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Physical Phenomena in Real Time

The use of videos allows teachers to tame the vagaries of experimentation while engaging students in the process of physics.

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There is a growing realization that nurturing scientists for the 21st century requires engaging students in the processes of doing science (*1*). For students to be engaged in the process of doing physics, they need to learn to think like a physicist. Physics is more than the final content that we assess in a traditional exam. Much of its richness is the process through which physicists acquire knowledge and those specific "habits of mind" that are necessary to practice physics. For example, when solving an experimental problem, a physicist needs to decide what features of the problem are relevant and which features can be ignored, how to represent the problem in different ways, including mathematical expressions, how to use available equipment to collect necessary data, how to analyze the data, and how to evaluate the results (*2*, *3*). Investigations are subject to the variability of experimental conditions and unanticipated complications. What if we could guide students so that they can make progress in a short amount of class time, yet still be engaged in the process of doing physics?

The Rutgers Physics Teaching Technology Resource (http://paer.rutgers.edu/pt3/) engages students from middle school to college in the process of physics. It contains more than 200 videos of real-life physics experiments that students can view and analyze as they learn new material, perform labs, carry out independent projects, or do homework. Videos allow them to see physical phenomena in real time and then again in slow motion for data collection. The videos do not contain tools for quantitative analysis. Instead, students need to decide themselves what data to collect and how to collect them. The goal is to engage students in actions and decisions similar to those of real physicists by working with simple experiments.

Physicists observe physical phenomena, collect data, find patterns in the data, and devise multiple explanations or mechanisms behind the patterns, test those explanations with more experiments, and apply their theories to solve real-world problems (*4*). Although it is a complex and nonlinear process, its logic can be used in physics instruction. A physics learning system called Investigative Science Learning Environment (ISLE) models this process for the students (*4*). In ISLE, all experiments that students encounter can be placed into one of three categories according to their roles: observational (experiments that are used to generate explanations), testing (used to test explanations), or application (experimental problems to solve for which one needs to synthesize multiple explanations and/or relations). The video Web site follows this scheme, helping an instructor form a learning progression that mirrors the process of doing physics.

To learn a new concept, students can start with a carefully selected set of observational experiment videos. They do not make any predictions of their outcomes before viewing but describe what they see or collect data. Students then use such representations as motion diagrams, force diagrams, and ray diagrams to analyze collected data to find patterns. If possible, students can then devise explanations or mechanisms for these patterns. Next, students can test their explanations by using them to predict the outcomes of new experiments, through a testing experiment video (sometimes there are multiple testing experiments), with the goal of ruling out the explanation instead of proving it. Finally, students can apply their new knowledge to solve real-world problems through an application experiment video.

Many application experiments are also reprised in a special section titled "Surprising data and puzzles." Each puzzle has a video that contains two experiments from which a particular quantity can be determined. Students must reconcile different outcomes by analyzing experimental uncertainties and theoretical assumptions. For example, one puzzle requires students to determine the height of a table in two different ways (see the first figure). Both experiments use many of the advantages afforded by a video format—such as the lack of markers, measuring instruments, and peripheral technology—and few instructions beyond the statement "find the height of the table in two different ways." Students have to decide what to measure, how to measure it, and what assumptions to make, while the camera frame helps constrain their attention and focus on the table, the falling ball, and the swinging pendulum. Additionally, students can step through the video frame by frame to measure how long it took for the orange ball to hit the floor and the period of the pendulum's oscillation, as both would be difficult to record in real time. Finally, having the falling ball and the swinging pendulum next to each other encourages students to compare their two methods. After finding that the height results obtained from the two experiments are not exactly the same, students can identify and estimate sources of instrumental uncertainty and then compare

A screen shot from the "table height" experiment. The orange ball rolls off the table and falls to the ground. The small metal ball on the right is attached to a string that is connected to a bar resting on the tabletop. The resulting pendulum swings back and forth, exhibiting simple harmonic motion. The length of the pendulum is roughly the height of the table.

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A series of screen shots of E. Etkina on in-line skates being pulled by D. Brookes. Students are asked to observe Eugenia's motion, draw a motion diagram, and decide if she is moving at a constant rate or at an increasing rate.

the two height results taking those uncertainties into account. If the two numbers still do not match, they may think about sources of systematic uncertainty and how they might affect calculations.

"Surprising data" experiments have situations whose outcomes are difficult to predict correctly if one does not examine auxiliary assumptions. These experiments help students understand the role of assumptions in physics. For example, a traditional physics projectile problem may admonish students to "ignore air resistance." Correspondingly, students should predict that a projectile launched at 30° would fly the same distance as a projectile launched at the same speed at 60°. However, in one of our testing experiment videos in the "surprising data" section, a projectile launched at 60° falls roughly 8 cm shorter than the distance traveled by the same projectile launched at the same speed at 30°. Students need to decide if this is just random variation, or if air resistance has a different effect on the two projectiles despite student's calculations suggesting that both projectiles should fly the same distance.

To help instructors, the Web site explains how to use the videos, describes the underlying teaching philosophy, and provides examples of how students can work with the videos. All videos work with any curriculum and with any textbook and are supported by questions, all of which allow students to work independently at their own pace. In addition, there is a teacher component only available for registered teachers (registration is free) and invisible for the students. These pages explain why a particular experiment is important, how to analyze data, and so forth.

The Rutgers Physics Teaching Technology Resource receives feedback from active users, which helps illustrate the variety of ways in which the videos can be adapted and used in different instructional settings. A high school teacher from Nebraska uses some of the videos as an introductory demonstration to stimulate a discussion. For example, the video titled "David Hits a Ball so That It Travels in a Circle" leads to a discussion on what type of force is necessary to achieve circular motion, whereas the "Eugenia on Rollerblades" video usually results in students bringing in their Rollerblades to do a demonstration for the class. The videos also support struggling students and those who have missed a laboratory session.

A professor at the Physics Department at Oregon State University uses the videos for an in-class demonstration (see the second figure). Students record data directly from the videos, providing "buy-in" that they are investigating real scientific phenomena. These easily implemented videos lay the groundwork for student-generated explanations of physics laws.

A professor in the Department of Biology and Physics at Kennesaw State University uses the videos for assessment. For example, when a wand is rubbed with fur, it initially attracts a pith ball toward it. However, when the two touch, the pith ball is suddenly repelled. After watching this video, students need to explain what happened using previously learned physics concepts. Students first talk to their neighbors before discussing the video as a class. Many students comment that the videos make things clearer and bring everything together.

Those who prepare teachers have commented that the Web site allows them to share many experiments regardless of the amount of equipment available at schools. In districts with limited funds, videos become great free resources. In addition, electrostatics experiments help students observe phenomena when the weather is not cooperating.

In summary, the Web site allows access to a rich experimental environment free of cost and safety concerns. It helps students engage in practices similar to those of scientists where they have to make decisions on data collection and analysis and want to explore phenomena in slow motion. It simplifies some of the distracting complexity of real-world experimentation. It can be used to help students of all ages learn physics in a way that reflects the process of doing physics.

References and Notes

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5. We thank A. Van Heuvelen, S. Murthy, M. Lawrence, M. Gentile, L. Largo, Y. Sakano, A. Warren, D. Maiullo, and many others who provided ideas and technical assistance for our project. This work would be impossible without the funds from the U.S. Department of Education and the NSF.

10.1126/science.1186992

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Science, **330** (6004), .
DOI: 10.1126/science.1186992

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