large group model critique described above and thus serves as a way of evaluating a succession of activities related to the analogy and its interpretation. The pre-assessment was given to all students immediately preceding presentation of the river delta analogy. The assessment asked students to draw their idea of how blood gets from the heart to the big toe and describe what happens to it after it gets to the big toe. A third question on the post-test asks students to list similarities between the water pipes and the vessels of the body.

Table 3. Understandings of circulatory system structure shown by students prior to and post-instruction via analogies, model-building and small and large-group discussion of different models.

Concept	**Pre % correct**	**Post % correct**	**% gain**
Vessels branch	41.3	100	58.7
Branching is from large vessels to small vessels	32.6	78.2	45.6
Blood returns to the heart after leaving the toe	52.2	90.9	38.7

We conclude that the analogies and succeeding activities were highly successful. The major error we saw during analogy use is what we have named before as “failure to map,” the lack of transfer of a base feature to the target. As discussed above, some students failed to transfer the idea of large- to -small branching from the pipes to the vessels.

Students asked to list things that were similar about the water pipes and the vessels in the human body mapped more things than we could ever have envisioned, and did so correctly. The average number of features mapped slightly greater than two, but a number of students made as many as five appropriate maps and collectively students were able to make a total of 13 useful mappings. These included visual features such as the shape of pipes/vessels (round), the length of the total system (both are very long laid end to end) but also ranged through more functional features such as cyclicality (students mentioned the water cycle), and the common existence of a source or pump. There were very few inappropriate maps.

Discussion: This is a highly successful set of activities in that two of the understandings we wished students to achieve, the idea that vessels branch as they leave the heart, and that this branching must be from big to small, were achieved by the overwhelming majority of students. This is in contrast to some of the analogies that will be described below, analogies that produced far lower gains in target understandings. In this paper we are not attempting to make strong implications about a probable cause in a controlled experiment, but rather, in the spirit of an exploratory case study, we are attempting to generate insightful hypotheses about mechanisms that can explain the observed effects.

The features of the analogy and the context in which this analogy was presented can be used to help explain both the errors that we did see and the final gains in understanding .The difficultiy in mapping functional relations could be explained as follows. We described the pipes analogy on the complexity dimension as intermediate→complex. It may be that there are two levels of complexity. The students seemed to be able to reason fairly fluently about the geometric structure of the water pipes for distribution purposes and the one way flow within them. However, higher level relationships such as pressure and velocity are much more complex and abstract. Understanding and transferring these features is a much taller order, possibly even for most teachers. This motivates us to think much more carefully in the future not only about teaching strategy here, but about what feasible aspects of the target model and content goals are at this age level. We are encouraged, however, that these students could reason about a geomentric/functional relations at the intermediate level of complexity.

However, both base analogs are fairly familiar to students at the level of geometric distribution and can be easily visualized. This may help explain why students could discuss these analogies and make knowledge gains. Little explanation of base features and relations is required at this level. Second, the target itself is already partially-developed and somewhat familiar to students. Although our pre-assessment showed that a significant proportion of students lacked our target understandings in some areas, the students had already been through activities such as feeling their pulses, looking at their veins, and watching the animations, that gave them some familiarity with vessel structure and function. In addition, it seems likely that most seventh-grade students know something about blood vessels from prior experiences in school and in their daily lives. They may thus be able to make logic checks on potential mappings from base to target, limiting the tendency to transfer base features inappropriately.

Second, we can not separate out the effects of the two analogies, and consider them synergistic. This makes it somewhat difficult to identify analogy features that may have influenced their effectiveness. But we would suggest that having dual analogies was, in this case, useful, and that the familiarity of both bases and the relative familiarity of the target was a plus. The pipes analogy may act as a bridging analogy between more familiar but more distant river analogy and the target (Clement, 1983).

Third, the water pipe analogy was extremely fertile, in that we identified four or five features that mapped and students identified an additional eight correct mappings. This high degree of mapping is also a feature of analogies that has been discussed as a factor that may influence analogy effectiveness. We are encouraged that the students were able to reason in this way.

Secondary case study 1. Ear of corn analogy

The ear of corn analogy is placed near the beginning of the unit on cells, immediately after an activity in which students draw their views of what a thin section of their body would look like if they could look at it under a powerful microscope. In the analogy, students are asked to look at an ear of Indian corn or field corn and then draw and describe the pattern they see. Students are specifically instructed to look at the arrangement of the kernels and not to attend to other features of the kernels such as color and hardness. They are then asked to draw what they believe the cells of their body would look like if they were arranged similarly to the kernels in an ear of corn. The purpose of the analogy is to help students develop a model of cells as being arranged contiguously rather than with space between them. Prior research has shown that many students' initial models are of widely separated cells.

We have classified the ear of corn analogy as a far analogy because it shares few surface similarities with cells and as a visual analogy because its intention is to give students an image of what cells look like. We consider it to be our simplest analogy in that only one feature of the ear of corn is to be transferred – the arrangement of the kernels. We classify it as a familiar analogy because if students are not already familiar with the arrangement of corn kernels, they become so after inspecting an ear.

Data for formative assessment of the corn analogy included a pre/post analogy assessment and classroom observations. The ear of corn activity was followed by a development of a consensus drawing in small groups and by sharing and discussion of these models in the whole class.

Table 4. Students' ideas about the arrangement of cells in the body pre- and post- instruction. Instructional methods include the ear of corn analogy and small- and large-group discussion.

Concept	**Pre %**	**Post %**	**change**
Cells arranged closely, with little or no space between them	52.4	72.5	+ 20.1
Cells separated	33.3	14.5	- 18.8
Drawing unclear	14.3	13.1	- 1.2

Pre/post assessments asked students to draw their idea of what a thin slice of the body would look like if they could see it under a microscope. The post test also asked students to list similarities and differences between the ear of corn and cells in the body. Post results (Table 4) show some improvement in students' drawings, with a 20% gain in students who showed the cells as arranged contiguously (Table 4). A fairly large number of students produced drawings that could not be interpreted. In most of these drawings there is no clear indication that students are able to draw something that we can recognize as a cell.

As in the circulatory system analogies, we have some evidence from observations to suggest that discussion in small- and, perhaps more importantly, large group, contributed to the change in student drawings. Initial small group drawings varied greatly, with only two or three of the six representing our target model of closely-packed groups of cells. The discussion that accompanied students' sharing of drawings developed in small groups involved some discussion of reasons why cells would function more effectively if arranged contiguously. For example, a teacher asked students what would happen if he poked a fellow student and his cells were far apart. A student in one of the classes, noticing that some students had drawn cells in chains rather thanin contiguous groups, offered that cells could not be attached only in chains because they would come apart, “like a bead curtain.” We took this as evidence that she was engaged in some impressive visual model construction processes, and that she was making her own inferences from these models.

A considerable number of errors were seen in students’ lists of similarities between analogs. Most of these were what we call “overmaps” – attempts to find features in the target which are legitimate features of the base but not of the target. For example, a number of students drew cells in single chains and described them as “lined up in rows.” This seems to be a mapping of the linear arrangement of corn kernels. Other students listed such characteristics as “dark on the outside and “light on the inside, “They have the same shape and size,” “We both have a hard shell,” and “They both have small indentations.” These are both attempts to transfer corn attributes that cells do not possess and failures to list the similarity that we wished students to see. This is despite the book’s and their teachers’ admonitions to look only at the arrangement of the kernels and not at such things as color and hardness. This suggests that, for some students, even simple analogies are not so simple, that it is hard for some students to follow all the steps involved in their processing. Another possibility is that since cells and tissue are very unfamiliar structures for these students, they had fewer clues to go on for which mappings were relevant.

Secondary case study 2. School analogy

The school analogy compares functions of the main office, the trash receptacles, the cafeteria, the classrooms, the hallways, and the walls of a school to the functions of the nucleus, lysosomes, mitochondria, Golgi bodies, endoplasmic reticulum, and cell membrane of the cell. It establishes the expectation that just as a school is divided into places that have functions, the cell will be composed of smaller parts that have varying functions. The school analogy comes after the curriculum has established that the body is made of cells but serves as students’ initial exposure to the idea that cells have parts. We classify the school analogy as far, functional, and familiar. We consider it to be complex because it has a total of six features that map. We were unable to collect pre-analogy data on students’ ideas about organelles, but know from a student homework assignment that fewer than ten students had studied cells before in school. We also observed that only a few drew a nucleus when asked to draw cells. We therefore had no expectation that they would have any elaborated ideas about structures inside cells.

We have two years of post-assessments on this analogy. In the first year of our assesment, 66.6% of a subsample of students were able to identify the functions of all six organelles correctly on the post-assessment. Of the remaining group, most failed to map one or two items from the base to the target. One student in this group identified the school parts as cell functions, most likely out of confusion or inattention rather than belief. Data from our second year of assessment shows that students have good but not perfect recall of mapping in a quiz given approximately two weeks after instruction. 56% remembered school analogues for all six organelles, and the remaining 44% remembered at least three. Students tended to exchange ones they did not remember correctly, identifying Golgi bodies as like the trash bin in a school, for example. A survey of a range of student work, however, does suggest that for some students transitioning from the school parts and functions to cell functions and finally to a visual model which includes images of cell organelles proves difficult. We see base elements in target models quite frequently in student workbooks. This means students are learning to separate the model from the base only gradually and that this takes work. This is a complex analogy and we might expect students to have some trouble with it. Thus in this successful analogy we still see errors. We do not see the overmapping we might predict as a danger of a familiar analogy, but the logistics of this particular analogy make that unlikely – students would not be likely to invent an organelle.

Secondary case study 3. Fire analogy

In the fire analogy teachers first introduce the fire inputs oxygen and wood are mapped to mitochondrial inputs oxygen and glucose. Fire products carbon dioxide, water, and energy are mapped to identical outputs in the mitochondria. Although students are familiar with fires, the analogy elements we use are unfamiliar to students. We acknowledge that most of those who write about analogies assume that the base must be familiar to students, almost by definition (Goswami 1992), but we also think that a reading of the literature shows that many base analogs must be carefully explained to students.

We consider the fire a near analogy because so many analog features are identical, and in fact it shares similarities with analogies such as Stavy's (1991) conservation of matter analogy in which both analogs are examples of an identical or at least similar phenomenon. In this case, however, the analogy is not meant to help students understand a more abstract concept but to make the quite conceptually-difficult idea of the chemical changes that go on in the mitochondria more accessible to students than they might otherwise be. The analogy is also functional, in that it conveys information about the processes that occur in the mitochondria, and complex because of its large number of mappable elements and relations. In our trial this year, the fire analogy was presented after some more traditional-mode teaching of mitochondrial function, so it can be viewed as an analogy intended to make understanding more salient or deeper rather than one that introduces new ideas.

We were unable to assess understanding prior to the exploration. Post-analogy assessment results are presented in Table 5. Results represent the percent of students who were able to depict both base and target elements and connect them appropriately. Students were clearly less successful at mapping this analogy than they were at some of our other analogies. Student drawings suggested that students were confused, and many students included large question marks in their drawings.

Table 5. Elements mapped correctly from fire to the mitochondria in a post-assessment of the fire analogy.

	Oxygen	Fuel (food, glucose, fuel)	energy	Carbon dioxide	Water
% students mapping correctly	40.3	74.6	65.7	47.8	32.8

10.4% of students were unable to map a single item correctly. 44.8% remembered neither carbon dioxide nor water as outputs, and thus had no waste products for cellular respiration. This is significant in light of the fact that without waste products, particularly carbon dioxide, the student's conception of the circulatory and pulmonary systems is missing half of its function. Most of the errors students made could be classified as "failure to map" – inability to transfer an element that was understood in the base to the target, but students also appeared to have failed to understand the base completely. A number of students, for example, failed to include water as an output in the fire. We also saw a large number of "mismaps," misunderstandings of elements and relations so that inputs were labeled as outputs and vice versa. The majority of students, however, did seem to understand the fuel and energy aspects of the analogy. When asked in a separate question about what the energy sources of the fire and mitochondria are, nearly 75% were able to name these.

We thus have some evidence that elements of the base that students are more familiar with – fuel and energy – were recalled by more students. The gases carbon dioxide and oxygen were recalled by fewer. It comes as somewhat of a surprise that similar numbers of students recalled both CO_2 and O_2, because observations from classroom dialogue and interactions with students suggest that many if not most students were aware of a fire's need for oxygen. A classroom activity in which students extinguished a candle by putting a jar over it was a part of the unit.

We consider the student confusion evident in our assessment of this analogy to be a product of its unfamiliarity and complexity. We must also acknowledge, however, that this analogy is conceptually difficult in that it contains concepts such as chemical change. As in the other analogies, the teacher in this classroom attempted to follow the analogy with other activities that would give students a reasoning-based understanding of the target. For example, he had students construct a gumdrop model of the glucose molecule and then break it apart to produce CO_2 and water molecules. Observations suggest that many students had difficulty understanding this activity, however.

GENERAL DISCUSSION

First, we have to say that all analogies we have used have been successes in that pre/post assessments show considerable improvement in student understanding of our target concepts. Identification of error types and attempts to determine why some seem to be more successful than others is, however, an important part of our formative assessment of our curriculum. We have been able to identify features of our analogies that differentiate them from one another and have seen differences in student understanding with four of them. We have also seen different types of errors with different analogies. In the highly-familiar corn analogy, for example, overgeneration and subsequent overmapping of base features was a clear danger. In complex analogies such as the school and the fire, students may have had difficulty keeping track of features and thus failed to map some and mismapped others. In the unfamiliar and also conceptually-difficult fire analogy students may have made mapping errors because they did not understand and could not recall important features of the base. Retention of base features was an error we saw more rarely, but our evidence from the school analogy, where we saw this most often, suggests that this is most likely to occur when a complex target is not developed enough for students to adopt it and leave the analogy behind. We think it is also possible that the school analogy is sufficiently compelling that it is hard for students to leave behind.

Curtis and Riegeluth suggested that analogies which convey both structural and functional information are superior to those which convey functional information, with purely visual or structural analogies being the least desirable. While we can not confirm this hypothesis, it is interesting to note that our most successful analogy, the water pipes analogy, did contain both types of information. We have seen some student-drawn images that represent functions with the actual image of structures, however, and must note that the two types of information – structural and functional – have not been identified explicitly for students. Making the cognitive purposes of each analogy more explicit might be useful in this case.

Our analysis has suggested to us ways in which our initial table of analogy features was limited, however. We find it hard to make clear connections between analogy features and error type for several reasons. First, we have identified five dimensions along which analogies vary and others have identified more. It is thus virtually impossible, in considering a limited number of practical analogies for the classroom, to isolate any one analogy variable and use it to predict error type. Second, our analysis has led us to suspect that target features are very important. Both target familiarity and accessibility to reasoning processes seem to influence understanding in the students we have been observing. We suggest that students can perform “reality checks” on potential maps when they have some understanding of the target that is independent of the analogy. When these are absent, as when the corn analogy was introduced before students had much if any idea of what a cell was, inappropriate mappings may become common.

Lastly, we believe it is important to understand the context in which an analogy is presented to understand how it works. Our analogies have not served simply as beginning models that are then revised, their role has been more complex. Most are embedded in a complex matrix of other types of learning, prior conceptions, and the reasoning that occurs during the processing of the analogy. This has made our assessment difficult, because we are seldom assessing the isolated effects of the analogy itself. In our observations and in the changes we see occurring in pre and post assessments, we believe we see evidence of changes in students' models that occur partly through analogical transfer and partly through other means. We have not addressed the area of variability in students' responses to analogies thus far in our discussion, but in some analogies students' understanding has varied enormously. In the fire analogy, for example, nearly as many students were able to map all the elements in the analogy as were able to map none. Our experience with the classroom use of analogies is thus that they are part of a model development and revision process that occurs through a complex mix of learning experiences and which may occur in different ways for different students.

IMPLICATIONS

This paper is not about whether analogies work but about how to make them work. As Dagher (1995) has pointed out, prior research suggests that complex instructional analogies needed to be presented with extensive direction from teachers. Glynn (1991), for example, has developed a six-step "teaching-with-analogies" model that includes introducing base and target, mapping similarities, and looking at where comparisons break down. Our analysis of student errors has led us to revise the curriculum to include structured approaches to teaching with analogies, including some of Glynn's steps and comparison tables such as those described in Bulgren et al. (2000). In reasoning-centered curricula, though, we see a tension between openness to students' ideas and the highly-structured, teacher-centered method that most teachers use to present analogies. This has been a difficult balance for our participating teachers to negotiate, and we run the risk of excessive student passivity in the more teacher-driven portions of the curriculum. We feel that a solution may lie in a curriculum approach that is more explicitly centered around a model generation, evaluation, and revision pedagogy. In this framework, analogies may be seen as initiating a revisable model that is suggested to students when they cannot generate their own models or, alternatively, as a way of refining and deepening models developed in other ways. This suggests that invoking students' metacognitive awareness of the processes involved in model criticism and revision may be important for developing students' abilities to use analogies effectively. Material for doing this may come from the students themselves. We found that some students were able to reflect on the processes they use to understand analogies, saying such things as "you have to pay attention so you don't get confused." Finding ways of extending insights from these students to others might be a way of reducing the variability in students' success with analogies. In addition, it is worth noting that students in the classroom we studied use spontaneous analogies extensively in classroom conversations. We would like to think about ways students' natural analogizing could be used to help them understand the more structured and complex analogies teachers give them.

CONCLUSIONS

We began this paper with the question: Should different kinds of analogies be treated differently in instruction? We and others have identified ways in which instructional analogies vary, and we have also identified instances where some error types are associated with some analogy features. Our observations also suggest, however, that learning through analogy can be a complex process, even when a particular analogy seems very simple. For the middle-school students we have been observing, learning through formal analogies is a new experience, and we believe that their needs are best served when teachers and curriculum developers establish a consistent protocol for presenting, processing, and applying the knowledge that is contained in instructional analogies. This protocol might be similar to those suggested by other authors (Glynn, Bulgren) and would involve establishing familiarity with the base, identifying the target and establishing grounds for comparison, mapping the base to the target, confirming understanding of target knowledge, establishing the limits of mapping, applying the knowledge, and then moving on to complete students' mental models using other techniques. We suggest that analogies are complex and may not be effective if used without thoughtful preparation, particularly when an analogy uses a base that is familiar to students before instruction begins or is complex in terms of the number of mappable and unmappable elements and relations. Such differences may affect the amount of work in analogy processing that needs to be carried by students. We therefore suggest that teachers may need to allow more time for those phases that emphasize features that are identified as difficult in a particular analogy, such as spending more time on the "negative analogy" – the parts of the base that cannot be mapped --when the base is familiar and the target is very unfamiliar.

The present results are case study results from a single classroom. For various reasons, teachers will not always be able to implement recommended teaching strategies for using analogies in the curriculum. More detailed case studies of classroom analogy use are very much needed, in order to study the effect of large and small group interactions, and the teacher's effect on these, while using analogies. Tactics for leading discussions of analogies that operate at a moment to moment level may be very important in fostering productive discussions. We need to understand and provide more information to teachers about these tactics.

There are thus many factors that can influence learning and complicate the study of analogies in the classroom. We believe that future research will need to use a number of different research methodologies to examine these in order to expand and further refine our understanding in this area.

We suggest that it is necessary to build teachers' understanding of the ways in which analogies are understood by students by building formative assessment into designed curricula such as *Energy in the Human Body*. We also suggest that building students' metacognitive awarenesses and abilities is critical in the model-centered approach we emphasize. The protocols that we and others have suggested should help students develop some types of metacognitive awareness during the processing of analogies, but we also believe that students need to develop broader types of awareness of their own learning processes. Because analogies are mingled with other types of learning, they need to understand the special approach to learning that is required in using an analogy.

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Observations from a Middle-School Life Science Curriculum. Article. Jan 2003.Â This study compares the use of form and function analogy object boxes to more traditional lecture and worksheet instruction during a 10th-grade unit on human body systems. The study was conducted with two classes (N= 32) of mixed ability students at a high-needs rural high school in central New York State. The study used a pretest/posttest design, in which the two classes alternated between conditions for the four systems (skeletal, digestive, immune, nervous). Both conditions involved students in quality instruction addressing the same concepts for the same amount of time. Additionally, all students participated in hands-on labs. Curriculum and instruction are the meat of the educational process. Real change in education comes with changes in the content that teachers teach and students learn, and in the instructional methods that teachers use.Â To obtain a richer picture of the types of standards being developed by states across content domains, the committee examined more closely the content standards documents developed by seven states that represent both early and more recent developers of content standards, as well a regional mix.1 We looked at standards documents to get a sense of whether they were strictly academic or.Â Post-school outcomes, curriculum, and instruction in special education. Although there are several types of observational procedures or techniques that have been used to examine effective teaching (e.g., charts, rating scales, checklists, and narrative descriptions), the most widely used procedure or research method has been systematic classroom observation based on interactive coding systems.Â Several studies, such as that of Elizabeth Fennema and Penelope Peterson, have found that some groups or types of students are treated differently by teachers inÂ They also found that students from an upper-middle-class elementary school asked more questions than students from lower-middle-class schools.Â Similarly, classroom observations should not be tied to summative decisions like salary increases.