Interactive Analogies

Sean P. Brophy
sean.brophy@vanderbilt.edu
Vanderbilt University
Box 45, GPC
Nashville, TN 37201

Daniel L. Schwartz
schwardl@ctrvax.vanderbilt.edu
Vanderbilt University
Box 45, GPC
Nashville, TN 37201

Abstract: The goal of this paper is to describe our initial efforts at developing what we call "interactive analogies." Interactive analogies are pairs of simulations. In the attempt to answer specific problems, students interact with each simulation and map the analogous structures in each. Interactive analogies provide a complementary use of analogies and simulations; the weaknesses of one approach are handled by the strengths of the other. In the beginning of the paper we provide a quick overview of the strengths and weaknesses of simulations and analogies, and how interactive analogies may provide an excellent combination of the two. Afterwards, we describe an example of an interactive analogy we have developed for the domain of electrical circuits, and we describe some "telling cases" from our pilot study to illustrate its usefulness and things that need to be considered. Finally, we discuss work we are currently conducting and issues we hope to address in the future.

1. Introduction

The goal of this paper is to describe our initial efforts at developing what we call "interactive analogies." Interactive analogies are pairs of simulations. One simulation comes from a target domain like biomechanics (e.g., a heart) and the other simulation comes from an analogous domain like fluid mechanics (e.g., a pumper fire truck). In the attempt to answer specific problems, students interact with each simulation and map the analogous structures in each. Interactive analogies provide a complementary use of analogies and simulations; the weaknesses of one approach are handled by the strengths of the other. For example, simulations, on the one hand, do not always provide a causal model that students understand. For example, simulations of voltage do not always help students understand the idea of a drop in potential energy. Analogies are useful in this regard because they allow students to draw on prior knowledge from a related domain (e.g., the difference between the fluid pressure at the top of a tank and the bottom of a tank). On the other hand, analogies do not provide feedback that helps students progressively map the structures between two domains. For example, simply telling someone that a battery is like an elevated water tank will not help most students work out the relevant similarities. Simulations provide useful feedback by allowing the student to test out possible relations. In the beginning of the paper we provide a quick overview of the strengths and weaknesses of simulations and analogies, and how interactive analogies may provide an excellent combination of the two. Afterwards, we describe an example of an interactive analogy we have developed for the domain of electrical circuits, and we describe some "telling cases" from our initial pilot studies that illustrate its usefulness. Finally, we discuss work we are currently conducting and issues we hope to address in the future.

2. Simulations, Analogies, and Interactive Analogies

Among their many positive qualities, simulations offer the flexibility to demonstrate multiple dimension of a specific situation or phenomenon. They allow a learner to practice in specific situations. And, they provide a natural experimentation-feedback cycle. Ideally, multiple interactions with a simulation can naturally induce an iterative, inquiry cycle of posing a question, making a prediction, designing and performing an experiment (i.e., running the simulation), and applying the results to update an existing mental model. White and Frederiksen have done extensive research on the benefits to learning about the inquiry process while learning about physics through interacting with a simulation tool called ThinkerTools [White and Frederiksen 1998]. The ability to repeat a simulation provides learners with the opportunity to systematically explore a particular phenomenon in a reasonably "realistic" manner.

Typically, however, simulations are somewhat opaque to students. Microworld simulations, for example, are often complex with the underlying model hidden from view. This creates an incredibly difficult induction task for students. They are faced with multiple variables, and often times, have no model or prior knowledge to guide their selection and manipulation of variables or their attention to specific outcomes. The result is necessarily trial and error. Even when correlations are found among the variables of a simulation, the student does not necessarily find the underlying structure, agents, or constraints that cause the correlated outcomes. One way to help students who use the inquiry potential of simulations is to provide specific objectives or goals that help them focus on specific concepts targeted for learning [CTGV 1997; Crews, Biswas, Goldman and Bransford in press; Bell 1998; Brophy 1998]. In this case, simulations may be introduced within a problem-solving context to get students to focus attention on key features of the simulation. As we describe below, another approach is to provide an interactive analogy to complement the simulation.

Analogies can be used to help explain a difficult concept in a given domain by referencing a similar concept in a more familiar domain. For example, explaining that an aorta in the heart is like a flywheel or tank can help the student understand that the aorta helps to make the flow of blood more continuous even though heart beats are not. There is a substantial body of psychological literature that explores the value of analogies in coming to understand and communicate a target concept or domain [e.g. Reeves & Weisberg 1994; Gentner 1989; Gick and Holyoak 1983; Holland Holyoak Nesbett and Thagard, 1986; Ross & Kennedy 1990]. The benefits include helping learners to find important structural relations and providing conceptual grounding for abstract concepts.

There are limitations to analogies, however. One limitation is that students may not find the appropriate structural correspondences. A second limitation is that students may not have sufficient knowledge of the analogy to use it productively; they may have partial knowledge of both the target and the base domains. A third limitation is that analogies only typically hold in partial ways across domains. Gentner and Gentner [1983], for example, discuss how certain analogies only help for certain situations in simple electrical circuits. They explored how people use two different analogies for current flow in electricity; teeming crowds and flowing water. Consequently, students who learned one analogy could solve one kind of problem but then used it inappropriately for another type of problem. A fourth limitation is that analogies are often used as "one shot deals" and students do not get an opportunity to exercise the analogy in multiple situations. Perhaps, the greatest limitation of an analogy as an instructional vehicle is that it does not provide any external feedback. People are basically stuck trying to "think their way through" the analogy on the basis of very abstract concepts like coherence and systematicity.

Interactive analogies provide a potentially excellent way to marry the strengths and weaknesses of simulations and analogies. The simulations provide a chance for students to experiment and gather feedback on the quality of their developing analogies, and to revisit their analogy in multiple contexts, some in which the analogy holds and some in which it does not. Reciprocally, analogies provide the structure and guidance that help students select likely variables for manipulation and attention during inquiry, and they provide for the conceptual grounding that helps students make sense of the results of their simulation. In our work on interactive analogies we supplement this natural complementary by designing learning activities that entail interacting with the simulations simultaneously, and that help further guide student inquiry both into the target domain and the correspondences between the two domains. The assumption is that this not only develops conceptual understanding of the target domain, but it can also help strengthen an individual's understanding of the analogous domain.

3. Interactive Analogies in the Context of Simple Electrical Circuits

In our work, we have experimented with asking learners to compare a simulation of a fluid system with a simulation of a simple battery operated flashlight. Our pilot research consisted of interview with second and fourth year electrical engineering students. Our preliminary results suggest that students develop a better understanding of electricity, of fluid mechanics, and that the interactive analogies help students self-assess and guide their own inquiry.

Electricity is a particularly hard domain to comprehend because there are few visible features to help create a model of electrical behavior. The electrical engineering students we have worked with can often provide quantitative solutions to problems by using formulas like Ohms law. But, we have found that most of them are unable to describe a systems level behavior of a circuit in qualitative terms. Moreover, they often rely on analogies they are taught in class that, because of their partial nature, only cause deep misconceptions. Good examples come from problems where we used a simple flashlight [see Fig 1] consisting of two batteries, a switch and a bulb. We asked questions like “Where should you place a fuse to protect the expensive halogen light bulb?” or “What happens to the voltage and current if we change the bulb from a 5 Watt value to a 10 Watt bulb?

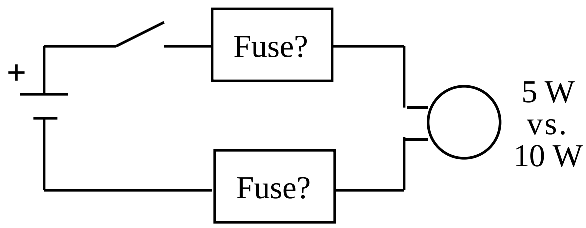

Figure 1: Simple Flash light circuit.

Many students insist a fuse must go between the positive terminal of the battery and the bulb because when the current flows through the switch it will “blow” the fuse before it reaches the light bulb. This is wrong. The idea of current flowing through the wire sequentially is like filling an empty pipe up with water. Students make their mistake because they have not had a chance to make the correct analogy between the water flow analogy they were taught and electricity. The proper analogy is that the circuit acts more like a full pipe of water. Because water cannot be compressed very well, a flow in one part of the circuit causes a simultaneous change in all parts of the circuit. Therefore, the amount of current that flows is a function of the components in the closed system, and the current is the same amount throughout the circuit as soon as the switch is closed. To protect the light bulb it doesn’t matter if the fuse is before or after the bulb.

Another common misconception students demonstrate relates to the amount of resistance associated with the power consumed by a component. All our students understand that switching from a 5 watt to a 10 watt bulb increases the light and power draw. However, their intuitions lead them to think that more power means more resistance. They believe that increasing heat/light results from increased resistance just as increased friction increases heat. Again, one can see how a flawed analogy causes problems. The correct explanation is that the 10 watt bulb has less resistance and this allows more current to flow and deliver power. In one case, even an expert articulated this misconception. Fortunately, the expert had enough mathematical knowledge to correct this misconception by noting the equation for power (Power = Voltage*Current). The expert understood that for the power to increase either the voltage or current must increase. Because the voltage from the battery is constant, the current must increase. From this revelation, the expert realized that the only way for the current to increase is if the resistance decreases based on Ohm’s Law (Current = voltage/Resistance).

To address these types of problems and to help students develop a deeper understanding, we developed tandem simulations of a simple electrical circuit and a simple water system. We created the simulations to help students interact with two systems from different domains that are analogous at some level. Based on the concept of energy transfer it is possible to compare an electrical system to a fluid system in certain circumstances. Figure 2 illustrates the juxtaposition of two analogous systems and the type of equipment that can be used to indicate various properties it displays. Figure 2a is a simple flashlight system designed to transfer the potential energy stored in the batteries to light and heat energy radiating from the light bulb. The user is given an ammeter and a voltage meter that can be connected anywhere on the component in the simulation.

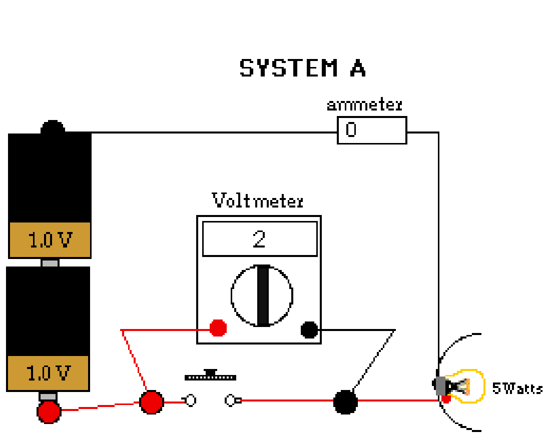

Figure 2a: Electrical System

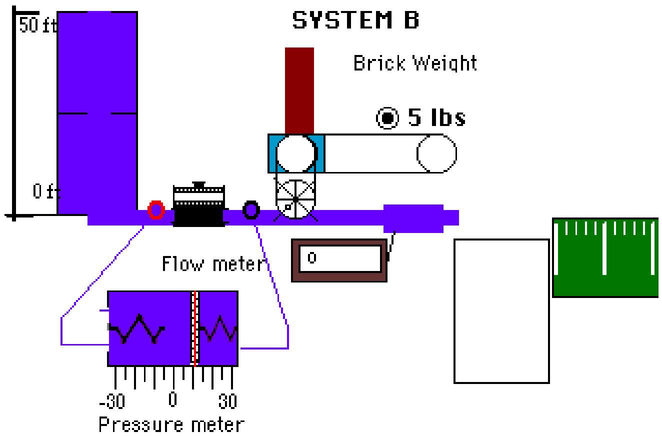

Figure 2b: Fluid system

Figure 2b illustrates a fluid delivery system designed to convert the energy stored in a water tower into mechanical energy for moving bricks by throwing them. Similar to the ammeter and voltmeter in the flashlight simulation, the fluid system has a flow meter and pressure gauge to monitor various parameters of the system.

We used the interactive analogies as a way to help students overcome misconceptions they displayed while defining solutions to a trouble shooting challenge related to a simple flashlight. To remediate these misconceptions, we used a sequence of interactive analogies to help students focus on various dynamics of the two systems. First, we asked the participants to map the relationships between the electrical system and the fluid system including the various components and how they work. In several instances we explained the idea of the brick thrower and the pressure and flow meter in the fluid system. All the participants understood the function of the voltmeter and how to use it. Then, we turned the systems "on" by closing the switch in the electrical system and opening the valve in the fluid system and asked them to make correlations between the dynamic portions of the systems, i.e. current and power consumptions. The goal of the next set of simulations was to help focus attention on making predictions on how changes in one domain would be manifested in the other domain. This was done by starting with simulations in one domain, then moving toward an interactive analogy. That is, two states of the fluid system were presented to a student, one with the tank full the other with the tank only 80 percent full. The goal was for students to comment on how this change altered the dynamics of the system. This set up the next interactive analogy consisting of the flashlight system with weak batteries and the fluid system with lower tank level. Before interacting with that analogy students were asked to make predictions about what they think the comparison is between the two domains. These interactive analogies provide an opportunity to use/practice the analogy generatively by using the analogous domain (water) to predict behavior in the target domain (electricity) in multiple situations.

We used these interactive analogies in several exploratory pilot studies. One example illustrating the strength of interactive analogies relates to a question we posed about the behavior of electricity in the flashlight. We demonstrated to students that when a voltmeter is connected across an open switch, then the voltage is equivalent to the voltage across the batteries as shown in figure 2a. Then we demonstrated that if the switch is closed, as in figure 3a, then the voltage goes to zero. This effect was not intuitive to most students, and many had not even noticed it. Most students could not describe why the voltage is initially equal to the battery voltage and why it goes to zero when the switch was closed. But, when we introduced the same phenomenon using the fluid system then students could easily work through the concept of equalization. That is, when a valve is closed, as in figure 2b, then the pressure (or potential energy) on one side of the valve is higher than on the other side. When the valve is open and water is free to flow, then the pressure equalizes across the valve. This simple demonstration helped them quickly make the move toward understanding of voltage as potential energy and that the water flowing is similar to current flowing. When the electrical system is shown right next to the fluid system, it becomes easier to understand some of the concepts of electricity.

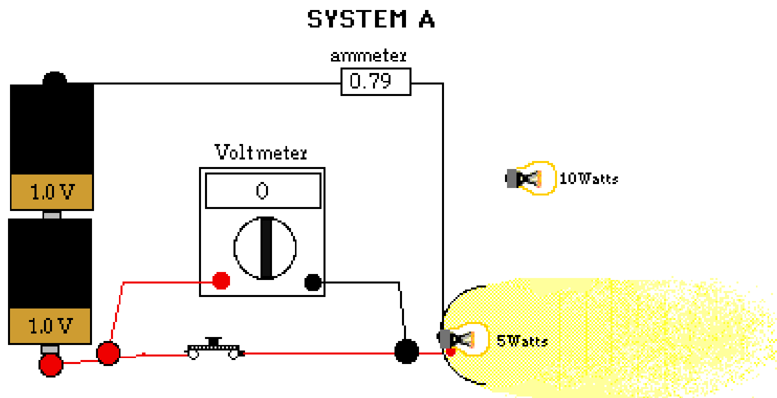

Figure 3a: Active Electrical System

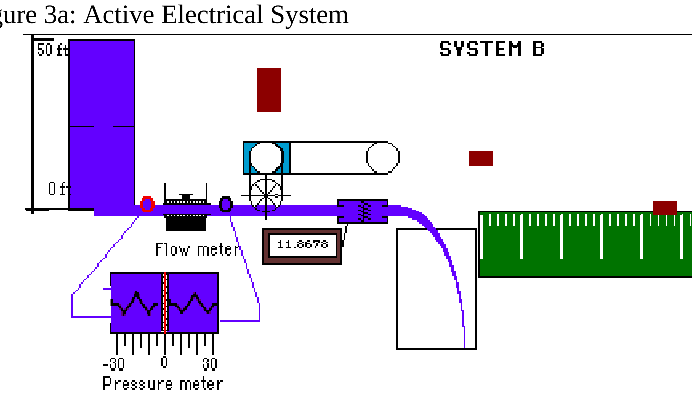

Figure 3b - Active Fluid System

Pairing simulations from different domains provides an opportunity to notice important features of both domains. One assumption about interactive analogies is that a learner isn't always fluent in either domain. Comparing and contrasting the two system can help improve understanding of the base domain. In the current case, one individual developed a better understanding of flow pressure as they came to a better understanding of a voltmeter. Another individual learned about the effect of raising a column of water on the potential energy (pressure) to the system. So, for example, the individual concluded that he could improve the flushing of his water-efficient toilet by raising the tank. This would add pressure without requiring an equivalent increase in the amount of water. Previously, he thought that the only way to increase water pressure was to "pile up" more water so it would press down.

One of the most exciting benefits of interactive analogies is that they helped the students get a better understanding of the limitations in their own understanding. This formative self-assessment helped guide students in their inquiry of the simulation and the questions they asked of the instructor. For example, seeing the water pouring into the tank and looking at the negative lead of the batteries led one student to realize that they did not fully understand the concept of ground. To the student, the water simulation exhibited ground because the water flowed into the tank. But, the electrical simulation did not exhibit ground but instead showed a positive to negative flow. This led to a fruitful discussion about how the notion of voltage was relative. So, for example, if the whole tank system were raised or lowered, the effective pressure would be the same. This led to a discussion about the voltage in the battery system and how it might differ if the system connected with the ground instead of the negative terminal of the battery.

Limits with interactive analogies currently fall into two classes. The first relates to deciding when to rely or not rely on an analogy. As stated earlier, the mapping between analogies is not always perfect. Part of learning to use an analogy is knowing the occasions where the analogy works. Some errors occur because people do not realize an analogy has broken down. Other errors occur when a valid analogy exists, but a participant does not accept it. For example, one participant predicted, like many others, that replacing a 5 watt bulb with a 10 watt bulb would increase the resistance in the circuit which would reduce the flow. He was very surprised to actually see the current increase. Without prompting he experimented with the water system to come up with a similar analogy. He recognized the mapping which related light intensity to brick distance, but was unwilling to believe the analogy was right and that the resistance in the 10 watt bulb could actually be less than the 5 Watt bulb.

A second class of limitation occurs when neither simulation provides the particular insight one needs to move ahead. Even in situations where the analogy between two systems is very close, the prior knowledge of the learner is insufficient. For example, one participant struggled to explain why there was a pressure drop across the valve and paddle wheel. He could correctly configure the electrical system to demonstrate the analogous voltage drop across the switch and light bulb. He recognized that this was a clue toward solving it, but could not describe why this phenomenon would occur in these systems.

It is important to note that these limitations rose in an experimental context, not in an instructional context. Ideally the limitations indicate the types of resources one would include when using interactive analogies for classroom instruction. We believe that it is useful to combine interactive analogies with meaningful instruction to help develop deep understanding. Interactive analogies, for example, can prepare students to learn more from traditional activities, such as lecture (Schwartz and Bransford in press).

4. Future studies

We are currently conducting a straight forward, proof-of-concept study to examine the benefits of interactive simulations. In the simulation condition, students solve problems with a simulation of some simple circuits. In the analogy condition, students solve problems with the electricity simulation plus they are told to think of a water analogy to help them. In the interactive analogy condition, the students receive both a circuit and a water simulation. This "added-value" design should help us partial the effects of interactive simulations. There are four types of effects of particular interest. The first is whether the interactive simulations show benefits on post test items requiring the solution of circuit problems. The second is whether the students are better prepared to learn new concepts outside the context of the simulation (e.g., capacitance). The third is whether the interactive simulations make student thinking more visible. We are particularly interested in whether this approach will help students and teachers make formative assessments of their understanding. The fourth type of measure is more descriptive in that it tries to describe how student learning, particularly experimentation, feedback, boot strapping, and self-correction, is affected by the interactive analogies.

There are also a number of issues about the design and use of interactive simulations that we plan to explore. One issue is whether the two simulations should be automatically yoked. For example, if a student manipulates one simulation, should the other simulation update itself to stay in correspondence (as in much of the work on linked representations). Alternatively, perhaps the student's task could be to change one simulation first, and then try to figure out how to put the analogous simulation into correspondence. A second issue is how to encourage students to explain their understanding of the mapping. We do not want students to understand correspondences merely at the level of correlations. That is, we want them to be able to articulate the corresponding structures and causal relations. One possible approach is to have students explicitly map out the correspondences between components as well as correspondences in qualitative relations (i.e., if X goes up in domain one and Y goes down, what is the equivalent in domain two). A complementary approach is to ask students to explain the "unifying concept" that makes the relations parallel (e.g., a store of potential energy for a tank and a capacitor). A third issue is whether the interactive analogies can be designed to help students understand the limitations of a given analogy. This helps students develop a more fine-grained understanding of the detail of the target domain, and it helps students learn when to abandon one analogy, perhaps in favor of another.

References

[Bell 1998] Bell, B. (1998). Investigate and decide learning environments: Specializing task models for authoring tool design. The Journal of the Learning Sciences, 7(1), 65-105.

[Brophy 1998] Brophy, S. P. (1998). Learning Scientific principles through problem solving in computer supported and laboratory environments. Unpublished Doctoral Dissertation. Vanderbilt University, Nashville.

[Crews Biswas Goldman and Bransford in press] Crews, T. R., Biswas, G., Goldman, S. R., & Bransford, J. D. (in press). Macrocontexts plus microworlds: An anchored instruction approach to intelligent learning environments. *Journal of AI in Education*..

[CTGV 1997] Cognition and Technology Group at Vanderbilt (1997). *The Jasper Project: Lessons in curriculum, instruction, assessment and professional development*. Mahwah, NJ: Erlbaum.

[Getner 1989] Gentner, D. (1989). The mechanisms of analogical reasoning. In S. Vosniadou & A. Ortony (Eds.) Similarity and analogical reasoning. Cambridge, England: Cambridge University Press.
[Getner and Gentner, 1983] Gentner, D., & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. L. Stevens (Eds.), *Mental Models*. Hillsdale, NJ:Erlbaum.

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

[Holland Holyoak Nesbett and Thagard 1986] Holland, J. H., Holyoak, K. J., Nesbett, R. E., & Thagard, P.R. (1986). *Induction: Processes of inference, learning, and discovery*. Cambridge MA: MIT press.

[Ross and Kennedy 1990] Ross, B. H., & Kennedy, P. T. (1990). Generalizing from the use of earlier examples of problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 16, 42-55.

[Reeves and Weisberg, 1994] Reeves, L. M., & Weisberg, R. W. (1994). The role of content and abstract information in analogical transfer. *Psychological Bulletin*, 115(3), 381-400.

[Schwartz and Bransford in press] Schwartz, D. L., Bransford, J. D. (in press). A time for telling. *Cognition and Instruction*..

[White and Frederiksen 1998] White, B. Y., Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*. 16(1), 3-118.