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This report describes the role of analogies in science instruction and presents research on a model for teaching with analogies. This model is being developed from research studies of textbooks and exemplary teachers; it provides guidelines for the strategic use of analogies during science instruction to explain fundamentally important concepts in ways that are meaningful to students. The model shows how exemplary teachers and textbook authors construct effective analogies to help students build upon new knowledge learned from textbooks by activating, transferring, and applying relevant existing knowledge. Contains 10 references and 4 figures illustrating analogies used in science instruction. (Author)

TEACHING SCIENCE WITH ANALOGIES: A RESOURCE FOR TEACHERS AND TEXTBOOK AUTHORS

SHAWN M. GLYNN, MICHAEL LAW, NICOLE M. GIBSON, CHARLES H. HAWKINS

National Reading Research Center

Instructional Resource No. 7
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NRRC

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Teaching Science With Analogies: A Resource for Teachers and Textbook Authors

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Michael Law
Nicole M. Gibson
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INSTRUCTIONAL RESOURCE NO. 7
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The National Reading Research Center (NRRC) is funded by the Office of Educational Research and Improvement of the U.S. Department of Education to conduct research on reading and reading instruction. The NRRC is operated by a consortium of the University of Georgia and the University of Maryland College Park in collaboration with researchers at several institutions nationwide.

The NRRC's mission is to discover and document those conditions in homes, schools, and communities that encourage children to become skilled, enthusiastic, lifelong readers. NRRC researchers are committed to advancing the development of instructional programs sensitive to the cognitive, sociocultural, and motivational factors that affect children's success in reading. NRRC researchers from a variety of disciplines conduct studies with teachers and students from widely diverse cultural and socioeconomic backgrounds in pre-kindergarten through grade 12 classrooms. Research projects deal with the influence of family and family-school interactions on the development of literacy; the interaction of sociocultural factors and motivation to read; the impact of literature-based reading programs on reading achievement; the effects of reading strategies instruction on comprehension and critical thinking in literature, science, and history; the influence of innovative group participation structures on motivation and learning; the potential of computer technology to enhance literacy; and the development of methods and standards for alternative literacy assessments.

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Teaching Science With Analogies: A Resource for Teachers and Textbook Authors

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Abstract. *This report describes the role of analogies in science instruction and presents research on a model for teaching with analogies. This model is being developed from research studies of textbooks and exemplary teachers; it provides guidelines for the strategic use of analogies during science instruction to explain fundamentally important concepts in ways that are meaningful to students. The model shows how exemplary teachers and textbook authors construct effective analogies to help students build upon new knowledge learned from textbooks by activating, transferring, and applying relevant existing knowledge.*

Sam Adams, a middle-school teacher, encourages his students to bring in newspaper articles about puzzling science phenomena. In today's class, one of his students, Rachel, reads aloud an article she found. The article concerns the unpredictable paths that satellites often take when they fall to earth. Rachel tells the class the title of the article, "Chinese Satellite Misses Land," and enthusiastically begins reading it: [1]

> A two-ton chunk of Chinese satellite plunged back into the atmosphere Thursday, took a 1,000-mile detour, and dropped into the Pacific Ocean west of Peru.
>
> Until the last moments, trackers at the U.S. Space Command expected the satellite to drop into the Pacific 500 miles west of the Baja California Peninsula along the Tropic of Cancer.
>
> It then skipped 1,000 miles south, according to the trackers.

At this point in her reading, Rachel pauses dramatically, allowing the other students to think about the surprising 1,000-mile detour the satellite took. One of the students, Eddie, shoots his hand into the air and, unable to restrain himself, bursts out: "How can a satellite take a 1,000-mile detour? And how come those trackers, with all the equipment and stuff they've got, couldn't figure out where the satellite was going to fall down?" Rachel pauses a little longer and says, "It's all explained here in the article." She continues reading aloud:

> Space debris traveling 17,000 miles an hour takes unpredictable twists and turns when it breaks in the thickening atmosphere. The trackers likened the effect to dropping a penny into water.
>
> "Sometimes it goes straight down, and sometimes it turns end over end and changes direction," one of the trackers said. "The same thing happens when an object hits the atmosphere."

Rachel finishes reading and grins at the other students, knowing that they enjoyed the article just as much as she did. Most of the students are nodding their heads, and Eddie voices their thoughts, saying: "Yeah, that makes sense. The satellite skipped sideways like a penny falling in water."

Mr. Adams congratulates Rachel on finding such an interesting article and, as he routinely does, briefly reviews the key points of the article to ensure that all students understand the phenomenon and the explanation. The explanation, in this case, takes the form of an analogy. Mr. Adams thinks it is a good analogy because it draws on an experience that most students are familiar with—a penny falling into water—and compares it to the puzzling phenomenon—a satellite skipping in the earth's atmosphere. Mr. Adams wants to make sure that the students correctly connect the satellite with the penny and the atmosphere with the water. He realizes that some students might misunderstand the analogy, thinking perhaps that the water is connected in some way with the ocean, so he makes a special effort to explain the analogy to the students and then questions them about it, just to check on their comprehension. Mr. Adams then mentally files away the analogy for future use. He likes analogies and often uses them when explaining science concepts to his students.

Teaching With Analogies

It is not surprising that authors and teachers routinely use analogies when explaining science concepts to students (Harrison & Treagust, 1993, 1994; Thiele & Treagust, 1994; Treagust, Duit, Joslin, & Lindauer, 1992). Analogies have always played an important role in scientific explanation, insight, and discovery. For example, Johannes Kepler, the eminent 17th-century astronomer, drew an analogy between planetary motion and clockwork.

Often, teachers and authors are unaware that they are using analogies—they do it automatically. Throughout their lessons, especially when responding to student questions, teachers regularly preface their explanations with colloquial expressions such as "It's just like . . .," "It's the same as . . .," "It's no different than . . .," and "Think of it as . . . ." In textbooks, authors use more formal expressions like "Similarly," "Likewise," "Along related lines," "In comparison to . . .," and "In contrast with . . . ." For the teacher and the author, these expressions are all ways of saying "Let me give you an analogy." Unfortunately, teachers' and authors' analogies often do more harm than good. That is because teachers and authors, lacking guidelines for using analogies, sometimes use them unsystematically, often causing confusion and misconceptions. The distinctions between the target concept, the analog concept, examples of the concepts, and features of the concepts become blurred in the

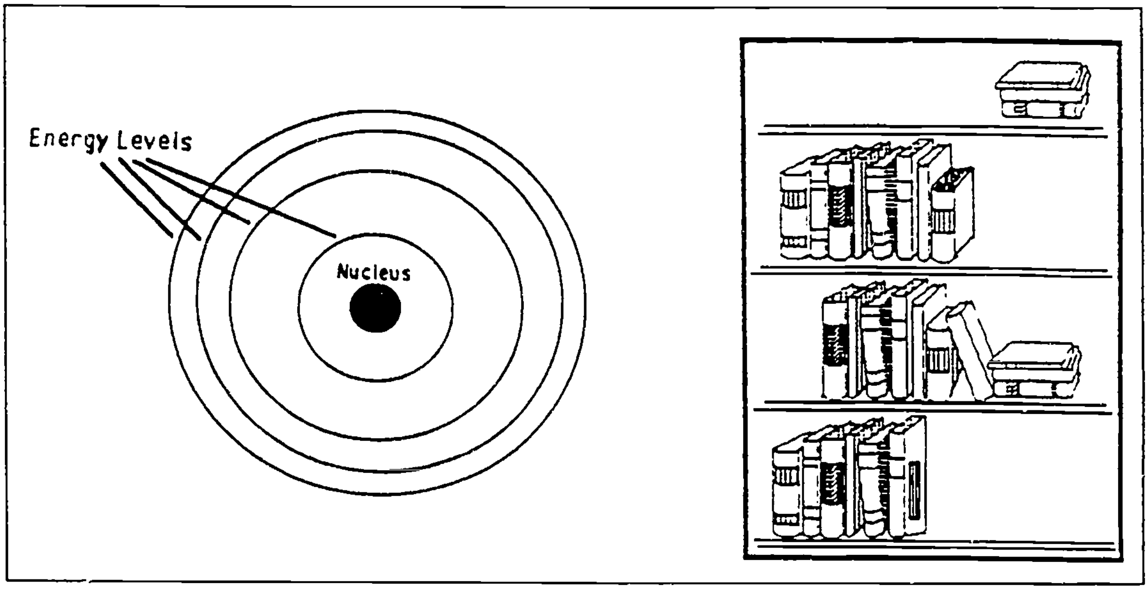

Figure 1. A visual representation of an analogy between a bookcase and Bohr's model of the atom.

students' minds. One solution, of course, would be to advise teachers and authors not to use analogy. That would be unrealistic because teachers and authors, like all human beings, are predisposed to think analogically. Consciously or unconsciously, teachers and authors will use analogies during explanation. The better solution is to introduce teachers and authors to a strategy that uses analogies systematically to explain fundamental concepts in ways that are meaningful to students.

The purpose of this National Reading Research Center (NRRC) instructional resource article is to acquaint teachers with a model for teaching with analogies. The Teaching-with-Analogies Model (Glynn, 1993a, 1991; Glynn, Duit, & Thiele, in press) provides guidelines for strategically using analogies during science instruction. The model shows how teachers and authors can help students to activate, transfer, and apply relevant existing knowledge when learning new knowledge from textbooks.

Development of the Model

The Teaching-with-Analogies Model was initially based on a task analysis of elementary-school, middle-school, high-school, and college science textbooks. A task analysis is a technique that identifies the basic processes that underlie expert performance of a task (e.g., see Goetz, Alexander, & Ash, 1992). The analysis identified how 43 textbook authors used analogies to explain new concepts to students. Analogies similar to those in the textbooks can be seen in Figure 1, in which the Bohr model of

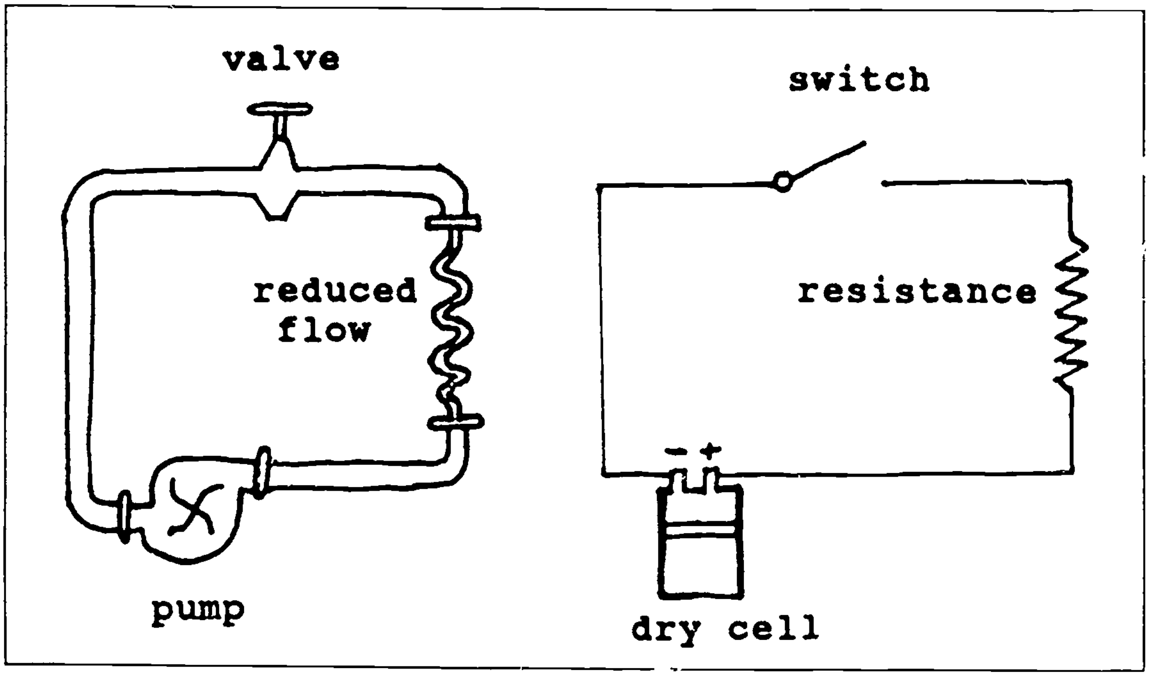

Figure 2. A visual representation of an analogy between ater circuit and an electric circuit

the atom is explained in terms of a bookshelf, and Figure 2, in which an electric circuit is explained in terms of a water circuit.

This model was further developed on the basis of a task analysis of the lessons of ten exemplary science teachers. The exemplary science teachers were from public middle and elementary schools. The teachers were identified as exemplary by the awards they had received and the judgments of principals, other teachers, and university teacher educators. All classes were multicultural, with 18 to 25 students in each class. Each exemplary teacher selected a lesson in which he or she made "best possible use of analogy-based activities to elaborate upon a key concept that the students had read about in their textbooks."

Some Exemplary Science Teachers

One of the teachers, Martha Gilree, taught an earth science lesson on the structure of the earth. She baked layered cupcakes for her students and explained that the cupcakes were analogs of the earth, with the four layers corresponding to the crust, mantle, outer core, and inner core of the earth. Using straws, the students took "core samples" from the cupcakes, examined the samples, and compared them to representations of the earth in their textbooks.

Another teacher, Joe Conti, taught a biology lesson on natural selection and "survival of the fittest." He took his children outside to an area of green grass where earlier he had scattered an equal number of green, yellow, and red uncooked noodles. He explained that the noodles represented different colored grasshoppers and that the students were hungry birds who preyed on the grasshoppers. The students "caught as many grasshoppers" as they could in the next five minutes and returned to the classroom, where a tally revealed that fewer green grasshoppers were caught than yellow, and fewer yellow than red. Joe then asked his students to hypothesize how a trait such as coloration can increase or decrease the probability that a species will survive in a given environment.

Still another teacher, Becky Wheeler, taught a physical science lesson on optics. She and her students built a simple, working camera and she used this camera to explain optic principles. Becky then explained that the camera was analogous to the human eye and, using a physical model of the eye, she compared its features to those of the camera. Finally, she taught optic principles common to both the camera and the eye.

An NRRC Video Highlight, "Teaching Science with Analogies: Building on the Book," shows Becky Wheeler, Joe Conti, and Martha Gilree teaching their analogy-based lessons (Glynn, 1993b).[2] This video demonstrates how teachers can use analogies to make textbook concepts more meaningful to students by helping students connect these concepts to existing, relevant knowledge.

Implications for Instruction

The task analysis of the exemplary teachers' lessons, in conjunction with the earlier analysis of textbooks, revealed six operations that ideally should be carried out when teaching with analogy (see Table 1). These six operations are the core of the Teaching-with-Analogies Model.

Table 1. Operations in the Teaching-With-Analogy Model

1. Introduce target concept
2. Cue retrieval of analog concept
3. Identify relevant features of target and analog
4. Map similarities
5. Indicate where analogy breaks down
6. Draw conclusions

In actual practice, the order in which these six operations are carried out can vary. It is usually important, however, for the teacher or textbook author to perform all of the operations. If the teacher or textbook author were to perform only some of the operations, leaving some to the student, it is possible that the student might fail to perform an operation or might perform it poorly. The result could be that the student would misunderstand the concept being taught.

Listen in on the following conversation between a seventh-grade science teacher, Ms. Davis, and one of her students, John. In this conversation, Ms. Davis demonstrates how the Teaching-with-Analogies Model can be used to increase John's comprehension of several key concepts he has read about in his textbook.[3]

JOHN: I'm worried about the next science test, Ms. Davis.

MS. DAVIS: Oh, what's giving you trouble, John?

JOHN: The stuff on electricity and electric circuits in our text.

MS. DAVIS: Electricity can be a tough unit, alright. Have you read your textbook carefully?

JOHN: I sure have, lots of times. The reading is really hard. All the new terms get me confused.

MS. DAVIS: What were some of those confusing terms?

JOHN: Well, I sort of know what a circuit is, but I'm not sure what "voltage" and "resistance" mean.

MS. DAVIS: What were some of the other electricity terms or ideas that you read about?

JOHN: Uh, I read about wires and batteries and switches.

MS. DAVIS: Yes, these are important parts of an electric circuit. You seem to remember all the important ideas from your reading. Can you put these ideas together and explain to me how an electric circuit works?

JOHN: Ah, no. That's the problem. I can't get a picture in my head of how this electricity stuff works.

MS. DAVIS: Well, don't be discouraged, John. You learned a lot of important bits and pieces from the text. Let me see if I can help you put these bits and pieces together, so you will understand how an electric circuit works. Perhaps an analogy will help. Do you recall when you and your classmates set up the aquarium in the classroom?

JOHN: Sure!

MS. DAVIS: And do you remember me explaining how the water circulated in the aquarium?

JOHN: That was easy, not like this electricity stuff. When you explained how the water circulates, I could actually see the pump and filter.

MS. DAVIS: Right! Well, now I'm going to help you "see" how the electric circuit works by comparing it to water circulation in the aquarium. Look at the classroom aquarium while I describe again how the water flows through it in a circuit, or a connected path. A current of water is drawn from the aquarium through a pipe by a pump which controls pressure. The water then flows through a filter, which slows the flow and catches impurities. Finally, the water returns to the aquarium through another pipe. Do you remember and understand that, John?

JOHN: Sure, Ms. Davis.

MS. DAVIS: Fine. Now think about this question. What might the water correspond to in an electric circuit? That is, what flows in the circuit?

JOHN: Electricity?

MS. DAVIS: Exactly! Very good. Now, the water is carried from the aquarium into the filter and back into the aquarium by means of plastic pipes. What do these pipes correspond to in an electric circuit?

JOHN: The metal wires?

MS. DAVIS: Right again. Okay, in the aquarium, the pump provided the pressure to move the water through the tubes. In an electric circuit, what device provides the pressure to move the electricity through the circuit?

JOHN: How about a battery?

MS. DAVIS: Yes, indeed, a battery, or a generator. Now for a tougher question. Like a pump, the battery produces a sort of electrical pressure. What's the correct name for this electrical pressure?

JOHN: I bet it's voltage.

MS. DAVIS: And I bet you're right! Here's a really tough question. We stuffed cotton in the aquarium filter to clean the water. This also had the effect of reducing the amount of water that flowed through the pipes in a given period of time. Likewise, in an electric circuit, the use of some poorly conducting metals in wires can reduce the amount of electricity that flows in a given period of time. In an electric circuit, what do you call this reduction in flow?

JOHN: Resistance!

MS. DAVIS: Correct, John; I think you've got it. To sum up, let's list here on the board the features of our aquarium water circuit that correspond to those in an electric circuit (see Figure 3). Now, John, keeping these features in mind, explain to me how an electric circuit works.

JOHN: Okay, I'll give it a try. An electric circuit is an unbroken wire path through which electricity can flow. In order for the electricity to flow, there must be a source of voltage, such as a battery. How much electricity will flow through a circuit in a given period of time depends on how much resistance there is in the material that makes up the wire. So how's that? I guess I've got this circuit business down pat.

MS. DAVIS: Very impressive, but we're not done yet. I still have a few tricky questions.

JOHN: Okay, Ms. Davis, give me your best shot.

MS. DAVIS: Look at this diagram of an electric circuit; it's similar to the one in your textbook (see Figure 4). The circuit contains a charged battery with a lit

CIRCUIT

Water Circuit	Electric Circuit
water	electricity
flowing water	electric current
pipes	wires
pump	battery
pressure	voltage
filter	poor coductor
reduced flow	resistance

Figure 3. Features of a water circuit compared to features of an electric circuit.

light bulb connected to the battery by a wire. What would happen to the electricity flowing through the circuit if you cut the wire and pulled the ends apart? Would you get a different result if you cut the wire to the right, rather than, to the left of the light bulb?

JOHN: Those really are tricky questions. Hmm . . . let me use the aquarium water circuit analogy. If I cut the pipe returning water to the tank, the water would continue to flow, but would probably spill out on the floor. On the other hand, if I cut the pipe taking water from the tank just above the water line, then the water would stop flowing. Now I'll apply this analogy to your circuit. If I cut the wire to the right of the bulb, then electricity would flow but spill out of the wire. If I cut to the left of the bulb, then electricity would stop flowing. Am I right?

MS. DAVIS: No, you are not, although your reasoning is good. When you cut or break an electric circuit at any point in the circuit, the electricity stops flowing everywhere in the circuit. That's the function of an electrical switch, by the way; it interrupts the circuit, stopping the flow of electricity.

JOHN: But why wasn't I right, Ms. Davis? I used the analogy.

MS. DAVIS: Because, John, no analogy is perfect. Analogies help us to understand some aspects of a new concept, but at some point every analogy breaks down.

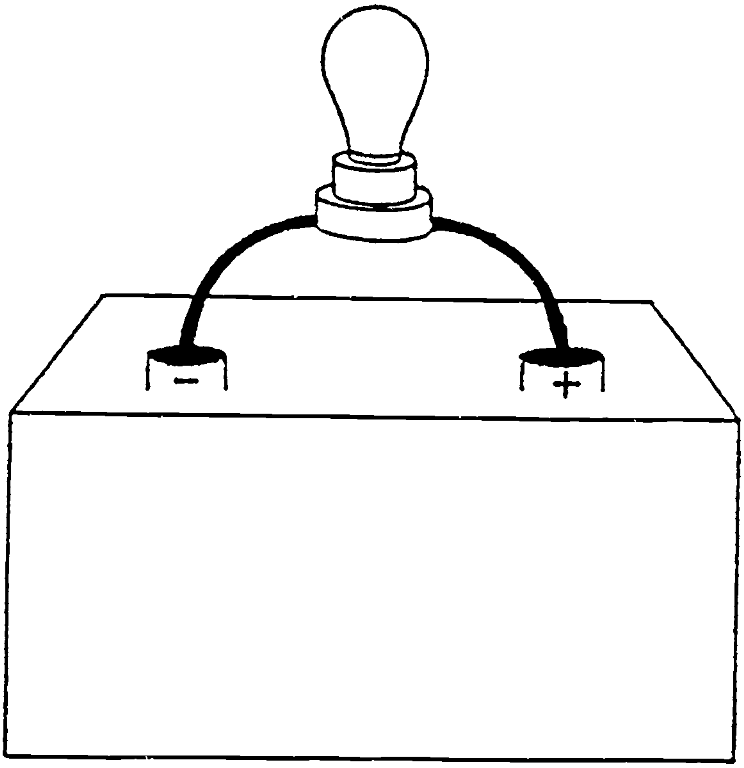

Figure 4. A charged battery and a lit light bulb.

JOHN: If analogies can give us the wrong answers sometimes, then I don't think we should use them at all.

MS. DAVIS: That, John, would be like "throwing the baby out with the bath water," if you'll forgive me for using another analogy. Analogies can be a big help to me when I explain new concepts and to you when you try to understand them. The trick is to use analogies carefully, keeping in mind their limitations and the wrong ideas that can arise when an analogy is carried too far. Used carefully, analogies can help you a lot, John, just as they've helped many of the famous scientists you've read about in your textbook.

JOHN: Which scientists?

MS. DAVIS: Oh, astronomers such as Johannes Kepler, who drew an analogy between the movements of the planets and the workings of a clock. And physical scientists such as Joseph Priestly, who suggested the law of electrical force by drawing an analogy from the law of gravitational force.

JOHN: Oh, yes, I remember their names. They used analogies, huh?

MS. DAVIS: Certainly. Analogies are important thinking tools. They can help us make the jump between old ideas we already understand and new ideas we're trying to learn.

JOHN: Is science the only area where I can use analogies?

MS. DAVIS: You can use analogies in all your subjects, John. They are powerful tools for understanding and problem solving. But do keep in mind their limitations.

JOHN: I will, Ms. Davis. And thanks a lot. I'm not worried about the test anymore.

In the preceding conversation, Ms. Davis effectively used an analogy to explain and enrich a complicated concept that a student encountered in a textbook. By drawing an analogy and using a guided discovery method with John, she demonstrated how the Teaching-with-Analogies Model can be used strategically in instructional situations. Specifically, Ms. Davis performed the following six operations in the Teaching-with-Analogies Model:

1. *Introduce target concept*. Ms. Davis introduced the target concept of "electric circuit" to John.
2. *Cue retrieval of analog*. Ms. Davis prompted John to recall what he knew about the analogous concept, the water circuit in an aquarium.
3. *Identify relevant features of target and analog*. Ms. Davis identified relevant features of the electric circuit (e.g., wire and battery) and water circuit (e.g., pipe and pump).
4. *Map similarities*. Ms. Davis compared, or "mapped," features of electric circuits to features of water circuits for John.
5. *Indicate where the analogy breaks down*. Ms. Davis pointed out to John the dissimilarities between electric and water circuits (e.g., the results when pipes versus wires are cut), using a textbook diagram.
6. *Draw conclusions*. Ms. Davis drew conclusions for John about electric and water circuits in particular, and analogies in general.

Conclusions and Recommendations

The Teaching-with-Analogies Model can serve as a guide for authors and teachers when constructing analogies to help explain key concepts. If the author chooses not to provide an analogy, but the teacher believes one is called for, the teacher can construct one for students. Or, if the author has provided an analogy, but the analogy is flawed, the teacher can use the Teaching-with-Analogies Model to improve it.

Teachers can use the Teaching-with-Analogies Model to modify an author's analogy and target it to the specific background knowledge of the students they teach. This is important because new content is meaningful only when it is connected to students' existing, relevant knowledge (Glynn & Muth, 1994). For example, a Minnesota science teacher might help students picture the earth rotating by comparing it to a spinning ice skater. A Georgia teacher, on the other hand, might draw an analogy to a roller skater, since children living in warmer climates are more likely to have experience roller skating than ice skating. By tailoring analogies to the particular backrounds of students, the science teacher can maximize the explanatory power of analogies and build upon the author's textbook coverage.

NOTES

[1]The "Chinese Satellite Misses Land" article was adapted from one that was released by the Associated Press, Washington, and which appeared in the *Athens Daily News*, Athens, Georgia, October 29, 1993, p. 3a. The classroom episode with Sam Adams, Rachel, and Eddie is fictitious.

[2]Martha Gilree, Joe Conti, and Becky Wheeler are indeed exemplary public school teachers in Georgia. For information on how to obtain the NRRC Video Highlight, "Teaching Science with Analogies: Building on the Book," please write to the National Reading Research Center, Aderhold Hall, University of Georgia, Athens, GA 30602 - 7125.

[3]The conversation between Ms. Davis and John, adapted from Glynn 1991 (pp. 234-237), is fictitious.

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