Scaffolding Students' Understanding Of Force In Pulley Systems

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Abstract. Recent research results have found that students using virtual manipulatives perform as well or better on measures of conceptual understanding than their peers who used physical equipment. We report on a study with students in a conceptual physics laboratory using either physical or virtual manipulatives to investigate forces in pulley systems. Written materials guided students through a sequence of activities designed to scaffold their understanding of force in pulley systems. The activity sequences facilitated students' sense making by requiring them to make and test predictions about various pulley systems by building and comparing different systems. We investigate the ways in which students discuss force while navigating the scaffolding activities and how these discussions compare between the physical and virtual treatments.

Keywords: physics education research, physical experiment, computer simulation, laboratory, scaffolding
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INTRODUCTION

The affordances and limitations of physical experiments and computer simulations have been described in science education research [1,2,3,4] in a variety of contexts. In some situations, physical and virtual manipulatives have been shown to offer equal support for learning [1,3]. In other contexts, virtual manipulatives have been shown to offer better support than physical manipulatives [2,4].

Previously, we have investigated the use of physical and virtual manipulatives to learn the physics concepts associated with simple machines. We found that students using physical and virtual manipulatives in undergraduate level introductory physics labs learn the concept of force in a pulley equally well [5]. The students in this study used both physical and virtual pulleys in sequence. After using the first manipulative, we found no differences between the groups in students' understanding of force as measured by a multiple choice test between the groups. We also observed no differences between the groups' force subscores after they had used both physical and virtual manipulatives. In this study we investigate the extent to which using either physical or virtual manipulatives can deepen students' understanding of force in pulley systems and provide the scaffolding necessary for them to construct their conceptions of complex pulley systems.

We have previously reported [6] that the pre- to post-test scores of students in this study showed significant increase but no significant interaction with treatment (physical or virtual) which indicates that students in both groups emerged with a similar level of understanding of force in pulley systems. Additionally, we found no significant difference in the student explanations of how pulleys work and are helpful both before and after completing the scaffolding activities. Here, we report on the ways in which students using the two manipulatives reason about the applied force in various pulley systems and explain their responses. Specifically, our research question is: What differences, if any, do we find in the responses and explanations given by students using physical vs. virtual pulleys when comparing the applied force in two different pulley systems?

METHODOLOGY

Students enrolled in an undergraduate introductory conceptual physics laboratory experimented with either physical or virtual pulleys in groups of four. In each laboratory section students were randomly assigned to a group, half of the groups used the physical manipulative (N=74) and the other half used the virtual manipulative (N=69). The groups were physically arranged to minimize leakage effects i.e. students could not interact with those seated at other tables.

Students in the virtual treatment used a ViPS Demo [7] to build and test different pulley systems while those in the physical treatment were given real 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.

Students in both treatment groups were provided identical worksheets containing questions designed to scaffold the development of their conceptions of how pulleys work. Worksheet questions led students to compare different pulley systems through several iterations of making, testing, and later revisiting predictions. Seven questions on the worksheet asked students to compare the applied force necessary to lift identical loads using two different pulley systems. We report on four of these questions (see Fig. 1).

Which pulley system requires the least amount of applied force to lift the load (the weight)? (The weights are equal in system A and system B.)

A) Pulley system A
B) Pulley system B
C) They require the same applied force.

Explain why you chose your answer above.

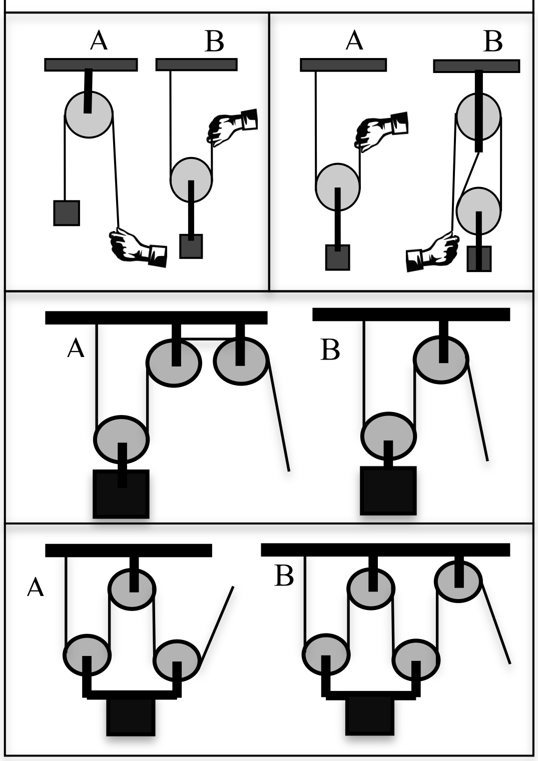

FIGURE 1. The text and diagrams for questions 3 (top left), 4 (top right), 7 (middle), and 8 (bottom).

The explanations given to these worksheet questions were coded using a phenomenographic approach [8]. The coder was blind to which treatment group the responses were from. All codes were mutually exclusive so that statistical significance could be discussed. A chi-square test was used to determine if there was a difference between the responses and explanations given by students in the physical and virtual groups. If the expected cell counts were less than five, a Fisher's exact test was used instead. The significance level was set at α=.05. For statistically significant results, adjusted residuals were examined to determine which cells contributed to the significance [9].

RESULTS & DISCUSSION

Before answering questions 3 and 4, students had the opportunity to play around with the manipulatives to determine the relationship between the load, applied force, distance pulled, and distance moved. While they had not yet been formally instructed to collect data to compare different pulley systems, we found several students collecting data during this phase. The responses to question 3 are shown in Fig. 2 and the explanations are summarized in Table 1.

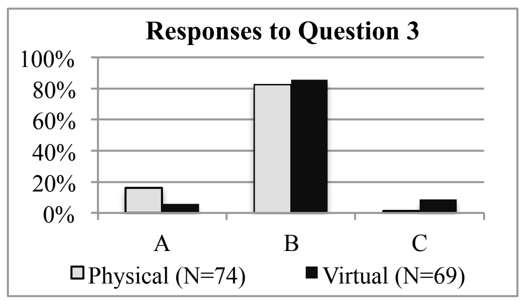

FIGURE 2. The answers given to question 3.

TABLE 1. Explanations for question 3. Asterisks denote the cell contributed to the significance. All categories are mutually exclusive.

Type of Explanation	Physical	Virtual
Cited Data	22%	26%
Load Attached to Pulley	16%	7%
Num. of Supporting Strings	15%	6%
Pulley Distributes Weight	12%	4%
Force-Distance Tradeoff**	1%	14%
Direction Pulled	7%	9%
Movable Needs Less Force	3%	9%
Discuss Tension	1%	9%
Going Against Gravity**	9%	0%
Other	14%	16%

There is a statistically significant difference between the two groups in the answers given by students to question 3 (χ^2(2, N=143)=7.439, p=.029, V=0.228). While there is no statistically significant difference in the most common response (moveable pulley B), students using the physical manipulative were more likely to choose the fixed pulley (A) than those using the virtual manipulative, while those using the virtual manipulative were more likely to say the systems required the same amount of force (C).

There was also a significant difference in the explanations given by students in each group (χ^2(3, N=143)=29.201, p<.001, V=.452). Students who used the physical manipulative were more likely to explain their answer using gravity. Those who chose the single fixed pulley (A) often justified their response by saying that the single movable pulley was "going against gravity" and would therefore require more force. Students who used the virtual manipulative were more likely to discuss the force-distance tradeoff when explaining their response. As previously reported [6], many students in the virtual group collected extensive data when initially playing around with the pulleys, so these students would have been more likely to observe the relationship between force and distance pulled.

The responses to question 4 are shown in Fig. 3 and the explanations are summarized in Table 2. The answers given by students in each group were significantly different (χ^2(2, N=143)=48.237, p<.001, V=.581). Students using the physical manipulative were more likely to say the single compound pulley required less force (B), while those using the virtual manipulative were more likely to respond that the systems required the equal applied force (C).

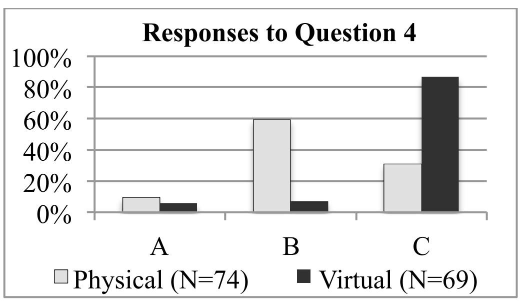

FIGURE 3. The answers given to question 4.

TABLE 2. Explanations provided for question 4. Asterisks denote the cell contributed to the significance. All categories are mutually exclusive.

Type of Explanation	Physical	Virtual
Cited Data	15%	28%
Same # of Movable Pulleys = Same Force**	4%	29%
More Pulleys Distribute Load**	32%	0%
Num. of Supporting Strings	11%	7%
Force-Distance Tradeoff	5%	12%
More Pulleys = Less Force	14%	3%
Pulling Up Compensates for Extra Pulley	4%	9%
Other	15%	13%

The explanations students provided in question 4 were significantly different between the groups (χ^2(7, N=143)=47.140, p<.001, V=.574). The physical group was more likely to state that the single compound pulley requires less force because there are more pulleys to distribute the load. Students who used the virtual manipulative were more likely to observe that the two systems had the same number of movable pulleys and therefore the same force.

After completing questions 3 and 4, students were led through scaffolding activities in which they compared a single fixed and single movable pulley. Questions 7 and 8 were asked directly after this comparison. The responses to question 7 are shown in Fig. 4 and the explanations are reported in Table 3.

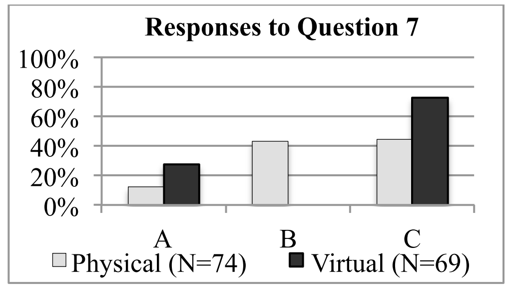

FIGURE 4. The answers given to question 7.

TABLE 3. Explanations provided for question 7. Asterisks denote the cell contributed to the significance. All categories are mutually exclusive.

Type of Response	Physical	Virtual
Extra Fixed Pulley Does Nothing**	34%	52%
More Pulleys = Less Force	9%	22%
Cited Data/Tested System	15%	7%
Same # Supporting Strands	8%	12%
Refers to Distance Pulled	9%	7%
Friction/Real World Effects**	14%	0%
Other	11%	0%

There is a significant difference in both the responses to question 7 (χ^2(2, N=143)=38.926, p<.001, V=.522) and the explanations (χ^2(6, N=143)=25.618, p<.001, V=.423). Students in the physical group were more likely to choose system B, while those in the virtual group were more likely to choose C. When explaining their responses, students in the physical group were more likely to discuss friction, while those who used the virtual manipulative were more likely to say that adding an extra fixed pulley does nothing.

The responses to question 8 are shown in Fig. 5 and the explanations are summarized in Table 4. Once again there is a significant difference between the groups in both the responses to question 8 (χ^2(2, N=143)=15.267, p<.001, V=.327) and the explanations (χ^2(9, N=143)=35.408, p<.001, V=.498). Students who used the physical manipulative were more likely to choose system B, while those using the virtual manipulative were more likely to say the systems required the same amount of force. When explaining their responses, students in the physical group were more likely to state that the more pulleys in a system, the more the load is distributed. Students in the virtual group were more likely to judge the systems by the rightmost pulley, considering A to be like a movable pulley and B to be like a fixed pulley.

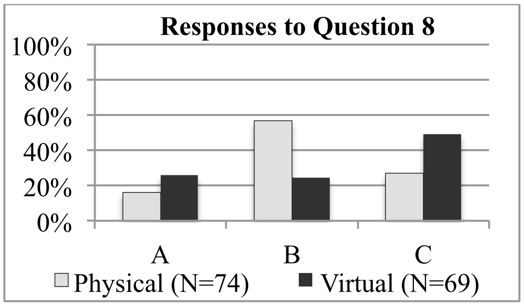

FIGURE 5. The answers given to question 8.

TABLE 4. Explanations provided for question 8. Asterisks denote the cell contributed to the significance. All categories are mutually exclusive.

Type of Response	Physical	Virtual
Extra Fixed Pulley Does Nothing	23%	39%
More Pulleys = Less Force	31%	12%
B Provides More Support**	22%	4%
Considered Only Rightmost Pulley**	1%	13%
Direction Pulled	9%	4%
Distance Pulled	1%	9%
Same # Supporting Strands	1%	6%
Pulling Up Compensates for Extra Pulley	1%	6%
Friction/Real World Effects	5%	1%
Other	4%	6%

SUMMARY & IMPLICATIONS

Students' responses and explanations to scaffolding questions were significantly different between the physical and virtual groups. Overall, students in the physical group were more likely than those in the virtual group to discuss real-world effects such as friction or gravity. This result is not surprising as the simulation presented a frictionless environment. Students who used physical manipulatives were also more likely to write about pulleys distributing the weight to reduce the applied force needed. The action of physically stringing pulleys and lifting the load may have caused students in the physical group to reason about pulleys in a different way than the virtual group.

In question 3, the virtual group was more likely to use the force-distance tradeoff while explaining their response. When initially playing with pulleys, most students in the virtual group collected data for distance and force so they would be more likely to observe this relationship. Even though all students collected data before answering questions 7 and 8, students in the virtual group were more likely to break systems into units of single movable and single fixed pulleys. This could be an artifact of seeing pulleys individually on the screen rather than physically building them.

While we observed no overall differences in students' scores *after* using the two manipulatives we found that they reason about pulley systems differently *while* using the manipulatives. In the context of pulleys we have found that students using physical manipulatives focus more on real-world effects which may be a desirable outcome, while those using the virtual manipulatives were more likely to break complex pulleys systems into individual units. It is therefore important for instructors to keep in mind their goals when choosing between physical and virtual manipulatives. Thus, we must further study students' reasoning resources as they work with these manipulatives to construct their understanding.

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REFERENCES

1. D. Klahr, L.M. Triona, and C. Williams, *Journal of Research in Science Teaching* **44**, 183–203 (2007).
2. N.D. Finkelstein, W.K. Adams, C.J. Keller, P.B. Kohl, K.K. Perkins, N.S. Podolefsky, S. Reid, and R. LeMaster, *Phys. Rev. ST Phys. Educ. Res.* **1**, 1–8 (2005)
3. Z.C. Zacharia and C.P. Constantinou, *American Journal of Physics* **76 ,** 425-430 (2008)
4. Z.C. Zacharia, G. Olympiou, M. Papaevripidou, *Journal of Research in Science Teaching* **49**, 1021-1035 (2008).
5. J.J. Chini, A.M. Madsen, E. Gire, N.S. Rebello, and S. Puntambekar, *Phys. Rev. ST Phys. Educ. Res.* **8**, 010113 (2012).
6. A. Rouinfar, A.M. Madsen, T. Do Ngoc Hoang, S. Puntambekar, and N.S. Rebello, "Comparing the Development of Students' Conceptions of Pulleys Using Physical and Virtual Manipulatives" in *Proceedings of the 2011 Physics Education Research Conference,* edited by N.S. Rebello et al., AIP Conference Proceedings 1413, Melville, NY, 2002, pp. 331-334.
7. Virtual Physics System [Software]. Available from http://iis.cse.eng.auburn.edu/~mynenls/vips/pretest/account.php
8. F. Marton, *Journal of Thought* **21**, 29-39 (1986).
9. S.J. Haberman, *Biometrics* **29**, 205-220 (1973).