Comparing the Development of Students' Conceptions of Pulleys Using Physical and Virtual Manipulatives

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Abstract. Research has shown that the concept of force in a pulley is learned equally well by students using physical and virtual manipulatives. We report on a study in which students enrolled in a conceptual physics laboratory spent two weeks investigating pulley systems using either physical or virtual manipulatives. Students were given written materials which guided them through a series of activities which scaffolded the construction of their conceptions of pulleys. Students were required to make predictions and then test these predictions by building and comparing different pulley systems. They were presented with a challenge to design the best pulley system to lift a piano at the end of each week. We compare how the students' conceptions of pulleys develop between the physical and virtual treatments as well as investigate the ways in which they use the manipulatives while completing the scaffolding activities.
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INTRODUCTION

While the affordances and limitations of computer simulations and physical experiments have been described in science education research [1,2,3,4], a clear consensus on the relative effectiveness of physical and virtual manipulatives has not yet emerged in the literature. In some situations virtual manipulatives have been shown to offer better support than physical manipulatives [1,3], and in other contexts physical and virtual manipulatives have been shown to offer equal support for learning [2,4].

Our previous research has investigated the use of physical and virtual manipulatives to learn the physics concepts associated with simple machines [5]. We have found that students learn the concept of force equally well using both the physical and virtual manipulatives. In this study we investigate the extent to which physical and virtual manipulatives can deepen students' understanding of force and provide the scaffolding necessary for them to construct their conceptions of complex pulley systems.

Our research questions (RQ) were:

RQ1) How does the initial interaction with the manipulatives influence students' ideas of how pulleys work and are helpful?

RQ2) Do students' ideas of how pulleys work and how they can be helpful change one week after interacting with the manipulative? Are there differences between the two manipulatives?

METHODOLOGY

Students enrolled in an introductory conceptual physics laboratory performed an experiment with pulleys using either physical or virtual manipulatives. In each section students were randomly assigned to a group, half of which used the physical manipulative (N=49) and the other half used the virtual manipulative (N=47). To minimize leakage effects, the groups were arranged such that those using the physical manipulative were seated in the front half of the room, and those using the virtual manipulative were seated in the back half of the room. Students did not interact with students seated at other tables.

Students in the virtual treatment used ViPS Demo [6] as shown in Fig. 1 to construct and test different pulley systems and used the pulley simulation (Fig. 2) on the CoMPASS website [7] to measure the force in the individual strands of each pulley. Students in the physical treatment were given the pulleys, strings, and weights needed to build the systems covered in the activity as well as the meter sticks and spring scales needed to collect data.

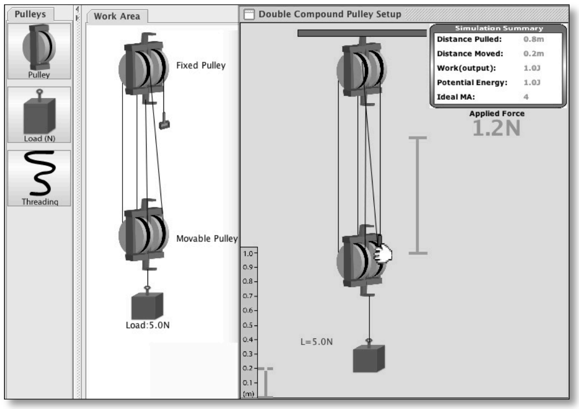

FIGURE 1. ViPS Demo pulley construction interface (left) and pulley experiment interface (right).

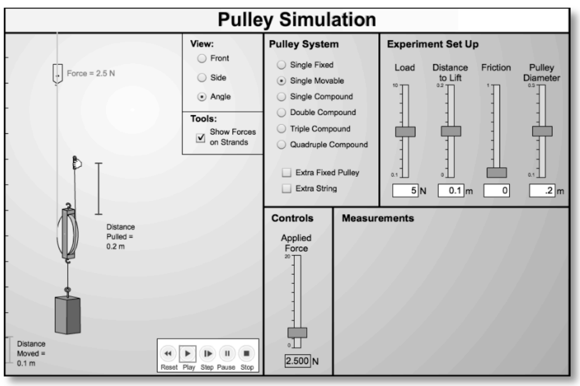

FIGURE 2. CoMPASS pulley simulation.

Students were given a pre-test at the beginning of the first week and a post-test at the end of the second week. Two weeks following the experiment, students were given a delayed post-test. The items on these tests were constructed to probe common misconceptions about pulleys and were modeled after Hegarty, *et al.* [8]. The internal consistency of the test was measured using Cronbach's Alpha (α = 0.717). Each question had an accompanying confidence six-point Likert scale ranging from zero (complete guess) to five (completely sure). Students were asked to circle the number corresponding to how confident they were in their answers.

Students in each treatment group were provided guiding questions on worksheets designed to scaffold the development of their conceptions of how pulleys work. The worksheets led students to compare different pulley systems through several iterations of predicting, testing, and then revisiting their conceptions. The worksheets given to the groups were identical except for the specific instructions needed to use the manipulative (such as the login information for the simulations).

Responses to the open-ended worksheet questions were coded using a phenomenographic approach [9]. Before coding, student responses were entered into a spreadsheet allowing the coder to be blind to which treatment group the responses were from. The codes were mutually exclusive so that statistical significance could be discussed.

In order to determine if there was a difference between the responses given by students in the physical and virtual groups, a chi-square test was used. When expected cell counts were less than five, a Fisher's exact test was used. For statistically significant results, adjusted residuals were examined to determine which cells contributed to the significance [10].

RESULTS

Students' test scores are reported in Table 1. There was a significant increase in the scores from pre-test to post-test ($F(1,141)=500.4$, $p<.001$, $r=.883$) and from pre-test to delayed post-test ($F(1,141)=414.4$, $p<.001$, $r=.864$). There was a significant decrease in scores from the post-test to delayed post-test ($F(1,141)=20$, $p<.001$, $r=0.353$). There were no significant differences between the treatments ($F(1.6,220)=2.1$, $p=.183$).

Students' confidence scores are reported in Table 2. There was a significant increase in the scores from pre-test to post-test ($F(1,141)=313.9$, $p<.001$, $r=.831$) and from pre-test to delayed post-test ($F(1,141)=141.7$, $p<.001$, $r=.708$) and a significant decrease from post-test to delayed post-test ($F(1,141)=52.8$, $p<.001$, $r=0.522$). There were no significant differences between the treatments ($F(1.7,235.2)=0.134$, $p=.837$).

TABLE 1. Total test score out of 13: Mean (± S.D.)

Treatment	Pre-Test	Post-Test	Delayed Post-Test
Physical (N=74)	3.20 (±2.59)	8.34 (±2.72)	7.72 (±2.94)
Virtual (N=69)	3.16 (±2.64)	9.10 (±2.88)	8.39 (±2.87)

TABLE 2. Average confidence out of 5: Mean (± S.D.)

Treatment	Pre-Test	Post-Test	Delayed Post-Test
Physical (N=74)	2.29 (±1.15)	3.73 (±0.90)	3.31 (±1.08)
Virtual (N=69)	2.32 (±1.05)	3.83 (±0.83)	3.41 (±1.04)

After the pre-test, students were given a worksheet. The first item on the worksheet instructed students to play around with the different pulley systems and determine relationships between the load, applied force, distance pulled, and distance moved. While they were given no explicit instruction to do so, students took data and made observations which they recorded on the accompanying worksheet. Table 3 summarizes the kinds of data taken by students and Table 4 summarizes the observations made by students when they played around with different pulley systems. The categories listed in Tables 3 and 4 are mutually exclusive.

TABLE 3. Data taken using each manipulative

Type of Data	Physical (N=49)	Virtual (N=47)
Data for Force Only	13	4
Data for Force & Distance	14	37
No Data	19	4
Other	3	2

TABLE 4. Observations made using each manipulative

Observation	Physical (N=49)	Virtual (N=47)
Applied Force Only	4	0
Applied Force & Distance	1	3
Definitions	5	0
Distance	13	6
Force-Distance Tradeoff	10	5
None	14	27
Number of Pulleys	2	4
Other	0	2

There is a statistically significant difference in the kinds of data taken by the students ($\chi^2(3, N=96)=25.6$, $p<.001$, $V=0.516$). Students in the physical group were more likely to take no formal data or only take data for the applied force while those who interacted with the virtual manipulative were more likely to take a complete set of data.

There is a statistically significant difference in the kinds of observations made by the students ($\chi^2(7, N=96)=20.0$, $p=.004$, $V=0.456$). Students using the physical manipulative were more likely to provide a definition of applied force or state an observation of force, e.g. "the applied force decreases with more pulleys". Those using the virtual manipulative were more likely to not make any observations at all.

After students interacted with the manipulative, the next item on the worksheet asked them how pulleys work and how they are helpful. The question also appeared at the beginning of the worksheet given during the second week. Table 5 shows the categories of responses given in week 1 as well as the occurrence frequency for each. The same information is provided in Table 6 for responses given in week 2. In order to keep the categories mutually exclusive, a student who stated the reason why they thought a pulley was easier or required less applied force was categorized by their explanation. Those who merely stated that pulleys were easier or reduced the applied force appear in the categories marked "(No Explanation)".

TABLE 5. Week 1 responses to how pulleys work/help

Response	Physical (N=49)	Virtual (N=47)
Distribute Weight of Load	11	5
Easier (No Explanation)	6	6
Force-Distance Tradeoff	3	5
Less Work/Energy	3	6
More Pulleys = Less Force	7	10
More Strings = Less Force	5	5
Reduce Applied Force (No Explanation)	7	5
Other	7	5

There was no significant difference in the responses given in the first week by students in the different treatments ($\chi^2(7, N=96)=4.9$, $p=.661$).

TABLE 6. Week 2 responses to how pulleys work/help

Response	Physical (N=49)	Virtual (N=47)
Force-Distance Tradeoff	3	4
More Pulleys = Less Force	5	6
More Strings = Less Force	11	9
Pulleys Distribute Weight	11	5
Reduce Applied Force (No Explanation)	3	5
Strings Distribute Weight	14	10
Other	2	8

There was no significant difference in the responses given in the second week by students in the different treatments ($\chi^2(6, N=96)=7.3$, $p=.284$).

DISCUSSION

The test scores indicate that the activity likely increased student learning. There was no overall difference between the students using the virtual and physical manipulatives. However, a closer look at the data reveals there was a difference in the way in which the students from the different groups initially interacted with the manipulatives. Those using the physical manipulative were more likely to make observations about the applied force and less likely to take formal data than those using the virtual manipulative. On the other hand, students using the virtual manipulative were more likely to take data for the applied force and distance but make no further connections between the quantities as evidenced by written statements on the worksheet.

The simulation provides data for all of the physical quantities the students were asked about, so it is not surprising that those using the simulation more often took a full set of data. Students who used the physical experiment have the ability to actually feel the force which is being applied to the system. This could explain why students in the physical group more often made observations about the applied force.

While the student interactions with the physical and virtual manipulatives were significantly different, their responses to how pulleys work and are helpful were not significantly different. At the beginning of the first week, student responses focused on the idea of a pulley being easier or requiring less force because the weight is somehow distributed. When asked the question again at the beginning of the second week, student responses centered on the idea of the weight being distributed by the strings and that the more supporting strings in a system, the lower the applied force.

SUMMARY

Students' initial interactions with the manipulative were significantly different. However, their responses indicated that they had the same basic ideas of how pulleys work and are helpful. Both groups noted that pulleys made things easier/required less applied force. Students in the physical group mentioned that pulleys distribute the weight of the load more than those in the virtual group, but the difference was not significant.

When asked at the beginning of the second week how pulleys work and how they are helpful, there was no significant difference between the groups. The responses differed from those given in the previous week, however. In the first week, students often said that pulleys are easier to use than lifting a load directly, but they offered little explain as to why. In the second week, the idea that the strings in the pulley distribute the weight became the most common idea.

IMPLICATIONS FOR INSTRUCTION

This research demonstrates that although students interact differently with the physical and virtual manipulatives at the beginning of the activity, they emerge with the same basic idea of how a pulley works after completing the scaffolding activities. Thus, appropriate instructional scaffolding appears to compensate for differences between the affordances for learning offered by the two manipulatives.

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