Supporting Discovery-Based Learning within Simulations

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Abstract: This paper begins by presenting an overview of visualization in education, followed by two main theoretical frameworks to guide research: Dual coding theory and mental model theory. These ideas are used to frame design and research questions for educational simulations. Two main areas of simulation research are then reviewed: the use of different feedback representations and challenges faced by learners in discovery learning approaches. Research shows that discovery learning within simulations is very difficult for students, but can be effectively supported with the use of different simulation representations and creative designs to the simulation's interface. This research suggests that representation matters but is very context sensitive.

Over the past 15 years I have studied children and adults using educational simulations based on various pedagogical (e.g. inductive and deductive learning) and philosophical approaches (i.e. constructivist and objectivist). My goal in this short paper is to summarize some of this research and also provide some of the background that frames my research questions. As an instructional technologist, I have been influenced by the use of instruction to shape learning, but as someone who accepts a constructivist orientation to learning, I know that instruction is but one path to learning. When given little or no instructional support, I am interested in the strategies that people use to learn given the opportunities of an interactive simulation. Even more important, I am interested in those times when they run into problems and need help. My goal is not to withhold instruction from them, but to gain a better understanding of when instructional support is unnecessary or, conversely, most needed.

The general conclusions I have drawn from this research and experience are not neat and tidy. I am unable to say that simulations are "better" than other learning approaches. One of the most important conclusions is simply that learning with simulations is heavily context-bound. This does not frustrate me, but rather intrigues me. It reminds me that human cognition and motivation are among the most complex phenomenon we can study. As a researcher, it generates curiosity leading to more research. Yet, as an educator, I admit that I grow restless at times when design principles prove elusive.

This paper is presented in three sections. First, I present a brief overview of visualization in education. Second, I present two theories relevant to my work: Dual-coding theory, a well-established and studied theory that offers much guidance in deciding when and how to design visualization for educational materials; and mental models, a theory that attempts to model and explain human understanding of complex phenomena. I hope these first two sections give workshop participants some useful visualization background, at least for the design of highly visual educational simulations. Third, I address interactive multimedia, basing most of my discussion on the use of simulations. However, I also consider how attributes of microworlds can influence simulation design.

Visualization in Education: A Primer

There is a tendency to use armchair methods of deciding when, where, and how to incorporate graphics in instructional and training strategies and materials. This can lead to unexpected results. Research is just beginning to demonstrate conditions under which static and animated graphics are generally effective, as well as those where graphics serve no purpose or, worse, do harm (Levin, Anglin, & Carney, 1987). For example, consider the cultural symbolism of the owl. Many American teachers like to adorn their classrooms with fanciful images of a friendly wise owl to symbolize an educated person. Yet, an owl often represents an evil omen for many Native Americans, leading some students to be alienated by such graphics. All teachers should carefully consider the impact of such innocent graphics on all their students. Like most issues in education, the use of graphics represents a qualitative, not quantitative, issue. It is not simply a question of how many graphics are used that determines their effectiveness.

Three main types of graphics are commonly used in instruction: Representational, analogical, and arbitrary. Representational graphics share a physical resemblance with the object they are supposed to represent. For example, a passage of text explaining the purpose and operation of a submarine probably would be accompanied by a picture of a submarine. Representational visuals range somewhere between highly realistic (photographs) and abstract (simple line drawings).

Presenting students with an accurate representation of something may not always be the best learning approach. One such example is when students have little or no prior knowledge of the concept. Analogies or metaphors may be effective instructional strategies in such instances (Glynn, Duit, & Thiele, 1995; Glynn, 1995). For example, if students do not understand the idea that a submarine is able to dive under water, it might be more appropriate to first suggest that a submarine is analogous to a fish so students understand this characteristic. However, a better analogy would be a dolphin because it, like a submarine, must surface occasionally for air, or better yet, a whale, because of its size. Of course, a submarine is not a dolphin or a whale, so learners must understand that the analogy is being used only to represent similarities. Differences do exist, and it is important that students understand the analogy's limits. Educational psychologists often describe learning as a process that goes from the known to the unknown. An analogy can act as a familiar "building block" on which a new concept is constructed. Of course, if the student does not understand the content of the analogy, then its use is meaningless and confusing. Worse yet, students may form misconceptions from an inadequate understanding of how the analogy and target system are alike and different. The usefulness of the analogy, therefore, is largely dependent on the learner's prior knowledge. Graphics can help learner's see the necessary associations between parts of the analogy.

Arbitrary graphics offer visual clues, but unlike representational and analogical graphics do not share any physical resemblances to the concept being explained. In a sense, this category acts as a "catch-all" for any graphic that does not offer any resemblance of real or imaginary objects, but yet contains visual or spatial characteristics that convey meaning. Examples range from the use of spatial orientations of text, such as outlines, to flowcharts, bar charts, and line graphs. Charts and graphs are probably the most common types of arbitrary graphics.

So, the instructional designer is faced with many choices with how to represent information, concepts, and principles in educational material. As this section has demonstrated, the range of graphical representations is quite large. Consider, too, all of the other representations available beyond graphics — text, voice, music, sound effects, etc. This is further complicated by options that technology provides us. Of interest to me has been the computer's animation and interaction capabilities. Graphics can be animated, thus making a dynamic process come alive in an animated presentation. Animation can also be produced based on a person's input, such as a flight simulation program in which a virtual plane dives to the ground when the mouse is pushed forward.

Finally, all of these representations can be produced with highly differing degrees of quality. Just as the written word is expressed differently by tabloid newspaper writers and John Steinbeck, so too can instructional materials using graphics, text, and sounds, be produced with different quality assurances. All of these differences surely matter in how a person will eventually use the materials for learning.

Theoretical Support for Visualization in Learning

There is a large body of research demonstrating that the way information is represented matters greatly in the learning process. Two theories that are relevant to research on highly visual interactive simulations are dual coding theory and mental models.

Dual Coding Theory

In general, research indicates that pictures are superior to words for remembering concrete concepts. Paivio's dual coding theory is the most established and most empirically validated theory to account for this (Paivio, 1990, 1991; Sadoski & Paivio, 2001). This theory suggests a model of human cognition divided into two dominant processing systems — one verbal and one nonverbal. The verbal system specializes in linguistic or "language-like" processing. The nonverbal system concerns the processing of all nonverbal phenomena, including emotional reactions. However, since we are mostly concerned with visual information here, I will refer to this system hereafter as the visual system.

Dual coding theory predicts three distinctive levels of processing within and between the verbal and visual systems: representational, associative, and referential. Representational processing describes the connections between incoming stimuli from the environment and either the verbal or visual system. Associative processing refers to the activation of informational units within either of the verbal or visual systems, whereas referential processing is the building of connections *between* the verbal and visual systems. At the simplest level, dual coding theory predicts that words and pictures provided by instruction will activate these coding systems in different ways. Dual coding theory explains the picture superiority effect, mentioned earlier as it relates to the learning of concrete concepts, on the basis of two important assumptions. First, it is believed that the verbal and visual codes produce additive effects. That is, if information is coded *both* verbally and visually, the chances of retrieval are doubled. In other words, two codes are better than one. The second assumption is that words and pictures activate mental processing in different ways. Pictures are believed to be far more likely to be coded both visually and verbally, whereas words are believed to be far less likely to be coded visually.

The main application and study of dual coding theory to education has been in reading education. However, I believe it holds much promise in explaining and guiding efforts in designing multimedia for learning. Producing more referential connections should be expected when a user has the opportunity to interact with information in meaningful ways, especially given a variety of multiple representations. Simulations seem very well suited for such learning opportunities.

Mental Models

A mental model is a person's conceptualization, or personal theory, of some domain or environment (Gentner & Stevens, 1983; Jih & Reeves, 1992). Mental models serve as both explanatory and predictive tools as we interact in a complex environment. People form mental models to help themselves understand and solve problems in domains ranging from physics and parenting to kitchen appliances and elevators. Rather than being static or rigid, mental models are loosely organized and forever changing as people interact with their environment. Research of mental models usually comprises three things: the target system, the user's mental model of the target system, and the building of a conceptual model by someone else (such as an engineer or a teacher) to help the user understand the target system (Norman, 1988).

The target system is the actual system that a user is trying to understand, such as Newton's laws of motion or how a home's heating system works. With all of the attention on physics in this paper, let's explore the second. A person who incorrectly holds the "valve theory" of a home's furnace (i.e. theorizing that the thermostat controls a valve which lets heat into the room) would predict that moving the thermostat to 90 degrees would more quickly heat an icy house to the desired temperature of 70 degrees than would moving it to 80 degrees. However, since most furnaces operate on a "timer theory" (i.e. the thermostat simply turns the furnace on and off, but does not alter its output of heat), the user's mental model in which case does not match the target system, and consequently, the user may get confused and frustrated. A solution is to design the interface between the user and the target system in such as way as to better communicate the target system to the user, perhaps with labels or pictures on the thermostat itself. Such a design is called a *conceptual model*.

Conceptual models are often metaphorical, thus corresponding nicely to the use of analogical graphics described earlier. One of the most pervasive conceptual models for computers is the desktop metaphor, which likens a computer's operating system to an office desk complete with folders, files, and a desktop space in which multiple documents can reside. Of course, the computer is not *really* a desktop, but this metaphor helps most users make sense of a complex environment since the technical description of the computer (i.e. the target system) holds little meaning for most people. Such learning difficulties with older operating systems, such as MS-DOS, led Apple and Microsoft to adopt this metaphor. Is a desktop the *best* metaphor for a computer? Interestingly, most people have a hard time thinking of a computer in any other way. (Can you think of other metaphors for a computer?) Of course, conceptual models, like metaphors, can equally act to clarify or confuse. Just as a person who has no experience with a given metaphor may get little meaning at best or develop misconceptions at worst, so too may any one conceptual model help or hinder learning depending on the individual's experience with the metaphor. (As an amusing example, a recent television commercial on American television likens information technology to a basketball game with information being the ball. If you have never played basketball before, it unlikely this metaphor will work for you.)

Interactive Multimedia

There are many forms of interactive multimedia, so the focus here will only be on the use of simulations. There are two main ways to use simulations in education: Model-using and model-building. Model-using is when you learn from a simulation designed by someone else. This is common of *instructional* approaches where simulations are used as an interactive strategy or event, such as practice. Learning from using a simulated model of a system is different from learning from building working models in that the student does not have access to the programming of the simulation. The student is limited to manipulating only the parameters or variables that the designer of the simulation embedded into the simulation's interface. For example, in a simulation on Newtonian motion the user may only have the ability to change the mass of an object in certain increments, but not have the ability to change the initial starting positions of the objects or even how many objects will interact when the simulation is run. In contrast, model-building is where the learner has a direct role in the construction of the simulation. This approach is closely related to the work with microworlds. The concept of a microworld had its start with the Logo programming language developed out of the Massachusetts Institute of Technology in the 1960s and gained huge popularity with the advent of the personal computer in the early 1980s (Papert, 1980). Research and development of microworlds has come far since then, producing wonderfully creative products and approaches. A sampling includes Boxer (diSessa & Abelson, 1986), StarLogo (Resnick, 1991), SimCalc (Roschelle, Kaput, & Stroup, 2000), and ThinkerTools (White, 1993). Related to microworlds are modeling tools, such as StageCast, Geometer's Sketchpad (Olive, 1998), Interactive Physics, and SimQuest.

A review of microworlds is outside the scope of this short paper. Suffice it to say that the distinction between microworlds, modeling tools, and simulations can be very fuzzy. A simple delineation is in how the tool is used. I believe that a microworld possesses three main characteristics: 1) it provides an immediate doorway to a learner's inquiry in a domain by matching the learner's cognitive readiness to explore the domain; 2) it is intrinsically interesting to the user such that the user *wants* to explore the domain once seeing how the microworld works; and 3) the software allows the user to adapt (i.e. program) the software to explore new and interesting questions. Not surprisingly, the most celebrated microworlds, like Logo, are programming languages designed explicitly for the learning process. However, other software tools that have non-scripting interfaces, like Geometer's Sketchpad or Interactive Physics, can be considered either a modeling tool or microworld depending on their use in a classroom. It is very important to note that successful learning with a microworld assumes a conducive classroom environment with a very able teacher serving a dual role: teacher-as-facilitator and teacher-as-learner. The teacher's role is critical by supporting and challenging student learning while at the same time modeling the learning process with the microworld.

The question of when a microworld is or is not a simulation often troubles people. While ThinkerTools or Interactive Physics display trajectories of simulated falling balls, the underlying mathematical model makes the resulting representation much more "real" that a paper/pencil model. And although the ability to stop a ball in mid-flight has no analog in the real world, features like this make understanding the real world more likely. What is important is that the mathematical models of these environments represent the phenomenon or concept in question accurately followed by exploiting the representation for educational purposes. However, a tool like Geometer's Sketchpad is clearly *not* a simulation — its geometry is as real as it gets.

The model-using approach to simulations has had a long history in instructional technology, particularly in corporate and military settings. However, simulations have become very popular designs in the education market. There are three major design components to an educational simulation: The underlying model, the simulation's scenario, and the simulation's instructional overlay. The underlying model refers to the mathematical relationships of the phenomenon being simulated. The scenario provides a context for the simulation, such space travel or sports. The instructional overlay includes any features, options, or information presented before, during, or after the simulation to help the user explicitly identify and learn the relationships being modeled in the simulation. The structure and scope of the instructional overlay is, of course, an interesting design question and one that has shaped my research. Mental model theory offers much guidance to the design of an effective scenario and instructional overlay, such as thinking of them as an interactive conceptual model. This supports the idea of using metaphors to help people interact with the simulation.

My research with highly visual and interactive simulations has taken two paths. First, I have studied the use of different representations — graphical and textual/numerical — to convey the continual stream of feedback to students within science simulations. The difference is similar to the analogy of flying an airplane by looking out the window versus flying by the instruments. For example, when designing a simulation on Newtonian mechanics, one can represent feedback from the simulation in qualitative (pictures of moving balls) and quantitative (displays of the mathematics, such as the coordinates of the speed, direction, and position of an object), as shown in Figure 1. Second, I have investigated the relationship between how different scenario designs and varying levels of instruction support learning within a simulation. For example, I have studied how people make meaning from a simulation when it is designed with metaphors and model cases. I have also studied the strategy of breaking down the respective parts of a complex simulation so as to allow the user to focus on one aspect of the process at a time.

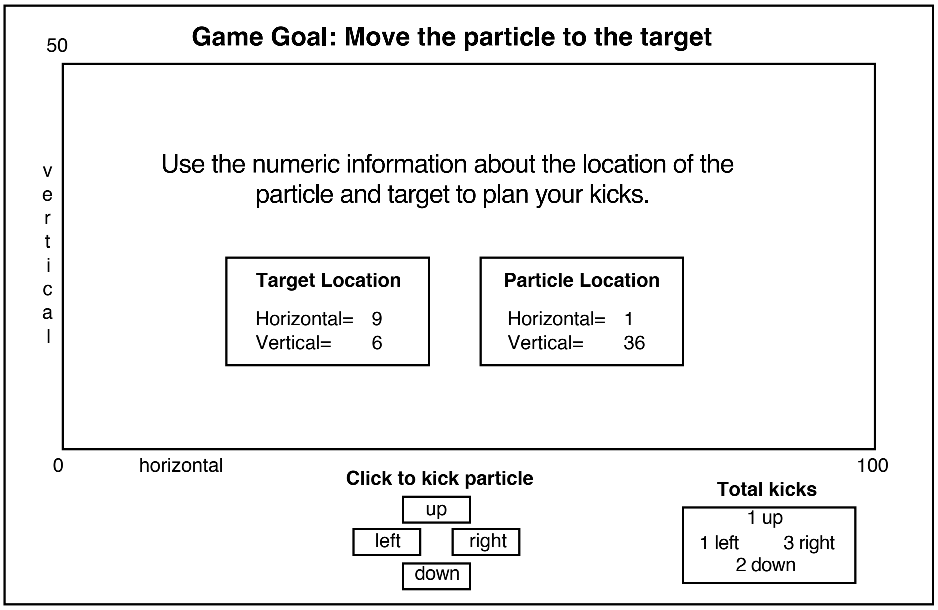

Figure 1. An example of a physics simulation in which feedback is presented solely in a numeric format.

A common goal for both research paths is my interest in understanding the relationship between presentation and interaction. So much of education is based on a teacher presenting information to students, followed by practice. I have long wondered if such an emphasis on up-front presentation is really necessary, especially when it is so divorced from the everyday experiences of the students. Using the rallying cry of "experience first, explanation later", I have investigated ways in which simulations can be designed to see if students are able to "discover" for themselves the rules underlying the simulation. If they are not, then what types of instructional inventions are necessary and when? Consequently, I have taken a minimalist approach to the use of instructional interventions in simulations.

de Jong and van Joolingen (1998) present one of the most thorough reviews of scientific discovery learning within computer-based simulations (of the model-using type). The goal of this type of research is to present a simulation to students and ask them to infer the underlying model on which the simulation is based. Scientific discovery learning is based on a cycle corresponding to the steps of scientific reasoning: defining a problem, stating a hypothesis about the problem, designing an experiment to test the hypothesis, collecting and analyzing data from the experiment, making predictions based on the results, and making conclusions and possible revisions about the robustness of the original hypotheses.

The research they reviewed shows that students find it difficult to learn from simulations using discovery methods and need much support to do so successfully. Research shows that students have difficulty throughout the discovery learning process. For example, students find it difficult to state or construct hypotheses that lead to good experiments. Furthermore, students do not easily adapt hypotheses on the basis of the data collected. That is, they often retain a hypothesis even when the data they collect disconfirm the hypothesis. Students do not design appropriate experiments to give them pertinent data to evaluate their hypotheses. Students are prone to *confirmation bias*, that is, they often design experiments that will lead to support their hypotheses. Students also find interpreting data in light of their hypotheses to be very challenging. In light of these difficulties De Jong and van Joolingen (1998) also reviewed research that studied ways to mitigate these difficulties. One conclusion they draw is that information or instructional support need to come *while* students are involved in the simulation, as compared to providing instruction prior to working with the simulation. That is, students are likely to benefit from such instructional interventions at the time they are confronted with the task or challenge. This often flies in the face of conventional wisdom that students should be prepared thoroughly before being given access to the simulation. The research also shows that embedding guided activities within the simulation, such as exercises, questions, or even games, help students to learn from the simulation. When designing experiments, students can benefit from experimentation hints, such as the recommendation to only change one variable at a time.

de Jong and van Joolingen (1998) also conclude that the technique of *model progression* can be an effective design strategy. Instead of presenting the entire simulation to students from the onset, students are given a simplified version, followed by having variables added as their understanding unfolds. For example, a Newtonian simulation could be presented first with only one-dimensional motion represented, followed by two-dimensional motion.

Finally, de Jong and van Joolingen (1998) also point out the importance of understanding how learning was measured in a particular study. There is a belief that learning from simulations leads to "deeper" cognitive processing than learning from expository methods (such as presentations). However, many studies did not test for application and transfer, so it is an open question whether a student who only successfully learns how to manipulate the simulation can apply this knowledge to other contexts. A student who successfully manipulates the simulation may not have acquired the general conceptual knowledge to succeed at other tasks. This review by de Jong and van Joolingen shows that there is still much researchers need to learn about the role of simulations in discovery learning and also how to design supports and structure to help students use the affordances of simulations most effectively. There are also many styles and strategies beyond scientific discovery learning. For example, an experiential or inductive approach would have students explore a simulation first, followed by providing organized instruction on the concepts or principles modeled by the simulation. With this approach, the simulation provides an experiential context for anchoring later instruction.

Results of our research closely match that found by de Jong and van Joolingen. Our research shows that adults are largely unable to learn from simulations without some form of guidance or structure (Rieber & Parmley, 1995). They also find the task of discovery learning very uncomfortable. They expect and want guidance. But, we also have found that it is also *not* necessary to design full-fledged instruction to support learning. We have found just providing people with very short statements of the physical laws as a type of content "hint" *while* they are interacting with the simulation is enough to produce learning mastery (Rieber, Chu, Tzeng, & Tribble, 1996). Our research confirms that model progression can be an effective strategy. Interestingly, there are also ramifications to a person's perceived self-efficacy when not using direct instruction to support learning in a simulation. For example, participants who were given a structured simulation learned as much as participants given a tutorial with the simulation, but they had less confidence in how they were performing on a test of their physics understanding (Rieber & Parmley, 1995).

Our qualitative research shows that not everyone approaches a discovery oriented activity in a strategic fashion. Although most prefer an experiential approach at first with graphical feedback, many are unable to break through to engage in strategic thinking. Put another way, many simply cannot get out of "twitch mode" to engage the simulation in a reflective, strategic way. As a consequence, they cannot form any articulate hypotheses to guide their experimentation in the simulation. But, those who engaged in strategizing early on show interesting patterns of preference with the way the task is represented in a simulation. For example, while most prefer a graphical representation at the start, as they gain expertise, they often prefer to switch to a textual representation. Numerical data gives them opportunities to build strategies.

In our research on the role of different forms of feedback (e.g. graphical vs. textual/numeric) in a simulation we have learned that different representations lead to different learning outcomes, but the type of representation that is best for learning shifts over time (Rieber, 1996). People are also not easily able to switch between different representations, even though it may be in their best interest to do so. For example, although many tasks can be made easier at first using a highly visual interface, there may be limits to how much understanding can be achieved without switching to a verbal or textual interface. But, switching from a graphical to a non-graphical interface prematurely may lead to excessive confusion and frustration. So, it is not simply a matter of having multiple representations available to learners that matters, but how to guide them to the most appropriate representation given their expertise and goals with the content. Other research on using multiple representations support the notion that simply giving users more than one representation does not lead to learning. For example, Ainsworth (1999) has theorized that the conflicting research on multiple representations can be interpreted as caused by a lack of consistency in the use and purpose of multiple representations. Ainsworth has proposed three functions of multiple representations, each calling for different levels of *translation* between the various representations. Translation refers to the ability of a learner to see the relation between two representations. The first function is to use representations to complement one another. That is, the same information is presented in multiple ways. The second function is to have one representation constrain interpretations of a second representation. The third function is to use multiple representations to construct a deeper understanding of a learning task. Different students will have different needs, depending on their learning goals and expertise in the domain. A student should not be expected to intuitively know how best to use multiple representations, so the simulation must be designed carefully to cue the student to use which representation when, and also to scaffold the student's learning.

Another group of research we've conducted has varied the design of the simulation's scenario with radically different model cases (Rieber, Noah, & Nolan, 1998). Each can highlight certain physical attributes differently — none is perfect, so exploring each provides a unique lens for capturing a little more understanding of the physics. For example, we have tried to teach about the relationship between acceleration and velocity by presenting the following four models to people: 1) a pure Newtonian model without any context; 2) a ball rolling on a table top that one can tilt up and down; 3) a spaceship floating in outer space; and 4) an unorthodox model consisting of a refrigerator coasting on a frictionless floor.

Two of these — the ball on the table top model and "rogue" refrigerator model — are shown in Figure 2.

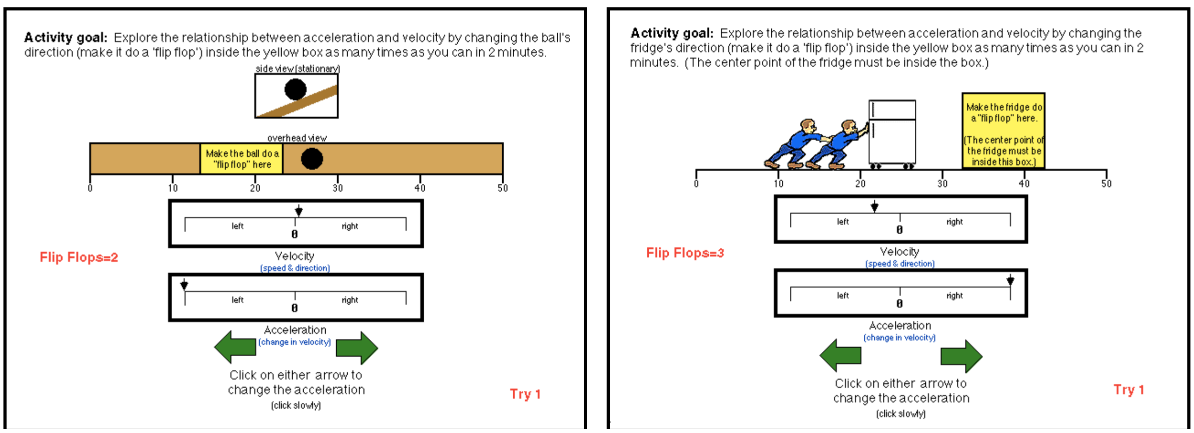

Figure 2. Two very different ways to represent a simulation about acceleration and velocity: a ball rolling on a table top that can be tilted (left) and a refrigerator moving on a frictionless floor (right).

Of these two models, the ball on the table top model has some very distinct advantages, from a physics point of view. For example, consider the non-intuitive situation of an object moving one direction (velocity) while its acceleration is in the other direction. The object would slow down gradually, eventually coming to a stop, then slowly gain speed in the other direction for as long as the force producing the acceleration is applied. Students who are presented with this example without any context (i.e. pure Newtonian model) become very confused and confounded by this example. Many give up. However, the rolling ball on the tilting table model, as elaborated in Figure 3, makes these motion relationships much clearer. As Figure X shows, the acceleration force is generated by the earth's gravitation and can be changed from left to right or from right to left just by tilting the table in either direction. Once the ball gains speed in one direction, tilting the table in the *other* direction would make the ball slow down *while it continues moving in the same direction* for a short distance, followed by the ball coming to a stop, then reversing direction with the ball slowly gaining speed.

However, the "rogue refrigerator" example, while an accurate representation, fails to capture well the importance of the acceleration force being constant. One must imagine that the fellows pushing the refrigerator are doing so with a constant force throughout the refrigerator's movement. These fellows also magically appear on either side of the refrigerator instantaneously as the user clicks either acceleration arrow. Interestingly, in our research, people strongly prefer interacting with the refrigerator model. We think this is so simply because it is such an amusing example.

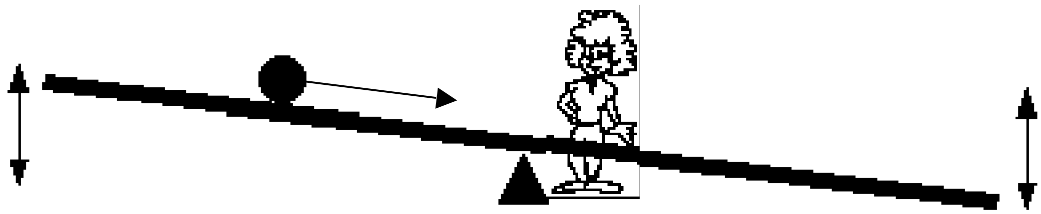

Figure 3. Imagine that the ball is moving down to the right. What would the ball's motion be if the person tilts the table the other way (i.e. change the acceleration, due to the earth's gravity, from "left to right" to "right to left")? The ball would continue moving to the right a short distance, stop, then starting moving the other way.

Finally, we have also studied the use of gaming within a simulation to help student focus their attention on developing strategic thinking (Rieber & Noah, 1997, March). Interestingly, the use of a game generally interferes with explicit learning (ability to answer test questions), but improves participants' tacit learning (ability to perform on other tasks embedded in the simulation). Participants' level of enjoyment is also higher when given the game. Rather than improve their strategic thinking, participants tend to default into "video game mode" or "twitch mode" — they became so preoccupied with the game that this inhibits their ability to reflect on what they are doing and what they are learning. This antagonism between learning and enjoyment caused by the use of a game is most interesting. It is similar to the distinction that Norman (1993) makes between experiential cognition and reflective cognition. Experiential cognition is "a state in which we perceive and react to the events around us, efficiently and effortlessly" (Norman, 1993, p. 16). Reflective cognition, on the other hand requires deliberate thought and reasoning over time. One is not superior to the other. We rely on both. However, our research suggests that an over-enthusiastic view of gaming may inadvertently lead to learning environments that promote experience over reflection.

Closing

In this paper, I have outlined several broad themes related to learning within computer-based simulations. The field of instructional technology has wrestled with the implications of designing learning environments based on very different philosophical orientations. A key question is when to defer to instruction as an intervention. Presenting too much instruction with a simulation too soon may inhibit a student from the advantages of discovery learning — using the scientific method to think like a scientist. Instead, students may just continue to see science as an accumulation of facts and principles needing to be memorized. However, research clearly shows that most students are ill-equipped to handle the full discovery learning process without some level of support. Instruction is surely a viable means to provide some of this support. But other means for support deserve continued attention, such as providing hints and suggestions during the simulation, model progression techniques, carefully chosen model cases and metaphors, and appropriate use of multiple representations. Perhaps the most important support is a teacher who knows how to capitalize on the simulation's affordances for learning. Interestingly, emphasizing the importance of the teacher again relates simulations to microworlds.

I believe that representations matter a great deal in the design of simulations. As Norman (1993) notes, ideal representations must do three things:

1. Appropriately show important, critical features of a domain while ignoring the irrelevant;
2. Be appropriate for the person; and
3. Be appropriate for the task.

Decisions on the representation of a simulation's feedback are likely to depend on a complex interrelationship between the domain being modeled, outcomes in that domain (e.g. memorizing, concept formation, problem solving, etc.), levels of understanding (shallow, deep), instructional support (e.g. discovery, guided, directed), and the user's learning style.

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