CHAPTER
13

Imaginary Worlds

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Leaders today seem to be suffering from what might be called a failure of the imagination. We seem to be continually finding ourselves in situations where the leaders say something like "no one could have imagined that this would happen." For example: Who could imagined that Hurricane Katrina would breach the levies in New Orleans; who could have imagined that an insurgency would arise from the U.S. invasion of Iraq; who could have imagined that falling foam could critically damage a space shuttle; who could have imagined that people would crash airplanes into buildings; and so forth. Some time after such statements were made it has turned out that people did imagine such possibilities, so it was humanly possible, but the decision makers were committed to one way of thinking about these things and so did not imagine alternative ways that the world might turn out than what they expected. For several years I have been studying various aspects of imaginary worlds, when and how people construct and use them; but in looking back now I see that the seeds of this work were laid in the story understanding and memory research I did with Gordon Bower in the later 1970s.

Particularly striking in retrospect is a paragraph that appeared in a paper we published in the journal *Poetics* in 1980 (Black & Bower, 1980). The initial parts of this paper critiqued the extant story grammar theories of story understanding and memory, then proposed that the structure of stories could be characterized as one or more story characters acting on the world of the story trying to move the state of that world from the initial state to a goal state (i.e., problem solving in the Newell & Simon, 1972, sense) and that the critical path of state transitions (actions and events) that described the change that did occur would be the best remembered (and the further off that path the worse the memory). We presented a variety of data to support our approach, and it was our version of the basic proposal originally made by Schank (1975) that story memory is a causal and intentional network of actions, events, and states. I have done subsequent research that supports this basic idea (e.g., Black & Bern, 1981), but it has since been formalized and much more extensively researched by Trabasso, Graesser and their colleagues (see Goldman, Graesser, & Van den Broek, 1999).

However, the paragraph that struck me in a recent reading appeared near the end of the paper where, perhaps inspired by being in a journal called *Poetics*, we took poetic license (going beyond our existing formal research) and said the following in a section labeled "Storyworld" (pp. 247–248):

> Readers report that they construct visual images of the scenes being described in stories. They say they use the text to construct and enact a play in the theater of their mind's eye. Perhaps they even sit on top of the shoulders of the characters with whom they identify. We could dismiss such introspections as irrelevant epiphenomena if we could be sure that our theoretically reconstructed hierarchy of propositions and plans characterizing the subject's story knowledge were a complete rendering. However, it is likely that the subject's image of the storyworld has information implicit in it beyond that available in it beyond that available in the propositional listing of the scene. The subject can up-date and "see" dynamic changes of characters, objects, and locations in his storyworld: he has available for inspection not only the starting and ending state of a character's motion but also intermediate points along the dynamic path. The reader can "see" that objects afford or suggest certain actions and prevent others. Furthermore, the reader's storyworld model allows him to experiment with hypothetical changes in his imagination. So he can imagine what would have happened had circumstances been different in the storyworld. Thus, readers can answer questions like, "How could this story have been different if Superman had been unable to fly?", or "If St. George hadn't had a lance, how might he have overpowered the dragon? Could he have pacified and domesticated it?". By such questions we can learn something about the reader's model of the story world and of the characters in it.

Thus, this paragraph proposes that there is a level of memory representation for a story (the Storyworld) that provides a referent world for the symbols and relations in the propositional content of the story text to refer to, and thus adds the referent aspect of meaning to the sense aspect of meaning provided by the causal network of propositions (Carnap, 1956). This same general idea was also proposed shortly thereafter by the mental-model proposals by Johnson-Laird (1983) and Gentner and Stevens (1983), and the situation model proposal by Van Dijk and Kintsch (1983). However, there is also more: Specifically, the Storyworld proposal involves visual and spatial imagery, which not all the other proposals did, and in addition the idea that the Storyworld provided an ability to imagine how things could have been different from the way the story played out. This perspective on story understanding thus seems to have the flexibility of a modern video game where the players make different choices and the game narrative then proceeds differently (Black, 2006).

FROM STORYWORLDS TO IMAGINARY WORLDS

Earlier, we had done a series of studies showing spatial-layout effects in comprehension and memory of simple compound sentences and sentence pairs using deictic terms for the spatial manipulation (Black, Turner, & Bower, 1979). For example, college undergraduates would take longer to read a shift in point of view (e.g., " John was working in the front yard, then he came inside"; the readers have to shift the perspective point from which they are viewing this scene), than a consistent point of view with only one word change ("John was working in the front yard then he went inside")—they also misremembered the point of view shift sentences as being consistent instead (i.e., misremembered "came" as "went"). Thus even in this minimal situation, these college undergraduates (skilled readers) would set up a sketchy spatial layout for a sketchy story. In later research, Bower and Morrow (1990) showed that if study participants memorized the floor plan of a building (including the relevant objects in the building), then they used imagery to track a narrative protagonist as they moved through this building in the narrative: that is, as they moved through the Storyworld.

IMAGINING THE WORLD OF A CATHEDRAL

Recent research I have done seems to indicate that there is more to these Storyworlds than just objects laid out in space (Van Esselstyn & Black, 2001). Also, it seems unlikely that humans would have evolved a cognitive mechanism only for stories, so at this point I want to shift the terminology to calling them Imaginary Worlds and extending their application to content beyond stories (as indeed the mental-model theories cited earlier did). In this research, we were interested in whether using new technology that allowed learners to take virtual tours of three-dimensional (3-D) virtual spaces would allow them to remember facts and spatial relations about those spaces better than presenting the same content in a purely textual form or in a text and pictures form. In technology terms, we were comparing learning from hypertext, hypermedia, and virtual reality. We thought that providing the 3-D virtual tours would assist the learners to construct the Imaginary World that would then provide an effective way to organize the content for later memory retrieval because moving through the 3-D virtual worlds on the computer would correspond more exactly to moving through a 3-D mental world.

For content we used St. John's Cathedral, which is conveniently located adjacent to the Columbia University campus, but is rich in historical, architectural, and art history details (it is the largest gothic cathedral in the world, but still unfinished after more than 100 years). The basic design of the computer system we created is shown in Figure 13–1. There are three key areas of the screen: The rectangular area at the bottom of the screen presents the facts about the area of the cathedral that is shown in the picture and marked on the floor plan, the area on the right-hand side shows the floor plan of the cathedral with dots marking the key areas and where the learner is virtually located, and the picture is in the upper left-hand corner.

Across three experiments, we compared various combinations of this interface design to examine their effectiveness for helping learners remember the facts present in the text, the spatial location of a given item, and the spatial direction one would move to go from one item to another (spatial relations). We had a text-only condition, a text-plus-floor-plan condition, a text-plus-floor-plan-plus-static-picture condition, and a text plus floor plan plus a virtual tour picture. The virtual tour picture moved the learner through the cathedral as they moved the computer mouse. All the conditions, except the text only, could also move around the cathedral by pointing and clicking on one of the dots on the floor plan.

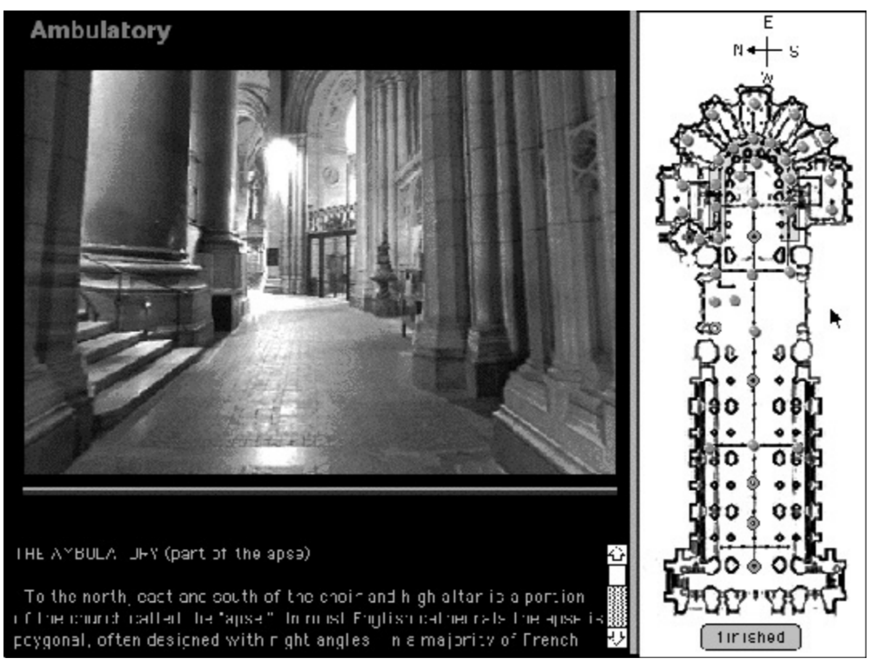

Figure 13–1. Cathedral multimedia program.

In the first two experiments, the text-only condition did very poorly but to our surprise there wasn't much difference between the text, text-plus-picture, and text-plus-virtual-tour groups as long as the floor plan was there to provide a spatial context. There was a slight difference in favor of adding pictures but not much, and the virtual tour was no better than the static pictures. Thus, our learners (and they were Columbia U. students) were able to construct a spatial imaginary world with minimal input (text plus a floor plan). We didn't examine whether these results varied with visual and spatial abilities (e.g., were high–visual and spatial ability learners better able to use minimal input), but these differences were probably muted here because we were dealing with high-ability learners (however, see the Constructing Imaginary Worlds section later in this chapter).

In a third experiment, we added some text to all conditions explaining why the cathedral is laid out spatially the way it is—that is one reason we chose the cathedral content, because it has a strong spatial design rationale. The pattern of results was the same, except that now the virtual tour group did much better than the others. This suggests that the most effective imaginary worlds are the ones where the spatial layout has a meaning and is not just arbitrary.

IMAGINING MARS COLONIES

In 2000, we had an opportunity to see what kinds of imaginary worlds middle school students in New York City would construct. This opportunity was provided by the nationwide Mars Millennium Project being pushed by several government agencies including NASA and the Clinton White House. This project was supposed to use the landing of two space probes on Mars to motivate precollege students to learn more about Mars and science in general by designing Mars Colonies. Unfortunately, these probes did not have the intended motivational effects because they crashed rather than landing—but the kids still seemed somewhat interested in the topic. Fortunately for our purposes, NASA put a lot of information about Mars on their Web sites for the kids to access as part of this project. We used this material together with discussions to inform the students we were working with in a South Bronx middle school, and then had them create their designs for Mars Colonies using paper and pencil.

We then scored those designs for how many entities were there, how many relations were specified between these entities, and whether they described how the Mars Colony would work in terms of physical (e.g., how are we going to get power like electricity), biological (e.g., how are we going to get air and water), and social (e.g., how are the colonists going to make decisions) systems. Crucial for specifying these systems is describing the kinds of functional relations that describe how entities move through space and affect each other (Hachey, Tsuei, & Black, 2001). The Mars Colonies designed by the students were completely disconnected and disjointed: They had almost no relations of any kind (much less dynamic functional relations); they merely laid out a bunch of entities spatially (e.g., the apartment building goes here, the McDonald's restaurant goes here, etc.). Thus, these students needed help to learn how to design dynamic imaginary worlds that had not just a surface but also functional relations behind the scenes that allow them to function and allowed reasoning about how the functioning might differ in different circumstances (as described in the Storyworld quote earlier).

Fortunately, we got another shot at fostering middle school students' abilities to imagine Mars Colonies because NASA tried again in 2004 and managed to land two terrific and very motivating Mars Rovers that are still going today, long after their anticipated lifetimes are over. We went back to the same school (but different students), but now prepared them to think in terms of dynamic imaginary worlds by having them learn to diagram dynamic earth science phenomena (e.g., how volcanoes work) using system diagrams like the one shown in Figure 13–2.

More formal system diagramming (e.g., *Stella II*) has proven too difficult for precollege students, but this system, designed by Lisa Tsuei, worked well for these middle school students. This system-diagramming approach uses different

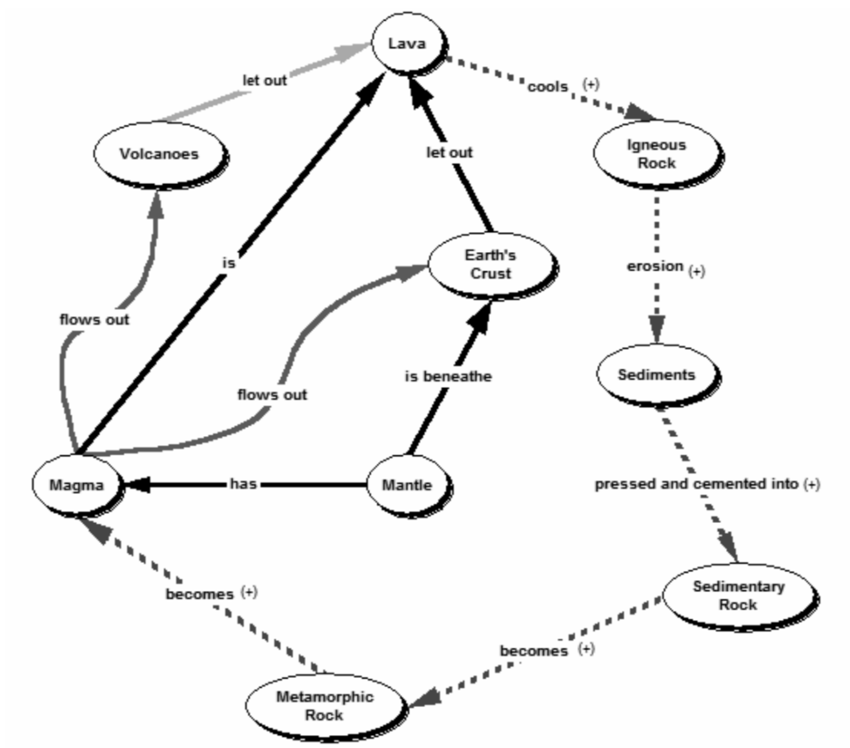

Figure 13–2. System diagram with different kinds of functional links.

kind of arrows to represent different kinds of relations: The wavy arrows indicate the functional relation of moving entities (e.g., lava flow), whereas the dashed lines indicate the functional relations of changes in entity state (e.g., lava cools from liquid to solid), and the solid lines indicate propositional relations between entities (e.g., the mantle has magma). After experience with these system diagrams in an earth science unit, the students transferred these concepts when asked to design Mars Colonies later: Now their Mars Colony designs represented dynamic Imaginary Worlds and colonies that worked (Tsuei & Black, 2006).

IMAGINARY WORLDS IN SCIENTIFIC INQUIRY

Efforts to improve the scientific reasoning skills of middle school students, or even adults like community college students, can be frustrating because people are resistant to applying simple scientific-reasoning rules like variable isolation—the idea that to conclude that a factor is causally related to another factor one has to vary the independent factor, keeping others constant, while looking for corresponding changes in the target dependent factor. People have a tendency to want to change more than one factor at a time, probably in an attempt to get a bigger effect, but it makes causal inferences problematic.

For example, we used a computer simulation of flooding to examine middle school students investigating what causes flooding (Kuhn, Black, Kesselman, & Kaplan, 2000). The cover story of this simulation game was that the students were developers trying to figure out how high off the ground they needed to build cabins on sites around lakes in the mountains so that the cabins would not be flooded. Figure 13–3 shows the basic elements of the computer screen design (this system has several kinds of screens but this is the main design). The box in the upper left-hand corner lists the candidates for factors that may cause an increase in flooding (water pollution in the lake, lake water temperature, soil depth, soil type, and site elevation). The students specify the values of the factors for a given site and the flooding level they expect, then the system tells them the actual flooding level both numerically at the bottom of that box and graphically showing in the next box to the right a water level on a cabin with supports at the level they predicted the flooding to be. A trial is composed of the students specifying the factor values, getting the flooding feedback, and then filling in the box at the bottom as to what they now believe about the causal relation between the factors and flooding (to help in this judgment the system also gives the results of the immediately previous trial in a box on the top right-hand corner).

If they followed the variable-isolation rule, then the students would proceed through these trials changing only one factor at a time, but instead they tended to change more than one factor at a time and they tended to stick to their theories about what is causal and what isn't despite the evidence presented by the results of the trials. Gradually, over a several-week period, students' scientific-inquiry skills and understanding of flooding slowly improved a little, but efforts to yield

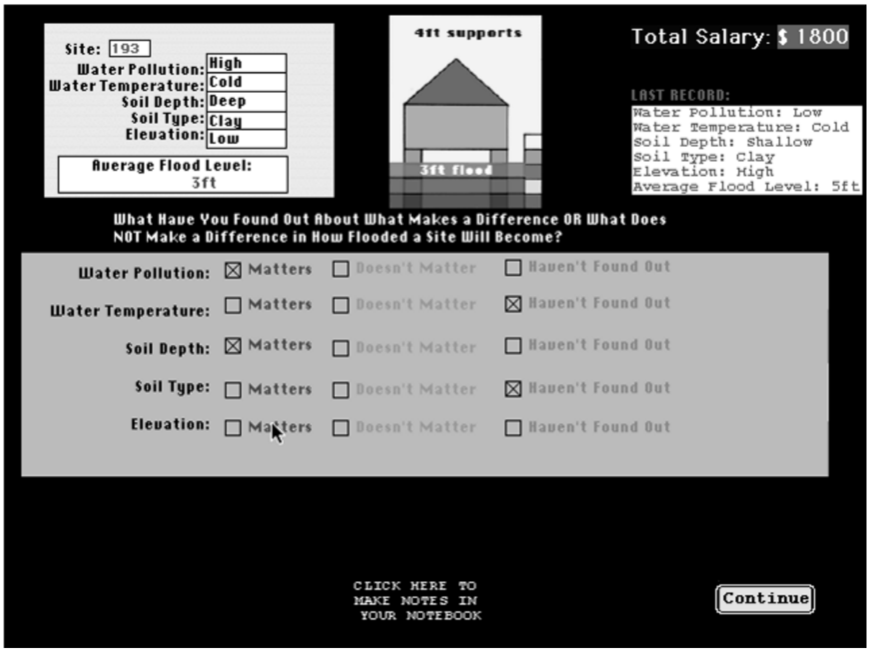

Figure 13–3. Flooding inquiry simulation.

larger improvement have seldom worked (in this case, we showed them effective and ineffective trial choices by fictitious "other" students but that didn't help).

There are many anecdotes from scientists reporting that they use Imaginary Worlds to conduct "thought experiments" to help them understand and develop theories. This has become an increasingly important ability as the scientific phenomena studied have become more and more removed from everyday experience. A striking example are the wild imaginings of string theorists in modern physics as related by the best-selling book *The Elegant Universe* by Columbia physicist Brian Greene (2000; and the striking graphic visualizations in the accompanying PBS TV show and Web site, www.pbs.org/wgbh/nova/elegant/program.html). Perhaps like these scientists, the participants in scientific reasoning studies are struggling to create Imaginary Worlds integrating a variety of factors rather than looking at factors in isolation. We tested this idea by adding a condition to our earlier experiment where we gave students some information as "hints" that might help them construct an Imaginary World of the causal mechanisms behind the factors (Kaplan & Black, 2003). Figure 13–4 gives an example of one such piece of information.

Students in one condition were given this sort of textual and graphic information that showed that the soil type of sand was more loosely packed and had

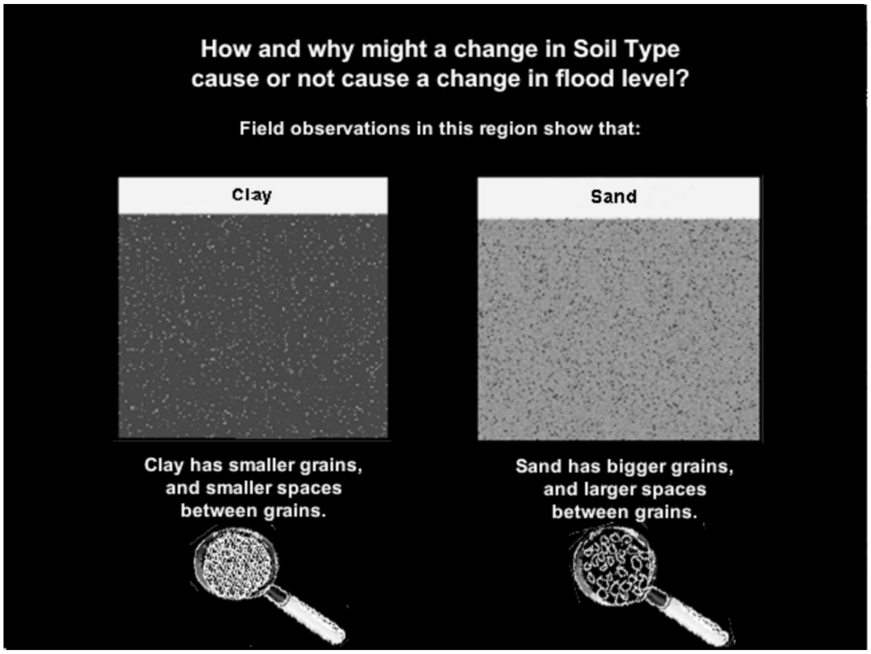

Figure 13–4. Flooding imaginary world hint.

greater spaces between the particles (and the particles are larger) than did the soil type of clay (with smaller particles). Thus, if they visualize the dynamic Imaginary World using this information, they could potentially see that water will more readily run through sand yielding less flooding than with clay (although, as this visualization could also show, it interacts with bedrock depth). The students who had this kind of Imaginary World component information showed more improvement in their scientific inquiry skills and better understanding of flooding than the students who did not. This suggests that viewing people's scientific reasoning in terms Imaginary Worlds may provide insight into what they are doing and how to improve it.

VIDEO GAMES AND ANIMATED AGENTS

Video games have been proposed by some (e.g., Gee, 2003; Prensky, 2004) as powerful environments for learning the kind of Imaginary World understanding and thinking I have been discussing. I have some sympathy for this position: For example, the flooding simulation described in the last section is like a simple video game. However, I have also argued (Black, 2006) that there is an inherent conflict between commercial entertainment game design and what is needed for effective learning: Specifically, commercial games try to make it as hard as possible for players to figure out why something happened (i.e., to enable the player to fully understand the game's underlying Imaginary World) so that they will play a long time and feel that they got their money's worth in entertainment value. However, for effective learning, games need to be designed so that after a short period of struggle the players/learners can get a depiction of why something happened (according to Schwartz and Bransford's, 1998, results, this should be effective for learning). Commercial entertainment games lack this explanatory transparency.

One system that provides a kind of transparency is the Teachable Agents project being done by Biswas, Schwartz, Bransford, and the Teachable Agents Group at Vanderbilt (2001). In this project, students learn about an ecological system (or potentially anything) by drawing concept maps similar to the system diagram shown in Figure 13–2 (but without the different shapes) to specify what an "agent" depicted as the drawing of a person on the computer screen would know about the topic. The students can then see how good their representation of the knowledge is by how well their agent can answer questions about the topic. An advanced feature of this system is that it can interpret the knowledge diagram drawn and generate the answers from there. Thus the students can learn by "teaching" their agents and then get feedback by whether the agent does well or badly.

We have a related project called the REAL (or REflective Agent Learning environment) in which we are trying to get the computer agents to demonstrate their knowledge by interacting with the environment in addition to answering questions (Bai & Black, 2006) , but the Teachable Agents project is much further along. REAL expands the transparency by adding a representation for procedures to the propositional and function relations in the Teachable Agent. Furthermore, it provides a depiction not only of how the Agent thinks the virtual world works, but also of how the virtual word actually works so that the students can learn from the contrast.

DIRECT-MANIPULATION ANIMATION SIMULATIONS

Some of our most recent research has focused on having students learn and use the functional relations between entities that the research described here and other research I have done with Dan Schwartz (Schwartz & Black, 1996a, 1996b) has seemed to indicate is the crux of being able to effectively construct and reason with dynamic Imaginary Worlds. We have been examining this issue by having middle school students learn physics concepts like conservation of energy (the relation between gravity and kinetic and potential energy) using variations on graphics simulations like the one shown for a roller coaster in Figure 13–5 (created by Maggie Chan). We have found what we call "direct-manipulation animation" to be

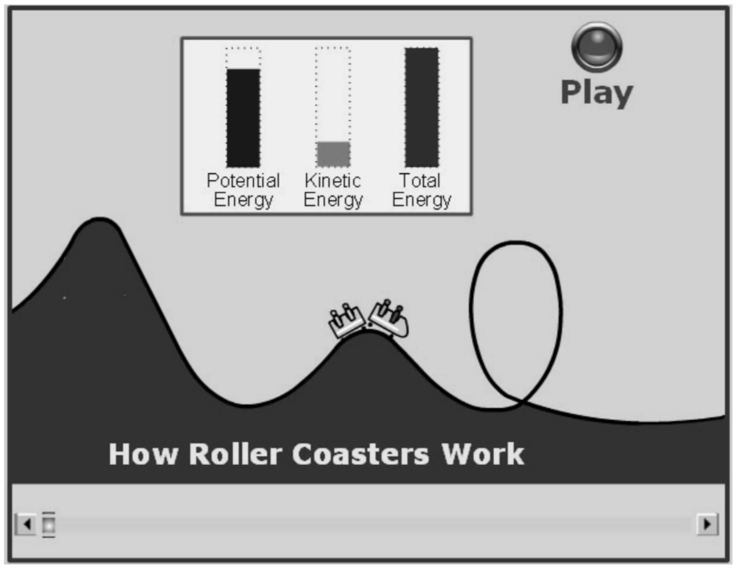

Figure 13–5. Roller coaster simulation.

particularly effective in having students learning these functional relations. Direct-manipulation animation (sometimes also called "user-controlled animation") has students manipulate one variable of interest (here height in the gravity well) by moving a slider, while observing the changes in values of other variables (here potential, kinetic, and total energy of the roller coaster cars).

Students in the direct-manipulation animation condition learned better on a variety of memory and problem-solving measures than did students who were played the animation as a movie (with no control over the cars), shown snapshots of critical points along the path shown as a slide show, or shown just the overall picture with textual explanations (Chan & Black, 2005, 2006a). Like other researchers, we have somewhat surprisingly found that animation is not more effective than the slide show condition, and sometimes worse (Mayer, 2001; Tversky, Morrison, & Betrancourt, 2002), but our direct-manipulation animation condition is better. Thus, graphic simulations that allow learners to directly manipulate entities and observe animations of the resulting changes in other entities is the best way we know so far of having students learn dynamic Imaginary Worlds.

CONSTRUCTING IMAGINARY WORLDS

Though a graphic simulation with direct manipulation animation is an effective way to learn the functional relations of Imaginary Worlds, is it always necessary? As we saw in the in the cathedral study, sometimes learners can construct elaborate mental representations of Imaginary Worlds with fairly minimal input. To investigate this question, Maggie Chan created two more graphic simulations to go along with the Roller Coaster simulation described in the last section—namely, a simple Swing simulation and a more complex Pole Vaulting simulation. Thus, we now have physical-system simulations involving conservation of energy at three levels of complexity: simple (the Swing), medium (the Roller Coaster), and complex (the Pole Vault)—of course, these levels of complexity are relative rather than absolute (one can certainly imagine much more complex systems than a pole vault). We also created two other kinds of learning materials to go along with the graphic simulations: namely, text alone and text plus diagrams. And we tried out these nine kinds of materials-complexity combinations on sixth graders and seventh graders (Chan & Black, 2006b).

For the seventh graders, we found that for the simple system (the Swing) text alone was sufficient (text, text plus diagrams, and simulations yielded similar learning results), but for the medium system (the Roller Coaster) text plus diagrams was needed (the text condition yielded less learning whereas the text-plus-diagrams condition was the same as the simulation), and for the complex system (the Pole Vault) the simulation was needed because it yielded better learning results than the other two conditions. Thus, we have an interaction between presentation type and system complexity. For the sixth graders, there was no interaction: The students with the simulations always learned better regardless of the system complexity, with those with the text plus pictures next best and the text only the worst. We measured learning in this study in several different ways, varying from memory tests to near and far transfer problem solving. The differences were biggest for the problem-solving tasks, but were also there for the other learning tasks.

These results suggest that more capable students (in this case the seventh graders) may be able to construct simple Imaginary Worlds with minimal input (in this case text), but as the Imaginary World to be constructed becomes more complex then more sophisticated kinds of learning materials and activities may be necessary (moving up to text plus pictures and to graphic simulations). However, as in the previous section, it seems you always stand your best chance of constructing an Imaginary World with a graphic simulation using direct manipulation animation—but in some cases simpler materials are sufficient.

SEED IDEAS THAT SPARK THE IMAGINATION

In this chapter, I have described the intellectual journey that I have taken sparked by the ideas seeded by my discussions with Gordon Bower in the later 1970s that are embodied in the paragraph from 1980 quoted at the beginning of this chapter. This seems like a very productive model of education when it can be made to work: namely, that teachers should try to plant seed ideas in their students that with cultivation will spark the imaginations of the students. In fact, this relates to some of the research I have described: Namely, in the graphic simulations described in the last section and the cathedral virtual tour described earlier, students (particularly more capable students) were frequently able to construct Imaginary Worlds based on minimal input. The key, of course, is knowing what minimal seeds need to be planted for what students and how they need to be cultivated in order to enable the Imaginary Worlds to grow.

In my own case described here, the beginning was examining a deeper kind of story understanding where readers would construct an imaginary world of the story that would allow them to consider alternative pathways the story could have taken. From there these ideas expanded into understanding and learning from other media and technologies like multimedia computer programs, simulations, video games, and virtual worlds. The tasks that would show understanding also expanded from remembering and answering questions about stories to solving math and science problems, and conducting scientific inquiry. Gordon Bower is a master at planting and cultivating productive seed ideas. Learning from his example, I try to do the same with my own students.

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