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About This Issue

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Analogies: Explanatory Tools in Web-Based Science Instruction

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This article helps designers of Web-based science instruction construct analogies that are as effective as those used in classrooms by exemplary science teachers. First, the authors explain what analogies are, how analogies foster learning, and what form analogies should take. Second, they discuss science teachers' use of analogies. Third, they examine examples of Websites that use analogies to explain science concepts. Finally, the authors provide guidelines for using analogies effectively in Web-based science instruction.

Introduction

Throughout history, exemplary science teachers have used analogies to introduce new concepts to students. The analogies serve as initial models, or simple representations, of science concepts. The teachers frequently preface their explanations with expressions, such as, "It's just like," "Just as," "Similarly," and "Likewise." These expressions are all ways of saying to students, "Let me give you an analogy."

Analogies play an important role in science instruction in all forms of media. Because Web-based science instruction is growing exponentially, and because its developers want to make it as effective as possible, the strategic use of analogies is receiving increased attention.

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For example, The Guiding Principles for Distance Teaching and Learning (American Distance Education Consortium, 2007), which are used to evaluate Web-based instruction, emphasize the role of analogies: "Learning by doing, analogy, and assimilation are increasingly important pedagogical forms. Where possible, learning outcomes should relate to real-life experiences through simulation and application."

This article is intended to help designers of Web-based science instruction construct analogies that are as effective as those used in classrooms by exemplary science teachers. These designers include not only professional designers, but science teachers and students as well, because Web design training has become part of many school curricula. In this article, we explain what analogies are, how analogies foster learning, and what form analogies should take. Next, we discuss science teachers' use of analogies. We then examine examples of Websites that use analogies to explain science concepts. Finally, we provide guidelines for using analogies effectively in Web-based science instruction.

What Is an Analogy?

An analogy is a comparison of the similarities of two concepts. The familiar concept is called the *analog* and the unfamiliar one the *target*. Both the analog and the target have *features* (also called *attributes*). If the analog and the target share similar features, an analogy can be drawn between them. A systematic comparison, verbally or visually, between the features of the analog and target is called a *mapping*. A graphic representation of an analogy, with its constituent parts, appears in Figure 1. An example of an analogy drawn between a water circuit and an electric circuit appears in Figures 2 and 3.

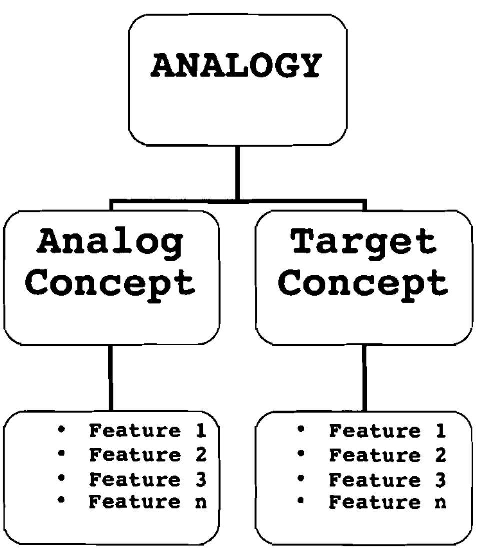

Figure 1. Graphic representation of an analogy, with its constituent parts.

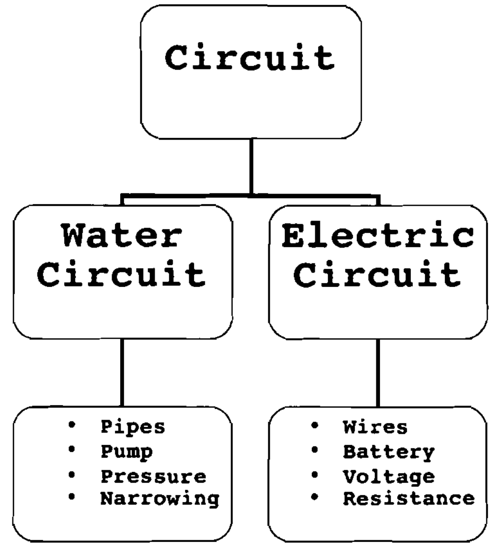

Figure 2. Analogy drawn between a water circuit and an electric circuit.

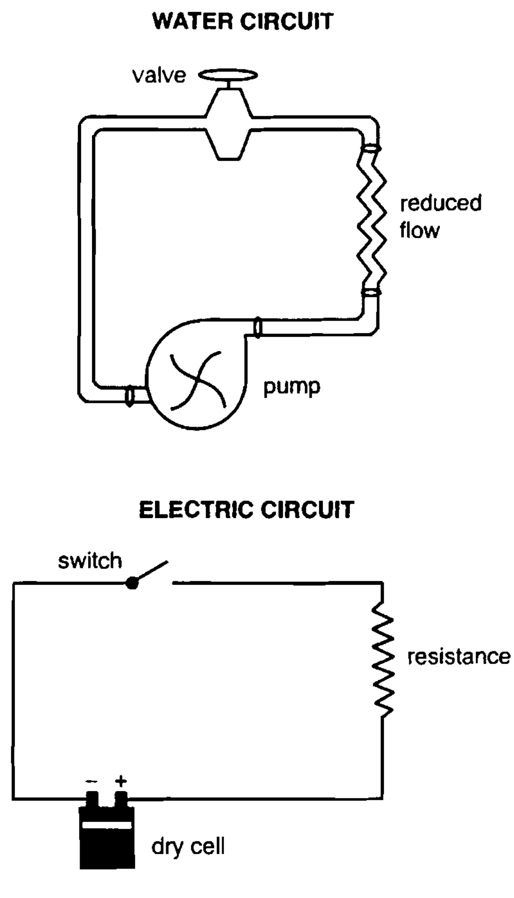

Figure 3. Analogy between a water circuit and an electric circuit.

Analogical reasoning can occur within a conceptual domain (e.g., physics) or between domains (e.g., biology and physics). When it occurs within a domain, it is often referred to as case-based reasoning (Jonassen, 2006).

How Do Analogies Help Learning?

In our view, the analogies used in classrooms, textbooks, and Web-based instruction should be designed to promote *elaboration*, the cognitive process of constructing relations between what is already known and what is new. Elaboration can be defined more precisely as "any enhancement of information which clarifies or specifies the relationship between information to-be-learned and related information, i.e., a learner's prior knowledge and experience or contiguously presented information" (Hamilton, 1997, p. 299). Elaboration can be activated by questions, objectives, personal examples, and other strategies, but analogies seem to be particularly appropriate because they can provide the rich, familiar contexts that successful elaboration requires.

Elaboration plays a critical role in a constructivist framework for learning science. In this framework, students develop by learning progressively more sophisticated mental models of science concepts. Often, these concepts represent complex, hard-to-visualize systems with interacting parts: An atom, a cell, photosynthesis, an electric circuit, and an ecosystem are all examples. Typically, such concepts are introduced to students when they are about 10 years of age (Grade 5), and then elaborated in subsequent grades, technical schools, and college. Familiar analogs (e.g., a factory) often serve as early mental models that students can use to form limited, but meaningful, understandings of complex target concepts (e.g., a cell). The analogy paves the way for the expansion of the target concept.

What Kind of Analogy Is Best?

One characteristic of research findings on the instructional use of analogies has been, unfortunately, the inconsistency of the analogies' effectiveness: Sometimes analogies enhance learning, and sometimes not (Glynn & Takahashi, 1998). This inconsistency has been due to weak operational definitions of analogies, to constructions of analogies that have failed to map analog features systematically onto target features, and to analogies that have largely ignored the important role that visual imagery can play in the learning process.

Instructional analogies are sometimes limited to simple assertions, such as "A cell is like a factory," without *explaining* the analogy. These assertions, or *simple analogies*, do not provide the instructional scaffolding that many learners need, particularly in the initial stages of learning a concept. A much better mechanism for providing instructional scaffolding is an *elaborate analogy*: "In an elaborate analogy, analog features are systematically mapped onto target features, verbal and imagery processes are active, and these processes mutually support one another" (Glynn & Takahashi, 1998, p. 1130). Elaborate analogies provide a rich, situated context for learning. By systematically mapping verbal and visual features of analog concepts onto those of target concepts, analogies can facilitate the cognitive process of elaboration.

Science Teachers' Use of Analogies

Observational studies we have conducted of middle and high school science teachers indicate that they frequently use analogies when explaining fundamentally important concepts. For example, we recently observed an eighth-grade science teacher, Ms. Judith Blake (a pseudonym), teach a unit on the *cell*. When introducing the unit to her students, she said:

> You might think of an animal cell as a tiny factory that uses materials, does jobs, and makes things. Just the way that different parts of a factory do different jobs, different parts of the cell do different jobs. The nucleus is like the factory control center, the ribosomes that make proteins are like the factory production machines, and the mitochondria are like the factory power generators.

Judith was using the Teaching with Analogies Model (Glynn, 2004), which she had learned in a professional development workshop conducted for teachers in her school system. Those teachers who did not participate in the workshop used analogies, but not strategically. In fact, in subsequent interviews, some of them commented that they were unaware they were even using analogies. One teacher told us: "I guess I do use analogies, but I don't think much about them. I guess I do it automatically, especially when students aren't catching on."

It is risky to use analogies without thinking about them because they are, to analogize, double-edged swords. If used effectively, they can enhance learning by building conceptual bridges between old and new knowledge; if used ineffectively, they can hinder learning by causing misconceptions. Knowing how to use analogies effectively is an important part of teachers' *pedagogical content knowledge* (Gess-Newsome, 1999).

Teaching with Analogies Model

The Teaching with Analogies Model (Glynn, 2004) was developed on the basis of cognitive task analyses of exemplary teachers and textbook authors. In both formal experiments and classroom settings, the use of the model has been found to increase students' learning and interest (Glynn, in press; Glynn, Duit, & Thiele, 1995; Paris & Glynn, 2004). When Judith used the "cell-factory" analogy, she followed the six steps in the model:

1. Introduce the target *concept*, the animal cell, to

students.
2. Remind students of what they know of the *analog concept*, a factory (e.g., an automobile factory).
3. Identify relevant features of the cell and a factory.
4. Connect (map) the similar features of the cell and a factory.
5. Indicate where the analogy between the cell and a factory breaks down.
6. Draw conclusions about the cell.

To help her students think about the analogy, Judith showed them Figure 4. She also warned her students, "This cell-factory analogy, like all analogies, breaks down in a lot of places. For example, things entering the cell pass through its outer layer, a membrane. But things entering a factory go through doors or windows."

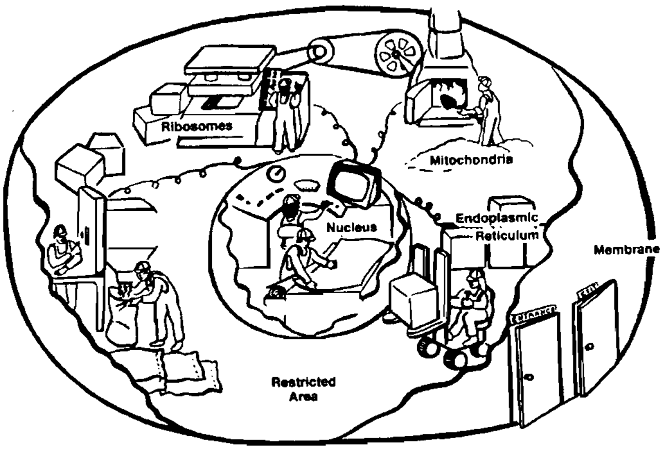

Figure 4. The cell-factory analogy.

Judith helped her students draw important conclusions about how the parts of an animal cell contribute to the functioning of the cell. She wanted her students to understand that cells are the building blocks of organisms, and all the functions that sustain life occur within a single cell. When the cells in an organism function well, the organism functions well, and when the cells do not function well, then the health of the organism deteriorates.

One implication of the Teaching with Analogies Model is that teachers should try to select analogs that share many similar features with the target concept. In general, the more features shared, the better the analogy. Another implication is that teachers should verify that students have not formed misconceptions. One way to do this is to ask focused questions about features that are not shared between the analog and the target concept.

Web-Based Science Instruction

Web-based science instruction refers here to science teaching and learning processes mediated by a Web browser, operating on the Internet. Web-based science instruction has enormous potential for complementing and enriching traditional science instruction (Herrington, Reeves, Oliver, & Woo, 2004; Kahn, 1997, 2001; Mayer *et al.*, 2006). Incorporating Web-based science instruction into traditional science curricula has already been shown potentially to increase students' motivation and achievement (Bodzin & Cates, 2002; Riffell & Sibley, 2005).

Web-based science instruction, in comparison with science instruction based on CD-ROM, videotapes, television, and other multimedia, lends itself to fast, easy updating. This is important because science knowledge is expanding rapidly and new knowledge must be continually incorporated into science curricula. Furthermore, the ability to implement science instruction, from a single source, to a wide range of operating systems, like UNIX, Windows, and Macintosh, is a major advantage that the Web offers.

Other advantages include the Web's capacity for dynamic interaction and the reliability and standardization of its technology. Anywhere in the world, students can access Web-based science instruction from any computer with Internet access, at any time, which makes it extremely convenient to use.

When Web-based science instruction has features such as audio, video, animated GIF images, interactivity, and hyperlinks, it is roughly analogous to the instruction of a science teacher, such as Judith Blake. But this analogy, like any analogy, breaks down in places. Judith is more adaptive and intuitive than contemporary Web-based science instruction, yet her interactivity is slower than that of a fast Web connection, even on her best day.

We examined many science education Websites (see Table 1) and found that elaborate analogies are often used to explain concepts, using various combinations of text, audio, video, animation, interactivity, and hyperlinks. For example, the Website of the Genetic Science Learning Center of the University of Utah (see Table 1) included a unit on stem cells, a complicated and controversial topic.

An analogy compares a stem cell with a "stem cell guy," an animated cartoon-like actor who dances on a stage and divides into two cells. Learners are informed:

> Like actors awaiting a casting call, stem cells wait for signals to tell them what to become. Stem cell guy has a lot of potential—he can become many different types of cells. But until he receives a signal, he must wait patiently and divide slowly. When stem cell guy receives a signal, he begins to differentiate, or gradually change into his destined cell type.

Table 1. Examples of science education Websites using elaborate analogies.

Beyond Books, The Cell: Down to Basics: *http://www.beyondbooks.com/lif71/4a.asp*
British Broadcasting Corporation and The Open University, Cell City: *http://www.open2.net/science/cellcity/*
Georgia State University, Department of Physics and Astronomy, Water Circuit Analogy to Electrical Circuit: *http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html*
Indiana University, Office of Science Outreach, Enzyme reactions: *http://www.indiana.edu/~oso/animations/An6.html*
Purdue University, Genomics Analogy Model for Educators: *http://www.entm.purdue.edu/extensiongenomics/GAME/lesson3.html*
The Association for Science Education, Electricity Analogy: *http://sycd.co.uk/electricity-analogy/*
The Audio Education Resources Site, More About Waves: The Water Analogy: *http://www.audioed.com.au/learnOL_demo/LOLdemo4.html*
The Genetic Science Learning Center of the University of Utah, Stem Cells Analogy: *http://learn.genetics.utah.edu/units/stemcells/whatissc/*
University of California at Los Angeles, Division of Astronomy and Astrophysics, Balloon Analogy in Cosmology: *http://www.astro.ucla.edu/~wright/balloon0.html*
University of Winnipeg, Analogy Between Simple Harmonic Motion and Uniform Circular Motion: *http://ecommons.uwinnipeg.ca/archive/00000030/*
Warrington Grid for Learning, Photosynthesis and Baking a Cake Analogy Exercise: *http://wgfl.digitalbrain.com/wgfl/web/science/ks3/homework/9cphotosynthesis.htm*

The stem cell guy analogy is not only animated, but interactive as well. We can select what kind of cell we want stem cell guy to be. We can click and drag him into a "differentiation phone booth" and dial a number on the telephone to differentiate him into the cell of our choice, such as a skin cell, bone cell, or red blood cell. If we dial, for instance, a skin cell, then we learn about skin cells and view animations about the role that stem cell guy plays as a skin cell.

The use of good text, audio, video, animation, interactivity, and within-site hyperlinks makes the stem cell analogy an engaging one. It is also a valid one, given that it is designed for "non-research audiences." The use of the analogy is generally consistent with the Teaching with Analogies Model, with one exception: Little attention is given to where the analogy breaks down. One example of this is the statement, "Like actors awaiting a casting call, stem cells wait for signals to tell them what to become." At this point the analogy breaks down: Actors await casting calls from directors or producers, but what is the source of a stem cell's signal? This is not explained, and a misconception could arise. To avoid a misconception, students should be informed that signals inside and outside cells trigger differentiation. The inside signals are controlled by a cell's genes, while the outside signals include chemicals secreted by other cells, physical contact with other cells, and certain molecules.

The Website of *Beyond Books* (see Table 1) includes science units for teachers to use with middle and high school students. In the unit The Cell: Down to Basics, a "busy factory" analogy is used to explain cell parts. The analogy compares the cell to a factory: "A cell can be thought of as a 'factory,' with different departments each performing specialized tasks." Cell membranes are depicted as swinging gates—clicking on these hyperlinked gates takes one to a related Website, which provides more information on cell membranes. Likewise, the endoplasmic reticulum is depicted as a moving factory conveyor belt—clicking on it takes one to another related Website.

The text in the unit is consistent with the Teaching with Analogies Model, including an indication of where the analogy breaks down:

> With the exception of chloroplasts, all of the parts of the cell examined so far can be found in all cells. But now, as the discussion turns to more specialized organelles, the factory analogy will no longer apply. As cells become more specialized, they may contain organelles that are not common to all cells. Since they are not common to all cells, they are not necessary for all factories.

The students' understanding of cell organelles and their functions is verified by means of interactive study questions, practice quizzes, key terms, and games. The text content is good and the analogy is animated, interactive, and hyperlinked; however, the implementation of these technical features should be updated.

Guidelines for Designing Analogies

Six guidelines should be kept in mind when designing elaborate science analogies such as those in Table 1. These guidelines are discussed here with a *focus on Web-based science instruction*, but they also apply to other forms of media:

(1) Designers should take into account the character-

istics of the target concept. If the concept is relatively simple and straightforward, an elaborate analogy might be unnecessary. Elaborate analogies are most helpful when the target concepts are complex and represent hard-to-visualize systems with interacting parts. These concepts are the ones that benefit most from Web-based elaborate analogies that use animation, interactivity, and hyperlinks to engage learners and foster their understanding.

(2) Designers should take into account the characteristics of the analog concept. A good analog is one with which the students are already familiar, so it does not have to be taught from scratch, it just needs to be reviewed by means of hyperlinked Websites. Another characteristic of a good analog is that it shares many features with a target concept, rather than just a few features.

(3) Designers should follow the steps in the Teaching with Analogies Model to introduce a target concept, suggest a good analog, identify similar features of the analog and target, visually map these features, indicate where the similarities break down, and draw conclusions about the target. Following these steps will help students to transfer relevant knowledge from the analog to the target and to draw valid conclusions about the target.

(4) Designers should hyperlink features of elaborate analogies to related bodies of knowledge. Creating hyperlinks, within the Website and to other Websites, simulates the exemplary science teacher's use of supplementary knowledge resources to enrich students' learning. Because students vary in their relevant background knowledge, designers should link to a variety of knowledge resources that are relevant, accurate, and authentic.

(5) Designers should animate elaborate analogies to ensure that they engage students' interest and promote understanding. Animation can help students to visualize the dynamics of processes (e.g., mitosis, photosynthesis, metamorphosis, oxidation, and erosion) by depicting temporal or causal sequences and the transitions that occur between stages and states.

(6) Designers should make elaborate analogies interactive to simulate the actions that exemplary teachers perform when using analogies. Students should be able to interact with components of the analogies by selecting embedded links. Actions such as questions, prompts, suggestions, and feedback should be incorporated into a hyperlinked, database-driven Website that gathers information from students, displays it, and provides them with evaluations of their understanding.

Conclusion

Just like exemplary science teachers, designers of Web-based science instruction can use carefully crafted elaborate analogies to help students understand concepts that represent complex, hard-to-visualize systems with interacting parts. Carefully crafted elaborate analogies in Web-based science instruction can help students build conceptual bridges between what they already know and what they are setting out to learn. □

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