Student Choices when Learning with Computer Simulations

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Abstract. We examine student choices while using PhET computer simulations (sims) to learn physics content. In interviews, students were given questions from the Force Concept Inventory (FCI)[1] and were allowed to choose from 12 computer simulations in order to answer these questions. We investigate students' choices when answering FCI questions with sims. We find that while students' initially choose sims that match problem situations at a surface level, deeper connections may be noticed by students later on. These results inform us on how people may choose education resources when learning on their own.

INTRODUCTION

Today's students have access to a wide array of learning tools, from traditional textbooks to the internet to computer simulations. The PhET project is one such learning tool, a suite of over 80 computer simulations of science topics. The PhET simulations (sims) are available for free and are widely used around the world. While PhET sims are often used in the classroom, people can also use the sims on their own in order to explore science topics. If a person goes to the PhET website,[2] they have many sims to choose from. In this preliminary study, we examine 1) the choices individuals make when answering physics questions with PhET sims, and 2) whether and how those choices lead to learning of physics.

PhET sims are based on established learning principles, cognitive and education research, over 250 interviews with students using the sims, and large-scale research studies which have contributed to the PhET research base.[3] Sims are designed to be highly interactive and to promote learning through exploration by users. We have found that students can and do readily explore and learn science content with the PhET sims, even with minimal explicit guidance.[4] Thus, it is reasonable to believe people can and do use PhET sims to learn without the guidance provided in most formal educational settings.

In this interview study, we presented select questions from the FCI[1] to students and allowed the students to choose from a set of PhET sims when answering the questions. Interview results reveal that students who may not necessarily know the correct answers to FCI question still demonstrate the ability to reason productively about these questions when given access to educational resources that allow for productive exploration with minimal explicit guidance. The PhET sims are one such resource. Students made interesting and reasonable choices when using these sims to develop their reasoning about physics concepts, and we observe consistency in the choices students made. These results inform us on how people may use sims to learn on their own.

METHODS

In this preliminary study, four students were interviewed for one hour each. Interviews were video-taped. Two of the students were non-science graduate students. The other two students were undergraduates enrolled in Light and Color, a course for non-science majors. Students were randomly chosen from those responding to a mass email, and paid a small amount for their time. Findings with the graduate students were substantially similar to undergraduates, albeit the graduates' use of sims was slightly more sophisticated. Here, we focus on results from the undergraduates.

During these think aloud interviews, students were presented with sheets of paper containing select questions from the FCI. Students were given access to

a web page containing thumbnail images of 12 PhET sims[5] (Fig. 1). The thumbnail images were small pictures of each simulation, along with the name of the simulation, which could be clicked to launch a sim.

Students were asked to answer the FCI questions as best they could while thinking aloud, and told that the simulations were available to use as they liked. Students were not given any further instruction on how to proceed or use the sims.
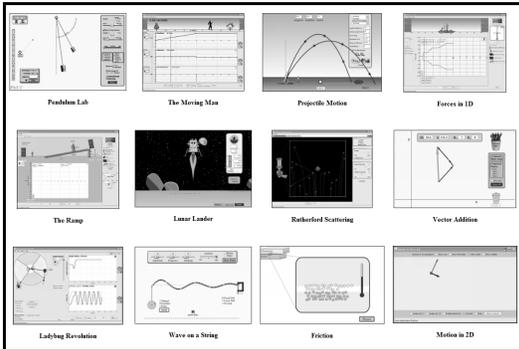

FIGURE 1. Web page with 12 PhET sim choices.

STUDENT INTERVIEW DATA

Summary of Findings

Interview findings are summarized in Table 1. Sims chosen by students "K" and "B" (undergraduates) are shown for each FCI question, listed in the order presented to students. In cases where students used more than one sim, the sims are listed in the order used. Details of these results are discussed below.

Table 1. FCI Questions and sims chosen by students K and B

Question	K Sim Choices	B Sim Choices
12	Projectile Motion	Projectile Motion
13	Projectile Motion	Projectile Motion
14	1. Force 1D 2. Projectile Motion	1. Lunar Lander 2. Moving Man 3. Projectile Motion
5	Force 1D	1. Force 1D 2. Moving Man 3. Rotation
6	Motion 2D	Motion 2D
7	Motion 2D	Motion 2D
25	Force 1D	Force 1D
26		Force 1D
27	Force 1D	Force 1D

Projectile Motion Questions

Students were first given a sheet containing questions 12-14 of the FCI. Question 12 asks about the

trajectory of a ball fired horizontally from a canon on a cliff. Both students chose the *Projectile Motion* sim to answer this question. See Fig. 2. Note that the sim is a very close match to the problem situation. Both students used the sim to question 12 correctly.

Question 13 asks about the forces on a ball thrown vertically into the air. Students also used *Projectile Motion* here. Both students aimed the canon straight up and fired the ball, using what they saw to answer question 13. Both students selected answer "C", which is incorrect because it includes "an upward force that steadily decreases until the ball reaches its highest point." Note that the sim does not explicitly include information about the forces on the ball. It shows only the trajectory, and students had to infer what the force must be from what the sim showed.

The last question on this page was #14, which asks about the trajectory of a ball dropped from a moving airplane. Here, student choices diverged at first. Students did not find the first sims they opened very useful and closed the sims almost immediately. Both students, however, did find Projectile Motion useful once they chose to use it. In fact, both students commented on how questions 12 and 14 were similar after they had used this sim. For instance, student B said that, "I guess, in a way, the force of the canon, like the canon ball being fired out, can substitute for the motion of the airplane." Thus while students may initially struggle to find a sim that is a close match to the problem situation, they may begin to recognize deeper connections between problem situations after using the sim.
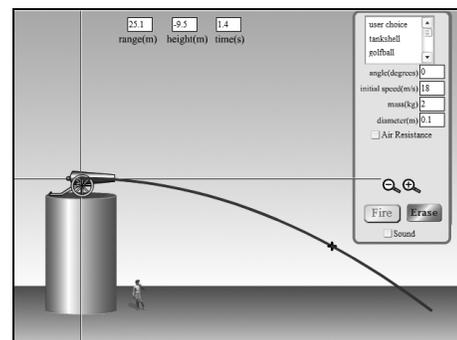

FIGURE 2. Projectile Motion sim showing trajectory of an object fired from a canon.

Circular Motion Questions

Students were next given questions 5-7. Question 5 asks students to identify the forces exerted on a ball moving through a circular channel. Both students initially chose *Force 1D*, shown in Fig. 3, perhaps because question 5 asks specifically about forces. Student B additionally tried to use the *Moving Man*

and *Rotation* sims on question 5, but he did not find these sims useful, stating "I don't see the connection. So I don't think anything here helps with that." Both students arrived at answer "C", which is incorrect because it includes a force "in the direction of motion" but does not include the centripetal force on the ball.

Question 6 asks about the trajectory of the ball after leaving the circular channel. For this question, both students used the sim *Motion in 2D* (Fig. 4). *Motion in 2D* shows the velocity and acceleration vectors for a ball moving in two dimensions. The ball can be moved by the user or set on several preset paths, including a circle. Both students attempted to recreate the problem situation by setting the path to circular and observing the motion and vectors. Both students then chose answer A, which shows the ball continuing in a circular path after leaving the channel. Student K said this was because the ball "wants to keep going like the force was pushing it." Student B initially said that the circular path was what the sim showed. However, after further exploration, K noticed that "since the chamber ends straight ahead…the end of the constraint is facing in a straight line. I can, I don't know, I would just think that it would continue in a straight line." He then answered path "B" (straight line) which is correct.

Question 7 asks about the trajectory of a ball on a string swung in a horizontal circle and released. Again, both students used *Motion in 2D*. In this case, both students set the ball in circular motion and used the "stop" button, which makes the ball slow to a stop. This led student K to say "looks like it would keep going straight," and answered "B" (ball goes in a straight line tangent to circle) which is correct. Student B, however, said, "as best I could tell it's going mostly straight but curving in the direction it's been moving," and answered "A" (ball continues in curved path). Note that both students were using the sim in almost the exact same way, yet interpreted what they saw very differently. Further, questions 6 and 7 rely on essentially the same underlying principle, yet both students reasoned very differently on question 6 than they did on question 7.

Horizontal Force Questions

The final set of questions (#25-27) involve a woman pushing a box on a horizontal surface. Question 25 asks about the force required to move a box across a horizontal floor at constant velocity. Both students used *Force 1D* to answer this question. Student B, who had tried *Force 1D* to answer an earlier question, now stated, "This time I have an idea of what to use." While recognized as potentially useful by both students, *Force 1D* did not turn out to help them with the question. In order to move the object in
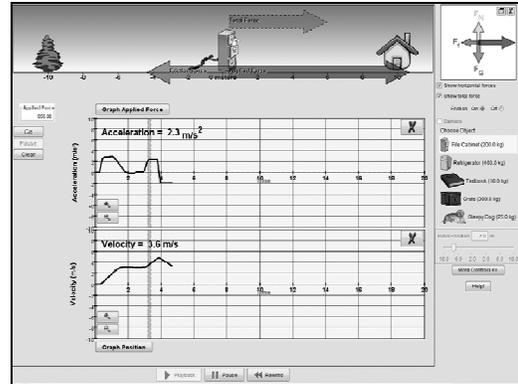

FIGURE 3. Forces in 1D sim showing force vectors on an object, acceleration and velocity graphs.
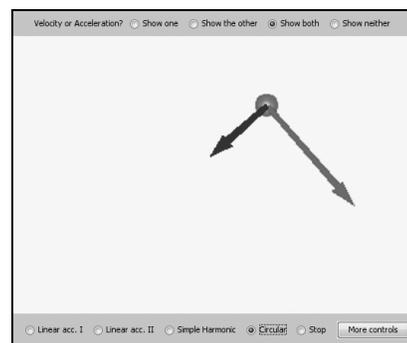

FIGURE 4. 2D Motion sim showing circular motion with acceleration vector (darker of two here, blue in sim) and velocity vector (lighter here, green in sim).

the sim, the user must apply enough force to overcome static friction. Student K figured out how to apply a force, but never applied a large enough force to move the object. He therefore could not recreate the problem situation of a moving box. Student B did get the object to move. However, his difficulty lay in the question wording, which involves the "magnitude" of the force. B said, "I don't know what magnitude is," and guessed at an answer (incorrectly).

Question 26 asks what would happen if the applied force was doubled. Student K answered (incorrectly) without using a sim. Student B used *Force 1D* again, this time opening a graph of velocity vs. time, as shown in Fig. 3. Student B watched the velocity graph as he doubled the applied force on the object and arrived at answer "E" (continuously increasing speed).

Question 27 asks what would happen if the woman stopped applying a force to the box. Here, both students used *Force 1D*. Student K again tried to use the sim, but could not get the object to move due to insufficient applied force. K nonetheless arrived at answer "C" (immediately starts slowing to a stop). Student B gave answer "C", using the simulation to confirm that his answer was correct by getting the object moving, then releasing the applied force.

DISCUSSION

In these interviews, we observe that students make very similar choices when using PhET sims. In general, students appear to first try and recreate the problem situation exactly. According to student B, "I pick [a sim], test it out to make sure it is what I think it is. And then seeing that it is, I just try and find ways to mimic the situation as best I can." We observe that this B's reflection matches our general observations of both students, at least in their first sim choices.

However, we also observe that after using a sim, deeper structural connections may become salient to students. On question 14, both students commented on the similarity between the ball fired from a canon and the ball dropped from an airplane. Notably, students did not make this structural connection until *after* using the *Projectile Motion* sim on question 14. Use of this sim was first cued for students by the close surface feature match to question 12. The students then closed the sim and reopened it for question 14. It is plausible that this sim would not have been a close enough match to question 14 for students to choose it had they not already used it on question 12 first. Note that students chose *Projectile Motion* on question 14 only after unsuccessful attempts with other sims, further suggesting a structural connection between the airplane situation and the sim was not immediately salient to students. This connection became salient after using the sim.

On question 5 regarding circular motion, both students appeared to cue on the word "force" in the problem statement. After choosing *Force 1D*, both students also realized fairly quickly that this sim did not help them answer the question. In keeping with the hypothesis that surface level matches are most salient to students initially, here we observe students rejecting a sim because of a lack of direct similarity to the problem situation. Instead, students tried to recreate the problem situation with *Motion in 2D*, with limited success. Given that students did choose this sim, minor modifications to *Motion in 2D* might have better helped students' learning by more strongly cuing intuitive ideas about forces.

Overall, students' sim choices were nearly identical. In many cases, students used the sims productively to answer FCI questions. In some cases, the information students gathered from sims was misapplied or misinterpreted. When using *Motion in 2D* for circular motion questions, student K stated, "these [vectors] are forces pushing on the ball." However, *Motion in 2D* shows the *velocity* and *acceleration* vectors, not force. Possibly, K's existing ideas about a force in the direction of motion led him to misinterpret the velocity vector in *Motion in 2D* as a force vector. This sort of misinterpretation is not isolated – we have observed the exact same misinterpretation of these vectors by a graduate student using *Motion in 2D*.

These findings may raise concerns that students will be led to incorrect conclusions if left to find and use educational resources on their own. Our interpretation of these results is more positive. We find that students did make productive choices in many cases, and the sims provided these students with many learning opportunities.

Education researchers often consider students' tendency to cue on surface features as a hindrance toward deeper conceptual understanding. We suggest that surface features can be used to bootstrap student learning of the deeper structure. There appear to be two key elements to achieving this. First is to present educational resources in such a way that surface features lead students to see the resources as useful for learning. This "hooks" students into using the resource. The second element is providing resources that are designed to foster productive learning with minimal explicit guidance. This allows students to explore deeper conceptual ideas and connections.

CONCLUSION

We investigated student choices when students were given access to computer simulations for answering FCI questions. Students were observed to make very similar choices, and to use the simulations productively to answer FCI questions. In general, students appear to choose sims that are close situational matches to the problem situations. However, use of sims may promote students noticing deeper structural connections that were not salient prior to using the sim. In this way, educational resources may use surface features productively to hook students into learning of deeper conceptual ideas.

ACKNOWLEDGMENTS

REFERENCES

1. D. Hestenes, M. Wells, & G. Swackhammer, *The Physics Teacher* **30**, 141-158 (1992).
2. http://phet.colorado.edu
3. C.E. Wieman, W.K. Adams, & K.K. Perkins, *Science*, 322/682-683 , October 2008
4. W. Adams, A. Paulson, & C.E. Wieman, 2007 *PERC Proceedings* (2008)
5. http://per.colorado.edu/podolefsky/phet_custom_fci/