

What Do Students Learn about Work in Physical and Virtual Experiments with Inclined Planes?

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Abstract. In previous studies, we have reported a difference in how physical and virtual manipulatives support students' understanding of the physics definition of work in the context of simple machines. We have shown that students who use the virtual manipulative (a computer simulation) before performing a physical experiment provided the correct response to multiple-choice questions about work more frequently than students who first use the physical manipulative. In this paper, we further analyze students' responses to a series of questions about work in the context of inclined planes to explore the models students used to answer the questions. While we had anticipated that students who performed the physical experiment would incorrectly respond to the multiple-choice questions in accordance with their observations (i.e. a longer ramp requires more work due to frictional effects), we actually observed these students more frequently using an alternate model that a longer ramp requires less work.

Keywords: physics education research, physical experiment, computer simulation, laboratory.

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INTRODUCTION

Educational researchers and practitioners alike are interested in understanding how students' learning is supported by interaction with computer simulations. Simulations offer many benefits over physical experiments, such as decreased set up time and dynamically changing graphs [1]. However, conventional wisdom suggests that students learn best from hands-on experimentation with physical manipulatives. Researchers investigating how college students learn from experimentation with virtual manipulatives have found mixed results. Some studies (e.g. Ref. 2, 3) have found that students' learning was better supported by experimentation with virtual manipulatives, while other studies (e.g. Ref. 4) have found physical and virtual manipulatives provided equal support for learning.

Our work has focused on the question of how physical and virtual manipulatives support students' learning about simple machines, specifically pulleys and inclined planes. We have investigated whether the comparative support provided by physical and virtual manipulatives is influenced by the physics concept (e.g. force or work) to be learned. We have previously reported that students were more likely to correctly answer multiple-choice questions about work in a frictionless environment after performing experiments with the virtual manipulative [5]. However, we note

that this type of analysis may have been biased against students who answered the question in accordance with their observations in the physical environment, which displayed the effects of friction.

In this paper, we present an analysis of students' responses to questions about work in the context of inclined planes. In the physical experiment, students observed an increase in the work required to lift the same load to the same height with a longer inclined plane due to frictional effects. This may have led students to select answers that indicate that a longer ramp requires more work, even when the question referred to a frictionless environment. On the contrary, we find that students more frequently used an alternate model that a longer ramp requires less work.

METHODOLOGY

Students enrolled in a conceptual-based introductory physics laboratory used both physical and virtual manipulatives to perform experiments about inclined planes during a two-hour laboratory session. This topic was not explicitly covered in the lecture. Two sections of students (N=53) performed physical experiments followed by virtual experiments (PV sequence), and two sections (N=55) performed virtual experiments followed by physical experiments (VP sequence). In both sequences, students performed the same types of trials and responded to the same analysis

questions. The physical materials included a wooden board and block, a brick, a meter stick and a spring scale. The simulation allowed students to adjust the length, height and surface of an inclined plane and displayed measurements. Students completed the same multiple-choice test about the physics concepts related to inclined planes before conducting any experiments (pre-test), after the first experiment in each sequence (mid-test, about one hour later) and after the second experiment (post-test, about one hour later).

In this paper, we focus on a small subset of the multiple-choice questions about work. We selected only those questions for which each multiple-choice option corresponds to an individual researcher-defined model that students could use to answer the question. Each option was assigned to a model and the frequency of use of each model was determined for each test in each manipulative sequence. Additionally, where students were asked to provide a written explanation of their answer, the responses were analyzed using a phenomenographic approach [6].

The questions that met the requirements for further analysis and their multiple-choice options are paraphrased in Table 1. Each of these questions specified that the effects of friction should be ignored. On the test, Q10 and Q13 were accompanied by diagrams of inclined planes. The answer options aligned with three possible models for work in the context of inclined planes. Model 1 corresponds to the canonical physics model; “*If frictional effects can be ignored, the work required to lift an object with an inclined plane depends only on the height to which the object is lifted.*” Model 2, “*A longer ramp requires less work to lift an object to the same height as a shorter ramp,*” represents a failure to distinguish between the physics definitions of force and work [7]. Model 3, “*A longer ramp requires more work to lift an object to the same height as a shorter ramp,*” implicitly includes frictional effects.

RESULTS & DISCUSSION

Figure 1 displays the frequency with which students selected the multiple-choice options corresponding to the three models described above. In the VP sequence, Model 1 (the physics canonical model) is the most commonly employed model across all three questions and all three tests. In addition, there is an increase in usage of Model 1 following the virtual experiment, which on Q8 and Q13 is followed by a decrease in usage after the physical experiment. The usages of the alternate models follow similar trends on Q8 and Q13, becoming less popular after the virtual experiment and more popular after the physical experiment. On Q10, Model 3 follows this same trend,

while there is a continued decrease in the use of Model 2 after each experiment.

In the PV sequence, no questions exhibited an increase in Model 1. Thus, the PV sequence seems to be counterproductive for promoting students’ understanding of work in a frictionless environment. Rather, there is an increase in Model 2 after the physical experiment for all three questions and a second increase after the virtual experiment for Q8 and Q13. For Q8 and Q10, there is a decrease in usage of Model 3 after the physical experiment.

It is reasonable to expect that we may observe an increase in students’ use of Model 3, which holds that a longer ramp requires more work, after the physical experiment since frictional effects with the physical equipment should demonstrate this trend. However, an increase in Model 3 after the physical experiment is only observed for Q13 in the PV sequence. Rather, an increase in Model 2, which holds that a longer ramp requires *less* work, is observed. This suggests that performing the physical experiment first promotes an incorrect work model that is also inconsistent with the expected frictional effects model. It may be that the physical experiment is less useful in helping students to distinguish between the physics definitions of force and work, and may even be enhancing the tendency to equate force and work as is often done in “everyday” language [7].

To further explore students’ responses to the question set, we analyzed their open-ended responses to the “explain your answer” prompts for Q8 and Q10. We discuss the main themes in students’ explanations for each model. In the analysis below, the frequency of a particular theme is given as (number of students using theme/number of students using model) summed across the mid-test and post-test for both Q8 and Q10, unless otherwise noted.

Students who chose answers consistent with Model 1 frequently explained that the work was the same because both objects to be compared were lifted to the *same height*. For example, for Q10 one student wrote, “Work is affected by the height so if they lift it the same height they do the same work.” This explanation was common across all three tests in both PV and VP sequences for Q8 and Q10 (PV: 28/96; VP: 49/144). After performing the physical experiment, students in the PV sequence more frequently (27/96) explained their answer by citing the tradeoff between force and ramp length and/or the equation relating force, length and work compared to students in the VP sequence (7/144). On the other hand, students in the VP sequence more frequently explained that work was the same for the two methods of lifting the box because there was no friction or that friction did not change (PV: 6/96; VP: 19/144). Similarly, students in the VP sequence more frequently explained that work is equal

TABLE 1. Description of work question subset (questions are paraphrased). In each question, students were instructed to ignore the effects of friction. Multiple-choice options are assigned to models.

Q#	Question	Model 1	Model 2	Model 3	Other
8	Moving an object with a <i>longer</i> ramp to the same height would cause work to:	Stay the same	Decrease	Increase	Not enough info
10	Does directly lifting a box or using a ramp to lift it to the same height require more work?	Both same work	Direct lift	Ramp	Not enough info
13	Of three different length, same height ramps, which would require the most work to lift a box?	All same	Shortest ramp	Longest ramp	Mid-length ramp

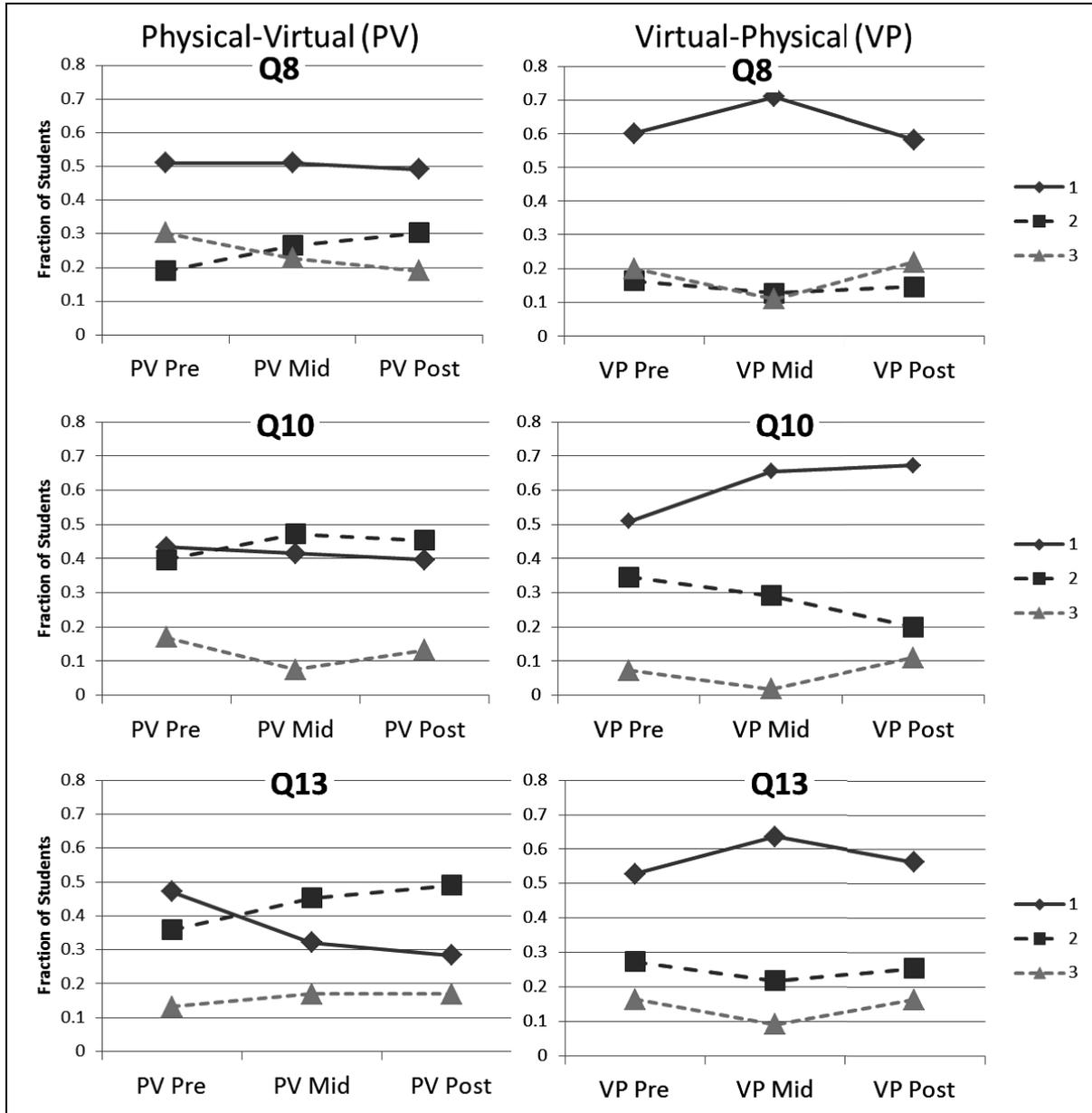


FIGURE 1. Fraction of students using specified models to answer work questions, by treatment. Model 1 suggests only height affects work needed. Model 2 suggests a longer ramp requires *less* work to reach the same height. Model 3 suggests a longer ramp requires *more* work to reach the same height.

to the change in potential energy (PV: 3/96; VP: 16/144).

Students in both sequences who chose answers consistent with Model 2 (longer ramp requires less work) explained that if less force was needed to lift the object, less work would be needed (PV: 15/79; VP: 10/42). For example, one student wrote, "Less force needed leads to less work." On Q8, students in the PV sequence more frequently stated that a less steep board required less work (PV: 9/30; VP: 2/15). For Q8, there was also a spike in the number of students in the PV sequence who restated their answer as their explanation (PV: 10/30; VP: 1/15), perhaps indicating that a longer board requiring less work was obvious to these students and did not need further explanation.

On Q10, students in both sequences made statements that indicated common sense reasoning that using a ramp is better than not using one (PV: 11/49; VP: 14/27). For example, one student wrote, "Mary is using the ramp, so she is putting in less work to get same results as Jane." However, students in the PV sequence more frequently stated that using the ramp would be less work than just lifting because there would be a mechanical advantage (PV: 14/49; VP: 1/27). These descriptions are similar, but the students in the PV sequence more frequently used the newly introduced term "mechanical advantage," (input force/load) which is related to force and not to work.

For students who chose answers consistent with Model 3 (longer ramp requires more work), we did not observe any major differences between the sequences. Students most frequently focused on the increased distance the object had to travel, but did not explicitly link the increase in work to increased frictional effects (PV: 24/33; VP: 15/23). For example, one student wrote, "Mary has to move it farther doing more work." However, no students discussed friction to support answers consistent with Model 3.

SUMMARY & IMPLICATIONS

We have previously demonstrated that the VP sequence frequently results in better student performance on multiple-choice questions related to work than does the PV sequence. Here, we demonstrate that for a subset of work questions the PV sequence in fact decreases the percentage of students choosing the correct answer. It has been pointed out that we may be penalizing these students for selecting answers consistent with the frictional effects they observe in the physical experiment. However, when we looked at the answers selected by the students, we found a larger increase in the number of students in the PV sequence choosing answers consistent with the model that a longer inclined plane requires less work

to lift an object to the same height as a shorter one (Model 2). This may indicate that the PV sequence more frequently leads students to fail to differentiate between the physics definitions of force and work.

We find support for this assertion in students' written explanations of their multiple-choice answers. We compared explanations provided by students in the PV and VP sequences to defend the *same* answer choices (i.e. compared explanations within each model). We found that students in the PV sequence often employed the term "mechanical advantage" to explain their Model 2 responses. Since this concept is associated with force and not work, this trend indicates that students are not fully differentiating between force and work. On the other hand, the virtual activity led some students to defend their Model 1 (canonical physics model) answers by discussing the role of friction. These results support the advantage of the VP sequence over the PV sequence and suggest that further efforts should be directed towards refining the VP sequence to enhance its ability to focus students' attention on both differentiating physics concepts and understanding the role of friction in the physical experiment. Future work will track how consistently students used each model and test for statistically significant differences between the sequences.

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