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Ever since the first generalized computer-assisted instruction system (PLATO[1]) was introduced over 50 years ago, educators have been adding computer-based materials to their classes. Today many textbooks have complete online versions that include video lectures and other supplements. In the past 25 years the web has fueled an explosion of online homework and course management systems, both as blended learning and online courses. Meanwhile, introductory physics instructors have been implementing new approaches to teaching based on the outcomes of Physics Education Research (PER). A common theme of PER-based instruction has been the use of active-learning strategies designed to help students overcome alternative conceptions that they often bring to the study of physics.[2] Unfortunately, while classrooms have become more active, online learning typically relies on passive lecture videos or Kahn-style[3] tablet drawings. To bring active learning online, the LivePhoto Physics Group has been developing Interactive Video Vignettes (IVVs) that add interactivity and PER-based elements to short presentations. These vignettes incorporate web-based video activities that contain interactive elements and typically require students to make predictions and analyze real-world phenomena.

A typical vignette

"Projectile Motion" is a typical example of the IVVs that have been developed. It is divided into seven "pages" and it takes about 5–7 minutes to complete. Page 1 of the IVV is a video of an instructor describing projectile motion and then tossing a ball [Fig. 1(a)]. Page 2 contains multiple-choice questions about the horizontal and vertical components of the ball's motion that probe the user's beliefs about projectile motion [Fig. 1(b)]. On page 3 the user measures the ball's horizontal position by clicking on the ball in successive video frames to create vertical lines that show how the (horizontal) position changes [Fig. 1(c)]. Later the user's predictions from page 2 are echoed back on page 4 along with a video showing the instructor explaining his own observations and conclusions [Fig. 1(d) and (e)].

PER basis of vignettes

Many different active-learning strategies have been studied and developed using PER. The "Projectile Motion" vignette makes use of the classic *elicit-confront-resolve*[4] (ECR) technique: it elicits a prediction from the user, *confronts* the user with an experimental result, and helps the user *resolve* any differences between them. This technique is a very effective method that has been used in many research-based curricular materials, including *Tutorials in Introductory Physics*[5] and *Workshop Physics*.[6] Another way we introduce active learning into vignettes is to invite the student to perform a video analysis. For example, the "Newton's Second Law" vignette asks the user to select the location of a lab cart propelled by a fan in successive video frames while a velocity-versus-time graph is created. This process is then repeated after adding mass to the cart (and using the same fan). By fitting straight lines to the two graphs and measuring their slopes, the user finds that the cart has half as much acceleration when its mass is doubled.

A meta-analysis conducted by the U.S. Department of Education of published papers that compare online learning to traditional instruction found that "online learning can be enhanced by giving learners control of their interactions with media and prompting learner reflection." [7] There is also evidence that increasing the interactivity of an online lecture may make it more effective compared to either a noninteractive online lecture or a face-to-face lecture.[8] Moreover, in a recent book,[9] Clark and Mayer describe studies demonstrating that students who are exposed to multi-sensory environments, such as pictures, animation, and video, had much more accurate recall than those who only hear or read information. The authors conclude that if the brain is able to construct two mental representations of an explanation—say, verbal and visual—then the mental connections are much stronger. Accordingly, IVVs make use of relevant pictures, text, and activities to enhance narrative videos.

Along these same lines, Derek Muller, the creator of the popular science-video website Veritasium.com, found in his dissertation research that "explicit discussions of alternative conceptions are more effective for learning than expository summaries."[10] Consequently, many of our vignettes show the instructor, students, or other participants discussing all the possible answers to multiple-choice questions. Similarly, the vignettes developed so far include instructor-led presentations, "person-on-the-street" interviews, discussions between students and instructors, and stories played out by student actors. The aim is to create a collection of IVVs with various styles and applications of PER that will help student users learn and at the same time inform the future development of interactive online materials.

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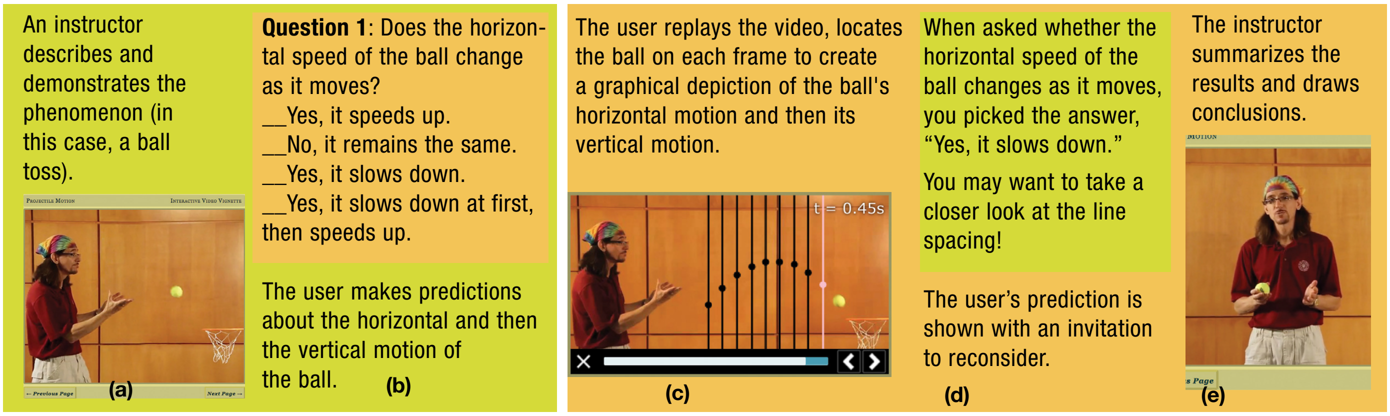

Fig. 1. Elements of the "Projectile Motion" IVV. The vignette begins with a demonstration and prediction, is followed by measurements and analysis, and ends with a summary and conclusions.

Another IVV example: "Newton's Third Law"

This vignette, like many others, deals with a concept that PER indicates is particularly difficult for students to learn. It features person-on-the-street interviews about collision forces as a function of the relative speeds and masses of cars [Fig. 2(a)]. Each interviewee is shown a video clip on an iPad of two identical carts on a low-friction track moving toward each other at the same speed and then colliding head-on. The instructor then asks for predictions regarding the collision force each cart experiences. All of those interviewed predicted that two objects of equal mass and speed would exert the same force on each other. Their predictions are subsequently tested when they view a video of the two carts colliding while a real-time force-versus-time graph shows that the force sensor readings from the carts are "equal and opposite" on a moment-by-moment basis.

Next, interviewees are shown a video of a real-life collision between automobiles of different masses and speeds [Fig. 2(b)], and over 90% of them claim that the larger, faster car exerts more force on the smaller, slower car. Many students who complete this vignette as an assignment in a physics course choose the same incorrect answer on the embedded multiple-choice question. The interviewees (and the user) are then confronted with a real-time force graph showing that the forces are equal and opposite on a moment-by-moment basis during a collision between a faster, more massive lab cart and a slower, less massive cart. The interviewees are shown reacting with surprise to the graphs.

Lastly, the instructor asks each interviewee (and the student user) which car he or she would rather be driving. Nearly everyone agrees that the driver of the small car is likely to receive more injuries. The instructor then shows another collision video that has miniature "people" sitting on the lab carts. The result of the collision is that the person on the more massive cart remains relatively unscathed (sliding forward slightly in his seat) while the person on the smaller cart is thrown violently and lands on his face [Fig. 2(c)]. The final wrap-up has the instructor summarizing the events by explaining how the lighter cart has a larger acceleration even though the interaction forces on the carts have the same magnitude. This sequence of activities demonstrates that the intuition of the interviewees regarding the relative danger to the drivers is correct even though their predictions of unequal forces are incorrect. The video ends with one of the interviewees saying, "It makes total sense. I'm surprised, but it makes total sense."

Vignette software

Interactive Video Vignettes are web applications written in HTML5 and JavaScript. These are standard technologies that work on devices likely to be used by students (laptops, desktops, and tablets). To make it easy to create vignettes, we are developing Vignette Studio, a Java application that runs on most desktop and laptop computers. Vignette Studio has a drag-and-drop interface, allowing vignettes to be constructed by dragging pages into place and then dragging various elements, such as videos, images, or multiple-choice questions, into each page.

In addition to the capabilities mentioned above, the software allows for multiple-choice questions with branching. For example, if the user chooses an incorrect answer, the vignette can branch to a specific video that demonstrates why such an answer cannot be correct before returning to the original question screen. Additional software capabilities are planned for implementation in the remaining years of the project.

Research on vignettes: Motivation and learning

For the past three years our IVV development group has been conducting research on the level of motivation necessary for students to complete assigned IVVs outside of class as well as on the impact of the IVVs on student learning of concepts targeted by the IVVs.

Motivating students to complete vignettes: IVVs are assignments to be done outside of the classroom. They may be used as homework, pre-class, or pre-lab activities. Students are given completion credit to encourage them to finish the assignment. The multiple-choice questions in the vignettes are not graded for correctness. This is to help ensure that students make their own predictions without feeling they are being judged. Since vignettes are done outside of class, we wanted to understand how to motivate students to complete them. Across six semesters we provided students enrolled in introductory physics at the University of Cincinnati several different incentives for completing the vignettes. Each level was tested across all courses for a given term. The levels of motivation tested included asking students to complete the vignettes to: (1) increase their understanding of the concepts, (2) prepare for a related question on the next exam, or (3) receive extra credit for completion of an IVV either on an exam or as an assigned homework activity. As shown in Table I, completion rates for motivation levels (1) and (2) were below 40%, but for level (3) they were over 80%, making it clear that students need completion credit to motivate them to do the IVVs outside of class.

Table I. IVV completion rates for different incentives.

Incentive	Completion rate	No. of students
1. Increase understanding	32%	737
2. Prepare for exam question	39%	586
3. Receive extra HW or exam credit	87%	1184

Our results are consistent with recent findings of instructors at the Air Force Academy who reported a completion rate of 40% when homework is recommended but without credit. Their completion rates rose to 80% if the homework assignment contributes to 10% of their course grade.[11] Another study conducted in the United Kingdom reported that homework completion is optimal (at something above 80%) if it counts for 10–20% of the grade.[12]

Impact on student learning: In order to gauge the impact of IVVs on student learning, a controlled study involving three instructors across six sections of algebra- and calculusbased physics was conducted at the University of Cincinnati. Each instructor taught two sections of the same course during the same term, and used a similar teaching approach and course materials across the two sections. However, one of the two sections for each instructor was assigned four IVVs (dealing with projectile motion and Newton's three laws) while the other section was provided standard textbook problems instead. Students were pre- and post-tested at the beginning and end of the term using the FCI[13] plus five additional questions. The additional questions were written as part of this study to assess student learning of concepts specifically targeted in each of the assigned IVVs. Although student pre-test scores across the treatment (321 students) and control (244 students) groups were similar, significant differences in post-test scores were found using t-tests ($p < 0.05$) for questions related to projectile motion and Newton's third law. In fact, up to double the number of students in the treatment group shifted from incorrect to correct reasoning on the post-test compared to the control group. On the post-test question for projectile motion, 91% of students in the treatment group indicated that the horizontal speed of a projectile remains constant whereas only 79% of students in the control group made a similar correct choice.

For questions associated with Newton's third law, including two from the FCI and one written for this study, on average 66% of students in the treatment group and 49% of students in the control group were able to correctly apply Newton's third law in scenarios involving the collision of objects of different mass. These differences in student performance were not observed for questions associated with Newton's first and second laws; however, the vignettes dealing with the first and second laws are significantly different in length, methods, and content compared to "Projectile Motion" and "Newton's Third Law." We are currently in the process of conducting more research to better understand differences in student learning associated with each of the vignettes. Nevertheless, we are encouraged to see that very short interventions of 12 minutes or less have the potential to achieve significant learning gains.

Instructor approaches to using vignettes: Our group is also studying other classroom implementations involving vignettes at UC, RIT, and Dickinson College. For example, in an algebra-based physics course at UC taught in a flipped classroom[14] environment, we combined one of our IVVs with the instructor's video lecture. Students viewed the lecture and completed the embedded IVV outside of class. They later

Fig. 2. (a) "Newton's Third Law." An instructor holding a tablet computer interviews passers-by about the forces in a collision.

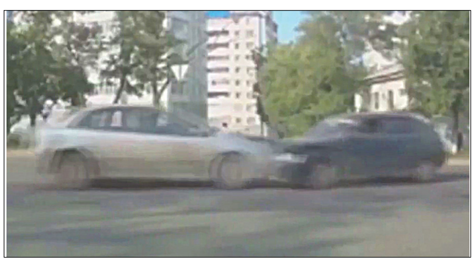

Fig. 2. (b) The instructor shows a video of a collision between a faster, heavier car and a lighter, slower car, and then asks for a prediction about the relative forces on the cars.

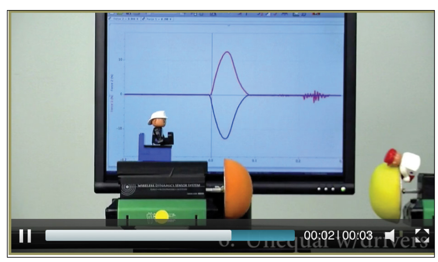

Fig. 2. (c) The instructor shows a fast, heavy cart hitting a slow, light cart. Even though force sensors record equal and opposite forces, the driver of the light cart reacts more violently.

provided feedback about the experience indicating that they found the embedded vignette engaging and enjoyable, and asked for more video lectures like this in the future.

How to obtain IVVs and Vignette Studio

Vignettes developed by the project are available for download from the IVV site hosted by ComPADRE, http://www.compadre.org/IVV/. A beta version of Vignette Studio with limited functionality is also available through the same website. The final version of Vignette Studio will be distributed as free open-source software.

Conclusion

Interactive Video Vignettes provide a way to put interactivity into otherwise passive online presentations. Their pedagogical effectiveness is being studied and preliminary results are encouraging. A collection of sample vignettes is available, along with Vignette Studio software that allows physics teachers to create their own vignettes. In addition, students who have used vignettes made many positive comments about them. For example, after completing the vignette on projectile motion, one student commented:

> *"The interactive portion was fabulous! I liked the lines of the position of the ball over time as you click on it. It made a great visual. It will stick with me!"*

Acknowledgments

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