Billiards in the Classroom: Learning Physics with Microworlds

By Michael D. Bertz

Using a computer simulation environment that allows students to experiment and play helps them to build personal understanding of physics concepts that might otherwise be difficult to grasp. When used in conjunction with meaningful class activities, such an environment can foster active student learning, critical thinking, and collaboration.

Have you ever found yourself lining up for a bank shot on a pool table and trying to gauge in which direction the ball will rebound off the bumper? This is an application of physics, though probably most people don’t think of it that way. These tangible, hands-on, everyday experiences offer great potential to help students appreciate the physics in the world around them, as well as to learn about the complex relationships of the phenomena at work.

Construction of Ideas

Students often have difficulty with complex and abstract physical concepts. Connecting the mathematical expressions from their physics textbook to behavior in the real world can be challenging for even the best students.

Learning theory suggests it is better for students to build their own understanding of these relationships and behavior instead of passively receiving what is taught to them. Experimenting with these physical concepts can offer great support for the formulation of these student-constructed ideas. But physics experiments and labs take a lot of time to set up; it can be difficult to actually observe the phenomena at work; and the experiments often describe only a few characteristics of behavior.

While there is no substitute for actually manipulating physical objects, a simulation that allows for the study of a multitude of behaviors and facets of physical processes—even some not possible in the “real
world"—offers the learner a chance to engage in a scientific way of learning about physics.

My partner Walter Patterson and I set out to provide an environment that would allow learners to gain an intuitive grasp of Newtonian mechanics, the interactions between objects in the physical world. In a microworld—a simulation system that gives the user complete control over the behavior of the system—learners are encouraged to experiment and discover in a hands-on fashion the principles of the system they are studying. Users can construct their own interpretations of the behavior they observe within the microworld, and develop their own sets of laws to explain this behavior. The aim is to provide an arena in which physics becomes more like it is for the physicist—full of experimentation and inquiry.

**Design of the System—More Than Just a Game**

TrickShot! is an exploratory environment within which learners can experiment with various physical properties to develop an intuitive understanding of the behavior of objects in physical systems. The metaphor used is a billiards table, which provides a game-like atmosphere to explore the principles behind behavior such as collisions, movement, and friction.

We felt that simply providing the ability to play might not elicit enough of the connections from the activity of the microworld to the mathematical models or actual physical behavior. Therefore, a multimedia educational "shell" is wrapped around the simulation environment, containing directed explanations, real-world examples, and "challenges"—problems for the learners to solve in the microworld using their own constructed understandings. This shell is seamlessly integrated with the microworld environment (see Figure 1), encouraging the learner to experiment with personal theories of the interaction of the balls on the table; compare them with the more formal physics concepts and real-world examples of the multimedia shell; and then test those theories in problem-solving situations.

The target audience for TrickShot! includes middle level or high school students, either in a preparatory physical science-type class or early in a physics class. The software is geared toward students with little or no exposure to physics. The system is meant to supplement classroom experiences, not replace them; TrickShot! complements classroom instruction by providing an experimental, exploratory laboratory for the students to develop personal models of the behavior of dynamic systems.

To construct their own interpretations of how physical objects dynamically interact, which they may know little about, students need something easier to grasp, a less formal way to develop an understanding of the concepts. The microworld environment is a two-dimensional surface
with the appearance of a billiards or pool table. The behavior of balls on a pool table as they interact with each other and with the environment is highly analogous to a dynamic system of objects governed by physical equations and laws familiar only to students with more advanced training in mathematics and physics. Even without this advanced training, however, a pool table is an everyday device that offers some degree of familiarity to the learner.

Even if users have not played pool before, they will have at least a cursory understanding of the game. This simple understanding may include a primitive model of the way in which the balls behave and interact, and the constraints of the environment on that behavior. Then, by altering various parameters within the environment, users can see cause and effect related to specific parameters and how they affect the entire system.

The exploratory nature of the microworld stems from the wide range of parameters that may be changed by the user, which affect the properties of the microworld and its dynamic simulations. Examples of these parameters include the friction on the table or the attraction of gravity.

Friction is one of those real-world effects that is often neglected in physics problems, but it is the property that explains why many objects, once set in motion, do not stay in motion (in what may seem to novice students as a contradiction of Newton's First Law—one of those formal physics concepts that sometimes doesn't make immediate sense in the "real world").

**FIGURE 1**

**TrickShot! Architecture**

- **Physics Concepts**: Friction, Collisions, Gravity, Advanced Concepts
- **Real-World Examples**: Friction, Collisions, Gravity, Advanced Concepts

*Image showing the TrickShot! Microworld architecture with links to microworld accessible at any time and challenges.*
Gravity, to most of us, is simply what holds us to the earth and makes things fall off cliffs. In reality, we ourselves exert a small but essentially negligible pull on the earth. The microworld system allows for the investigation of gravity, since the learner can change the Universal Gravitational Constant and the mass of the individual balls. The gravitational attraction between the balls can greatly influence that nature of the shot—imagine hitting a hook shot into the corner pocket by curving the ball around an “8” ball 20 times more massive!

The learning mechanism supported by the system is one of scientific inquiry. It is important for learners to begin to develop their own interpretations of the behavior and then test those hypotheses with learner-designed experiments and the system’s own challenge problems. Students can first play in the microworld, building their understanding through trial and error and observation. They can then move to the learning shell to investigate the concepts in a more formal manner, with concrete examples that show the concept at work in the real world, and “challenges” that put them back in the microworld to test concepts with experiments.

Alternatively, a learner can explore the learning shell first, and then move to exploration within the microworld. In both cases, the dynamic relationship of the parts of the system fosters creative construction of the student’s own model for behavior, testing of that model, and further explanation of the concept through the actual physics involved and real-world applications. All this is designed not only to hold the students’ interest and motivation, but also to ground their knowledge solidly in the development of intuitive understanding and in relating that understanding to actual physical behavior, using real-world examples as a bridge.

Another important benefit of the use of the system in this fashion, beyond learning physics, is supporting the practice and construction of the ability to form and test hypotheses. The system encourages the development of a structured, scientific method of discovery, just as a comparative literature class fosters critical thinking.

**Experimental Use of TrickShot!**

Trial applications of the system have been performed at Cross Keys High School in Atlanta, Ga. Students from tenth through twelfth grade, identified through the cooperation of Craig Liggett, a math and computer science teacher at the school, were able to come to a laboratory we had set up and
use the TrickShot! system. At the beginning of each class period throughout the morning, we briefly demonstrated the program to the students and explained how to use the controls—moving the balls around, changing the velocity on the balls, and running the simulation. This overview lasted no more than 5 minutes. For approximately 20 minutes after that, students were free to explore the microworld and the accompanying multimedia shell in any way they liked. Any “how-to” questions from the students were answered during this time.

After the exploratory period, students were given a series of “challenges” to attempt to solve. Each challenge was designed to demonstrate or require a qualitative understanding of a specific principle of physics that could be explored in the microworld (see Figure 2). These challenges included making a bank shot by adjusting the system parameters or causing two balls to orbit each other by modifying gravity and their initial velocity (speed and direction). Students were instructed to save their solutions to the challenges as they completed each one.

Finally, after spending approximately 20 minutes on the four challenges presented, students were given two brief questionnaires to fill out. The first questionnaire asked students to evaluate the software; these questions were open-ended and encouraged students to comment freely on what they had experienced. The second questionnaire was more structured and represented an attempt to gain information about the students. It asked about previous science, math, and computer classes, computing experi-

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**FIGURE 2**

**TrickShot! Challenge: Orbiting Planets**

Try to make the two balls orbit each other in a circular path. The balls should stay in a stable orbit for at least three orbits. To complete this challenge, you may need to adjust the velocities of the balls, and the values of the sliders.
ence, and the student's age and sex. The questionnaire also included five qualitative physics questions.

This same survey and physics mini-quiz was distributed to a roughly equal number of students who remained in Liggett's classroom; these students served as a "control" group, representing the state of the experimental group before using the software.

In assessing the software, we were primarily interested not just in whether or not the students liked the system, but rather with items such as the software's effectiveness and the students' learning. For example:

- How much time is spent in microworld vs. learning shell?
- Does learning occur, or just playing?
- Is there a connection made between learning shell and microworld (i.e., does testing and experimentation occur after a concept is presented)?

The results of the evaluation surveys suggest that the reaction to the software was uniformly positive; nearly all the students who used the system stated that it was fun, and that it helped them reinforce their understanding of physics. In addition, the students learned from using the software, as measured by the quizzes. For example, all the students who used TrickShot! correctly understood that gravity is what causes the earth to orbit the sun, compared to only half their counterparts who did not use the system.

Although it is not as dramatic as the difference in the gravity question, 67 percent of the experimental students correctly understood that friction causes a rolling bowling ball to slow down faster on carpet than on the surface of a bowling alley, as opposed to 57 percent for the classroom group who did not use the software. The focus of this paper does not permit a full analysis of the results, but three important overall observations can be made, based on the quiz results and interaction and discussions with the students.

First, the students do make connections between the behavior in the TrickShot! world, the physics concepts, and real-world examples in the learning shell (and subsequently on the quiz). We found, however, that the students need to develop problem-solving skills within the microworld (i.e., strategies for systematic experimentation to find a solution) for it to be most successful. The purpose behind the challenges is not just to encourage learning about the concepts within the microworld, but also to serve as a catalyst for the use of the multimedia shell as a learning tool.

All the information necessary to solve each of the challenges is contained and presented by the physics concepts in the shell. Navigation between the microworld and multimedia environment is possible at any time. We found that, while some students eventually jumped out to the multimedia shell on their own, we needed to guide most of the students in how to use it to generate a meaningful investigation of the physics concepts.
Once they saw how the system interacted between the simulation and the multimedia environment, many students realized its effectiveness. One observed, "If you had a question about anything, you could just click on it and find out about it," while another noted, "All the concepts interacted more than I thought. Each played on the action of the others."

Coupled with the need for guidance is a realization that asking the students to learn to use the microworld, explore the physics concepts in the shell, solve the challenges, and then fill out the questionnaires was a very tall order. In fact, several students indicated they really wanted more time to work with the environment; in the words of one student, "I would have learned more if I had more time."

While we never envisioned TrickShot! as a one-time, sit-down, use and leave system, we were not able to test it in its intended setting—a physics classroom for a quarter or semester. For the system to be truly effective, we feel the students must be able to "grow into" it, becoming familiar with using it as a problem-solving tool. Furthermore, the students should not simply play with the system; its use should be tied to meaningful classroom activities that foster experimentation and exploration and that support the creation of artifacts by students (e.g., shot setups that illustrate particular concepts) that can be shared with their classmates.

We discovered that collaboration was well-supported by the TrickShot! system, both by users sharing a machine and across different work stations. The students seemed to be very interested in each other's work, and offered criticism and suggestions, especially when working as a team at the same station. The system did not isolate the students; it was engaging enough to stimulate conversation and the development of collaborative work toward solving the challenges. If it were used in a classroom over the course of several weeks, we believe this type of collaboration would be enhanced as users became more experienced with the system and its simulation abilities.

**Conclusions**

TrickShot! gives students an intuitive feel for some difficult dynamic concepts of the interaction of objects. It allows for the formulation and testing of a model, the connection of that model to the physics concept that drives it, and further tying the model to concrete real-world instances of the concept at work. It is a useful tool to develop an understanding of an abstract concept that can be difficult for novice physics students, and it does so in an engaging manner. Furthermore, the system offers a model of learning less reliant on lectures and centered more around students actively build-
ing a personal understanding of concepts and the development of critical thinking skills and scientific inquiry.

One student, who initially characterized herself as not liking computers very much, had this to say about the system, when asked if she thought she learned anything by using the program:

Yes, because it's amazing that there is so much science in [billiards]. I never realized that gravity and friction made any difference in pool. [The program] was actually enlightening as well as entertaining.

Generating this kind of excitement about and personal connections with learning physics is what billiards in the classroom is all about. ~B

Further Reading

To learn more about the cognitive theory and ideas behind this system, further information about microworlds and constructive learning can be found in Harel and Papert (1991); ideas on tying learning to authentic situations and environments are seen in Collins, Brown, and Newman (1989) and CTGV (1990, 1993); more information about support for learning in engaging environments is in Soloway, Guzdial, and Hay (1994).

References


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