Comparing Student Learning in Mechanics Using Simulations and Hands-on Activities

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Abstract. Often computer simulation environments present students with an idealized version of the real world which can affect students' conceptual understanding. In this study we investigate the effects of completing an experiment in mechanics using this ideal world as compared to an identical experiment in the real world. Students in three of five conceptual physics laboratory sections completed the physical experiment while the other two sections performed the virtual experiment. The experiments were part of a unit on simple machines from the CoMPASS curriculum [1] which integrates hypertext-based concept maps in a design-based context. There was no statistically significant difference between the pre and post data of the students in the two groups. Students who performed the virtual experiment were able to answer questions dealing with work and potential energy more correctly, though neither group was able to offer sound reasoning to support their answers.

Keywords: pulleys, simulations, hands-on, concept maps, hypertext, student understanding, physics education research
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INTRODUCTION

Studies comparing the effectiveness of computer simulations to hands-on activities have shown varying results [1,2,3,4]. Students using simulations outperformed those doing a hands-on activity in electric circuits [1, 2] while the two were equally effective in learning about heat and temperature [4].

We investigate the effectiveness of virtual versus physical activities in learning mechanics in the context of pulleys. This study utilizes CoMPASS -- an inquiry and design-based curriculum that integrates hypertext concept maps and text in a design-based environment using physical or virtual activities (Fig. 1). The target concepts are force, work, potential energy, mechanical advantage and force-distance tradeoff. We examined how students enrolled in conceptual physics developed an understanding of these ideas after completing a physical or virtual experiment. Our research questions were:

Q1) How do students' overall conceptual understandings of pulleys change after completing physical versus virtual activities?

Q2) On which particular concepts did students show the greatest conceptual differences after completing physical vs. virtual activities? How was student reasoning about these concepts different?

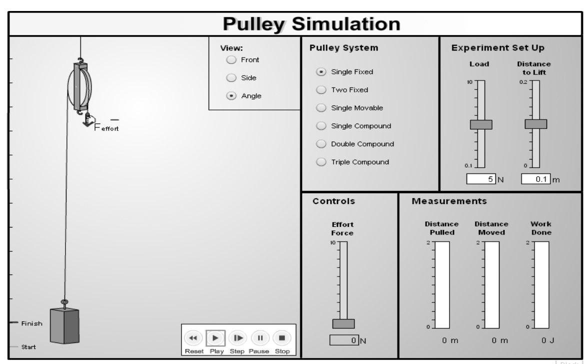

FIGURE 1. Screen shot of pulley simulation

METHODOLOGY

The participants were enrolled in a conceptual physics lab course. Students worked in groups of three to four for two hours. Two of the laboratory sections completed the virtual experiment using the simulation while the other three laboratory sections performed the physical experiment with pulleys, string and masses. The laboratory sections were assigned to virtual or physical experiments in a way that made the number of students in each group roughly equal. The instructions given and data gathered by both groups were identical. Both groups completed a multiple choice pre-test before starting the activity, then completed the activity and answered open-ended worksheet questions followed by a mid-test. Next, the group that had completed the virtual experiment did the physical experiment and vice versa followed by open-ended summary questions and a post-test. We used a phenomenological approach to analyze responses to the open-ended worksheet questions [5]. We also analyzed performance on the pre- and mid-tests.

RESULTS AND DISCUSSION

There was no statistically significant difference between the pre-test scores or the mid-test scores of the physical and the virtual groups as shown in Table 1. Thus, there is no difference between the physical and virtual groups in the overall understanding of pulleys as measured by the test.

TABLE 1. Pre and Mid Test Mean ± Std. Dev

Test	Physical (n=71)	Virtual (n=61)
Pre	36.5% ± 13.6%	33.3% ± 12.8%
Mid	47.5% ± 12.9%	48.7% ± 18.3%

In addition to comparing test means for the two groups, we looked for significant differences between the physical and virtual groups on individual questions on the pre- and mid-test and then mapped these questions back to the worksheet summary questions which asked about the same concepts. Two test questions with no significant pre-test difference, but significant mid-test differences, between the two groups were Q9 and Q13, as shown in Table 2. Both dealt with the concept of work.

Question 9 asked students to compare the work needed to lift a load using three different frictionless pulley systems -- single fixed, single compound and double compound. Table 2 shows scores on Q9 for the two groups. There was no statistically significant difference between the pre-test scores, but the mid-test scores were statistically significantly different ($p<10^{-8}$) with an absolute gain for the virtual group (39.3%) versus a loss for the physical group (−12.7%).

TABLE 2. Pre and Mid Test % Correct Responses

Treatment	Test	Question 9	Question 13
Physical	Pre	29.6%	52.9%
	Mid	16.9%	31.4%
Virtual	Pre	24.6%	52.5%
	Mid	63.9%	75.4%

We relate the performance on test Q9 with the categories of responses to worksheet Q4 (Fig. 2) which students completed immediately after the experiment. This question asked, “Based on your data, when you changed the pulley setup, how did it affect the work required to lift the object? Why do you think that is?”

The largest number of responses (80%) in the virtual group was in the ‘same’ category, i.e. they correctly identified equal work done in different pulley systems. Comparatively, 71% of the responses in the physical group were spread across three categories – ‘decreased’, ‘increased’ and ‘changed.’ This finding is not surprising, as the work in the physical experiment changes due to friction when additional pulleys are added. These results suggest that for most students it is necessary to have experienced a friction-free environment, such as a simulation to be able to answer Q9 correctly.

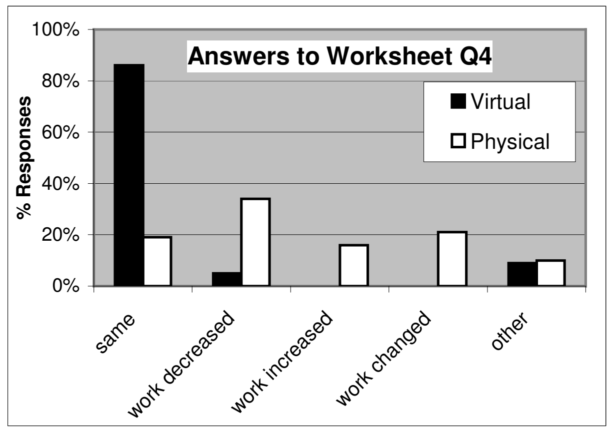

FIGURE 2. Student answers on worksheet question 4

To determine if the simulation group indeed had a deeper conceptual understanding, we examined student reasoning in the second half of worksheet Q4, “Why do you think that is?” The open-ended responses were coded and categorized into two different types of reasoning: covariational and mechanistic [6]. Covariational reasoning occurs when “an effect is attributed to one of its possible causes with which … it covaries” whereas mechanistic reasoning refers to “an explanatory account of observed results by describing the mediating process by which the target factor could have produced the effect.” [7] Covariational reasoning seeks to make a connection between cause and effect while mechanistic reasoning explains why. Thus, a higher instance of mechanistic reasoning may indicate deeper conceptual understanding.

Figure 3 shows that a vast proportion (over 90%) of the reasons given by both groups were covariational. The percentage of responses indicating scientifically accurate mechanistic reasoning was slightly larger in the virtual group (6%) versus the physical group (2%).

The main ideas cited in covariational reasons in both groups were changing distance or force, addition of more pulleys, constant load and more mechanical advantage. The main ideas cited in mechanistic reasoning include work being proportional to force and distance, energy not being created or destroyed and work being converted into an equal amount of potential energy.

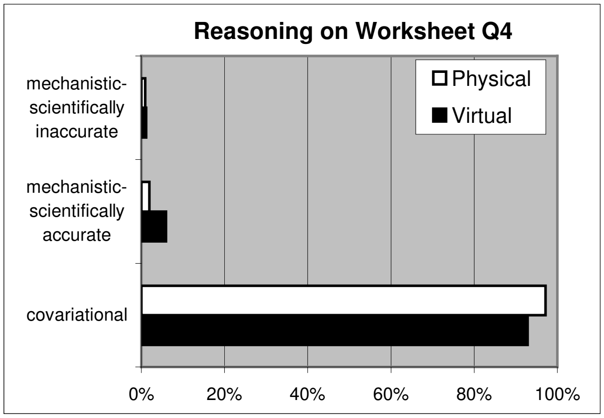

FIGURE 3. Student reasoning on worksheet question 4

Question 13 on the mid-test stated, "You use a movable pulley to lift a watermelon to your tree house. How does the work you do lifting the watermelon compare to its potential energy once lifted?" Table 2 shows no statistically significant difference between pre-test scores, but the mid-test scores were statistically significantly different ($p<10^{-6}$), with an absolute gain (22.9%) in the virtual group scores versus a loss (–21.5%) in the physical group.

The concept tested in test Q13 was similar to that assessed in worksheet Q5 which asked, "Based on your data, how does work compare to potential energy (PE) for a given pulley system? Why do you think that is?" Figure 4 shows that a larger number of the virtual group responses (62%) were in the 'Work = PE' category compared to the physical group (16%).

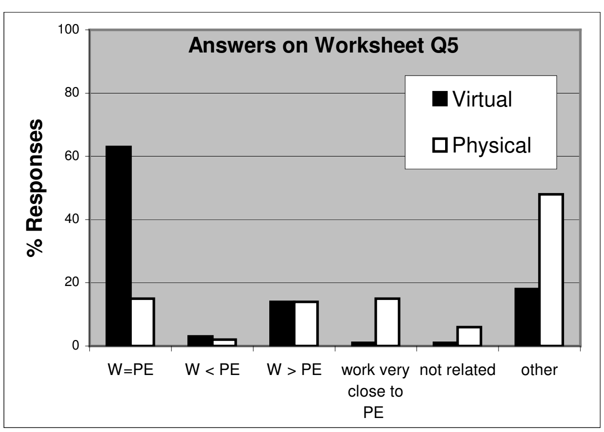

FIGURE 4. Student answers on worksheet question 5

The physical group responses were extremely varied, with only 18% seeing that the values of work and energy were very close and would be the same if there were no friction. Again, this is not surprising since the virtual group students had experienced the simulation where work and PE were the same. The large variation in answers given by the physical group is likely due to the measurement error in the force readings and thus the work values.

Figure 5 shows the response categories for each group on the "Why do you think that is?" portion of worksheet Q5. Covariational reasoning was used by vast majorities of both groups, however it was less prevalent in responses by the virtual group (66%) vs. the physical (90%) group students. Scientifically accurate mechanistic was more prevalent in the virtual group responses (19%) vs. the physical group (5%). Similarly, scientifically inaccurate mechanistic reasoning was also more prevalent in the virtual group (5%) vs. the physical group (1%). More students in the physical group (5%) vs. the virtual group (2%) cited evidence from their data instead of reasoning.

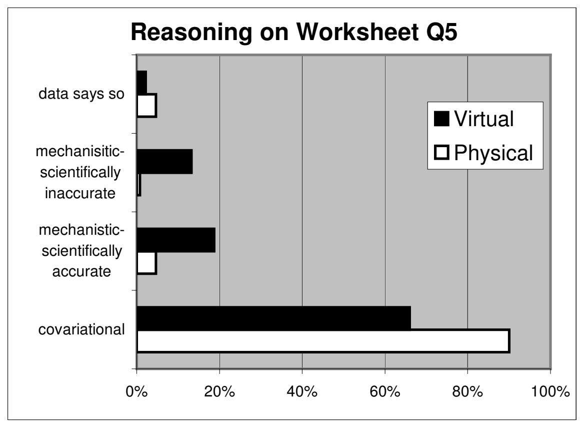

FIGURE 5. Student reasoning on worksheet question.

Common covariational reasoning included ideas about distance, force, work, potential energy and the number of pulleys such as "work was done in the vertical direction," or "the load and distance moved were constant." Common ideas given in the mechanistic reasoning responses were that "potential energy results from work," "energy is conserved," "potential energy increased which caused work to decrease," and "potential energy increased as mechanical advantage increased but work remained constant." As seen, these ideas relate a cause and effect, but may be scientifically correct or incorrect. Finally a handful of students referenced their data as to their reason, for example, "the data says so."

CONCLUSIONS

We address each of the research questions below.

Q1) How do students' overall conceptual understandings of pulleys change after completing hand-on versus simulation activities?

There was no significant difference found on the whole in student performance on the pre- and mid-test between groups of students who completed a physical experiment versus a virtual experiment. Therefore one might conclude that there was no difference in the two treatments on student learning using the activity. However, looking deeper as in Q2) below we find some differences.

Q2) Which particular concepts did students show the greatest conceptual differences on after completing hand-on versus simulation activities? How was student reasoning about these concepts different?

Student understanding of the relationship between work done while using different pulley systems with no friction as well as the relationship between work and potential energy in an idealized pulley system was significantly different in the physical group as compared to the virtual group.

Students in the simulation group showed large gains on the mid-test questions asking about each of these concepts while students in the hands-on group showed losses on the same questions. Thus, using a simulation that presented the students with a frictionless environment helped them form the correct conceptual ideas about work in an ideal world.

When students were asked to give reasons for their answers, we found that a vast majority of students in both groups used covariational reasoning, looking only at surface connections between scientific variables and not the underlying causal mechanism for these connections. Thus, using a simulation can allow students to answers questions regarding work and potential energy more correctly, but it does not necessarily develop a deep and complete reasoning of the mechanism underlying these relationships.

FUTURE WORK

This study has shown us that students who used the simulation as well as those that used the physical experiment lack depth in their reasoning on questions involving work and energy in a frictionless environment. In the future we plan to offer more scaffolding as students interact with the simulation. This scaffolding could be in the form of Socratic questioning by a facilitator or questions on the worksheet that cause students to reflect on data gathered and look for the underlying causal mechanism. We will know we were successful if we see a large increase in scientifically accurate mechanistic reasoning in student responses.

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