Comparing the Effects of Physical and Virtual Experimentation Sequence on Students' Understanding of Mechanics

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This study aims to understand how the sequence of physical and virtual activities affects student conceptual understanding of pulleys. We compared pre-, mid- and post-test scores of two treatment groups, which differed by the temporal order in which the physical and virtual activities were completed. We examined overall scores as well as scores on individual questions. In questions dealing with the concept of work, students who performed the virtual experiment first seemed to have blocked information learned in the physical. In questions about force, students in each treatment group showed similar gains from pre- to mid-test but from mid- to post-test there was no gain, consistent with the primacy effect. Further, students who performed the physical experiment first did better on force mid-test questions, consistent with advantages of kinesthetic learning.

In this study we investigate the effects of sequence of physical and virtual activities on student learning of various concepts in physics. The affordances and limitations of physical laboratory experiments and computer simulation activities have increasingly been described in science education research (De Jong & Van Joolingen, 1998; Finkelstein, et al., 2005; Triona & Klahr, 2003; Klahr, Triona, & Williams, 2007; Zacharia & Constantinou, 2008; Zacharia, Olympiou, & Papaevripidou, 2008). It has been shown that there are many advantages and disadvantages to using each type of manipulative. Klahr, Triona, & Williams (2007) reported that learning with a physical manipulative is advantageous as it is consistent with the concrete-to-abstract nature of cognitive development, because it increases student interest and motivation for learning and allows for more sources of brain activation because of the added kinesthetic element. On the other hand, physical manipulatives can decrease efficiency and productivity of learning, can allow students to spend time on activities that produce irrelevant information and can have a higher logistical and financial cost (Klahr, Triona, & Williams, 2007). Virtual manipulatives in the form of computer simulations have been found to be beneficial as they help students visualize problems and solutions, provide an interactive learning environment, and assist in the development of abstract concepts not available with physical materials (Zacharia & Anderson, 2003). Simulations also allow for the use of dynamically changing graphs, (Triona & Klahr, 2003) are less time consuming and don't require specialized equipment (Thornton & Sokoloff, 1990). Disadvantages of computer simulations include decontextualized representations of the real world (Hofstein & Lunetta, 2003) and teaching students science concepts in a different way than scientists initially learned them (Steinberg, 2000).

The growing body of research comparing physical and virtual manipulatives has yet to reach a clear consensus on the relative effectiveness of virtual and physical activities on student learning. Finkelstein et al. (2005) looked at how students learned about circuits differently with virtual or physical manipulatives. The simulations used by the students were similar to the physical materials, except that the simulations showed electron flow within the circuit, which the physical materials could not. Finkelstein reported that students who had used the virtual manipulatives, i.e. the simulations, scored better on an exam and were able to build physical circuits more quickly than students who had used the physical manipulatives. Klahr, Triona and Williams (2007) investigated how physical and virtual manipulatives affect student learning about mouse-trap cars. Students used either physical or virtual manipulatives to design their cars. The physical and virtual treatments showed the same effectiveness in helping students design cars. Zacharia, Olympiou, & Papaevipidou (2008) looked at physical and virtual manipulatives in the context of heat and temperature. One group of students used only physical manipulatives, while another group of students used physical manipulatives followed by virtual manipulatives. Students who used the physical and virtual manipulatives performed better on a conceptual test than students who used just the physical manipulatives. The time required for manipulating each type of equipment may have led to this result. The authors concluded that the simulation could be manipulated more quickly than the physical manipulative, increasing student learning. In another study, Zacharia & Constantinou (2008) once again used heat and temperature as a context to study physical and virtual manipulatives. In this study, they kept all factors equivalent for the physical and virtual conditions except the mode in which the experiment was performed. They found that the physical and virtual manipulatives were equally effective in helping students gain conceptual understanding.

In light of these studies, there is potential that the combination of physical and virtual manipulatives will greatly enhance student learning. There are many aspects of integrating physical and virtual activities that are worthy of investigation. The sequence of activities performed is of particular interest to us. In our study, we investigate the effects of sequence of physical and virtual activities on student learning in the context of pulleys. Our goal is to understand the affordances and limitations of each sequence of activities and to investigate the physics concepts that are most affected by sequence.

Theoretical Framework

This study examines the effect of temporal order of physical and virtual activities on student learning of various concepts in physics. We hypothesize that blocking and the primacy effect may contribute to observed differences between the physical-virtual sequence and the virtual-physical sequence. Blocking (Kruschke, 2003) occurs when learners presented with two cues in a sequence respond to the first cue over the second. The second cue is blocked when the first cue was found to predict the outcome correctly. The response to the second cue can be understood in light of two different models. The Rescorla-Wagner model explains that the blocked information is not learned because it is deemed to be extraneous since the information from the first cue predicted the outcome correctly (Rescorla & Wagner, 1972). A second model, learned inattention, explains that blocked information is not disregarded as irrelevant, but instead the students learn to ignore it (Kruschke and Blair, 2000). This theory is supported by the fact that students showed attenuation in learning blocked ideas in subsequent activities. Heckler, et. al. (2006) found that blocking can be affected by the relative salience of cues. Salience of the first cue over the second enhances blocking. Conversely when the second cue is more salient then the first blocking is reduced. For the purpose of this study we define saliency as how noticeable a concept is.

Another relevant theory is the primacy and recency effect (Haugtvedt & Wegener, 1994). Primacy occurs when learning is dominated by the first in a series of learning experiences. Recency occurs when learning is most affected by the last or most recent learning experience. Familiarity and personal significance with the material learned promotes the primacy effect while low familiarity or personal relevance promotes the recency effect (Haugtvedt & Wegener, 1994). We investigate learning in the two sequences keeping in view the primacy and recency effects.

Method

This study took place in a conceptual physics laboratory. Conceptual physics is a non-mathematical physics course designed to introduce students to basic physics phenomena. Students are typically non-science majors. This conceptual physics course consists of three 50-minute lectures each week accompanied by a 110-minute lab. Students performed the activities of this study as a part of their regular lab meeting. They were assigned completion credit for all parts of the activities except the post-test, for which they received a portion of their lab grade based on correctness. Students had not previously studied pulleys in the lecture portion of the course, though they had been exposed to the underlying concepts used to describe pulleys.

The activities students completed are part of CoMPASS (Concept Mapped Project-based Activity Scaffolding System), a design-based curriculum that integrates concept maps, hypertext, and physical and virtual experiments (Puntambekar, Stylianou, & Hübscher, 2003 and Puntambekar & Stylianou, 2002). This curriculum consists of several important parts. Learning is framed by a design challenge, in this case one in which students are asked to design the best pulley setup to lift a pool table into a moving van. To activate prior knowledge, students are given opportunity to make individual and group predictions and brainstorm questions they would like to know more about. To gather information related to the challenge, students navigate through the CoMPASS website where they are presented with interactive concept maps accompanied by textual descriptions of concepts related to pulleys as shown in Figure 1. Students also learn about pulleys using both a physical pulley setup (physical manipulative) and an interactive computer simulation (virtual manipulative) as shown in Figure 2. The temporal order in which students completed the physical and virtual activities was varied by lab section.

The sequence of activities performed by the students is as follows. All students began by individually completing a pre-test and then made individual and group predictions. Following this, they learned more about pulleys using the CoMPASS website. After gathering information, they performed the physical or virtual activity based on which lab section they were in. There were five lab sections in total. Three lab sections were randomly assigned the Physical-Virtual sequence (PV), while the other two lab sections were assigned the Virtual-Physical (VP) sequence. Next, students took a mid-test. Finally they performed either the physical or virtual experiment and completed a post-test. This sequence is illustrated in Figure 3.

The pre-, mid- and post-tests were identical and consisted of multiple-choice conceptual questions. While students completed the physical and virtual activities, they recorded data and answered open-ended questions on a worksheet. We coded and analyzed students' responses to the worksheet questions using a phenomenograhic approach (Marton, 1986). As per this approach student responses to the worksheet questions are categorized based on the meanings expressed in these responses. The categories are not predefined by the researcher. Rather, the categories naturally emerge from the data.

We analyzed the pre-, mid- and post- test data statistically on basis of the overall scores as well as scores on questions by concept. The instructions given to each lab section and the data gathered from each section was identical. Except for the type of activity (physical or virtual), we controlled for all conditions, such as the time on task and interaction with the instructor. Students spent about 30 minutes on each activity, although students spent a few extra minutes on the activity when working with the real pulleys. This extra time was mainly due to time required to set up various pulley systems.

Results and Discussion

Overall Test Performance

The overall pre-, mid- and post-test scores are shown in Table 1. The average overall test score by sequence is shown in Figure 4. To compare the pre-, mid- and post-test data for all students, a Repeated Measures Analysis of Variance test was used. We found the assumption of sphericity had been violated on all the comparisons using Mauchly's test, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. Results from Mauchly's test and sphericity estimates are shown in Table 2.

The Repeated Measures analysis shows that students' total scores changed significantly between tests. The interaction between the total score and treatment condition is not significant. This tells us the test scores changed in a similar way for the PV and VP sequences. Thus it seems there is no difference between the PV and VP sequences in the overall understanding of pulleys as measured by the test.

Significant changes in score from pre- to mid- and mid- to post-test were determined using contrast comparisons (Table 3). Both groups showed statistically significant gains in total score between the pre- and mid-tests. Only the PV group showed statistically significant gain between the mid- and post-tests.

These results may be consistent with the virtual experiment blocking further learning in the physical experiment. In the VP sequence, the pre- to mid-test gain was followed by no gain from mid- to post-test. This could be because students ignored or put aside information learned in the second activity. We speculate that the reason for this apparent blocking could be because of certain features in the virtual experiment that were absent in the physical experiment. In the PV sequence, there was a gain from pre- to mid-test, followed by a gain from mid- to post-test. In this sequence, students seem to learn from both activities and we see no evidence of blocking. These ideas will be explored further in the analysis of individual questions.

We also see evidence of the primacy effect in the overall test scores. In both the PV and VP groups, the pre-post gain overwhelmed the mid-post gain. So, students appear to learn more from whatever experiment, physical or virtual, that they experience first in the sequence.

Individual Questions

To gain more insight into the differences in learning because of temporal order of physical and virtual activities, we analyzed test questions by concept being tested. This is because we observed the same pattern in student response when we grouped questions by concept. There were three main concepts tested. These were force and distance, work, and mechanical advantage. The questions dealing with force and distance and those dealing with work showed significant differences between treatment groups. We looked specifically at questions Q1 and Q2-1, which dealt with the concepts of force and distance and questions Q9 and Q13, which dealt with the concept of work.

Questions About Work

Questions 9 and 13 (Figure 5) test student understanding of the constancy of work done across pulley systems and the equality between work and potential energy. In looking at the overall trends for these questions about work (Figure 6) there seem to be no differences between the pre-test scores, but the mid-test scores are different in both questions with a gain for the VP group versus a loss for the PV group. Then between mid- and post-test the VP group stays about the same while the PV group shows an improvement.

The improvement of the VP group from pre- to mid-test, but not from mid- to post-test is consistent with student learning from the virtual experiment blocking further learning from the physical experiment. Salience of the concepts of work and potential energy in the virtual experiment as compared to the physical experiment may have contributed to this effect. The simulation included a dynamically increasing bar chart that represented the values of work and potential energy as an object was lifted with a pulley system. In the physical experiment, the students measured force and distance values with a spring scale and meter stick, then used these to calculate and record the values of work and potential in a data table. Thus, it seems that the concepts of work and potential energy were much more noticeable in the simulation as there was a visualization of the concepts. Because of the increased salience of the work and energy concepts in the simulation, students learned about work from the simulation and then may have ignored or set aside the ambiguous work data collected in the physical experiment, thus blocking this information.

The PV group showed a loss from pre- to mid-test and gain from mid- to post-test. Apparently, this group learned incorrectly about work and potential energy from the physical experiment as seen by losses in mid-test scores and then corrected their understanding after they used the simulation. One factor that may have contributed to the PV group's performance from pre- to mid-test is the fact that only in a frictionless environment is work unchanged and equal to potential energy. So after performing the physical experiment, the PV group would not have seen data indicating that work is constant over different pulley systems and equal to potential energy when moving objects to the same height. The constancy of work and equality with potential energy was only seen after performing the physical experiment. But why do students change their post-test answers to match the trends seen in the virtual experiment after they first completed the physical? The framework on blocking explains that blocking can be significantly reduced or eliminated if the second cue is much more salient than the first. In this case the concepts of work and potential energy are more salient in the simulation, which was performed second in the sequence. According to the framework we expect to see blocking reduced or eliminated which is consistent with our data.

Questions About Force

Questions 1 and 2.1 (Figure 7) focus on how force and distance change with different pulley systems. The results are shown in Figure 8. There was an improvement from pre- to mid-test for both the VP and PV groups while there was no difference from mid- to post-test scores for either group. On average, the PV group performed better than the VP group on the post-test.

In the physical experiment, the students use a spring scale and meter stick to measure force and distance for several pulley systems. In the simulation, the force and distance values are displayed with dynamically increasing bar charts. So in both the physical and virtual experiments, the concepts of force and distance have high salience. With equal salience in both physical and virtual, we do not expect that blocking would be more likely to occur in one activity or the other. If blocking occurs, it would be equally likely in both the PV sequence and the VP sequence. In looking at the trends for the force questions, we do see students learning from the first activity they perform, and not improving after the second activity consistent with blocking of information from the second activity occurring equally for both sequences.

These trends observed in the force questions also appear to be consistent with the primacy effect. The primacy effect explains that students learn most from the first in a series of learning experiences. Studies have also shown that familiarity with an idea has been seen to induce primacy. Force and distance are typically more familiar concepts to students as compared to the idea of work and potential energy. So data consistent with the primacy effect can be expected for questions pertaining to the former concepts, such as Q1 and Q2.1 rather than the latter.

Additionally, the PV group performed better than the VP group on the mid- and post-test Q1 and Q2.1. Thus, it seems that performing the physical experiment first enhances student understanding of force and distance. These results are consistent with the idea promoted by physics educators such as Arons (1997) who states that to enhance learning the concepts must be 'explicitly connected with an immediate, visible or kinesthetic experience.' Thus, we speculate that the fact the students physically measured force and distance could possibly be related to their better performance on the mid- and post-test questions pertaining to these concepts. Although the VP group also physically measured these quantities in their second experiment, they did not show an increased performance in the post-test. This result is consistent with the notion that blocking of the subsequent physical experiment by the previous virtual experiment caused them to disregard their experience in the subsequent physical experiment.

Discussion and Conclusion

This study adds to prior research (e.g. De & van Joolingen, 1998; Finkelstein, et al., 2005; Klahr, Triona & Williams, 2007; Zacharia, 2005; Zacharia & Anderson, 2003), which has not reached a clear consensus on the relative effectiveness of simulations and physical activities on student learning. Research has also shown that combining physical and virtual experiments can benefit learning. This study investigates ways in which these can be combined most effectively in the context of pulleys.

In looking at the overall scores, we found that students who completed the physical activity before the virtual activity improved their scores after performing the virtual activity, whereas those who completed the virtual activity before the physical activity, showed no improvement after the physical activity. This result is consistent with the notion that the simulation provides high salience on certain concepts and induces blocking of further learning from the physical activity. We also observe evidence of the primacy effect in the students' overall scores. The students seem to learn from whatever experiment they performed first evidenced by the improvement in score from pre- to mid-tests in both groups.

We also found evidence of blocking and the primacy effect when looking at individual questions about the concepts of work and force. The high salience of the concepts of work and energy in the simulation may contribute to students blocking learning of these ideas in a subsequent physical experiment. Ideas such as force and distance are equally salient in both, thus blocking may have occurred equally in both sequences. When learning about force and distance, neither sequence is preferred based on saliency.

We also observed a primacy effect on questions dealing with familiar concepts of force and distance. In addition, the PV group scored higher than the VP group on these questions. When dealing with concrete and easily measurable quantities like force and distance, the kinesthetic act of measuring seems to improve student understanding. It is important for this to occur first in the sequence so that blocking will not disregard this important experience.

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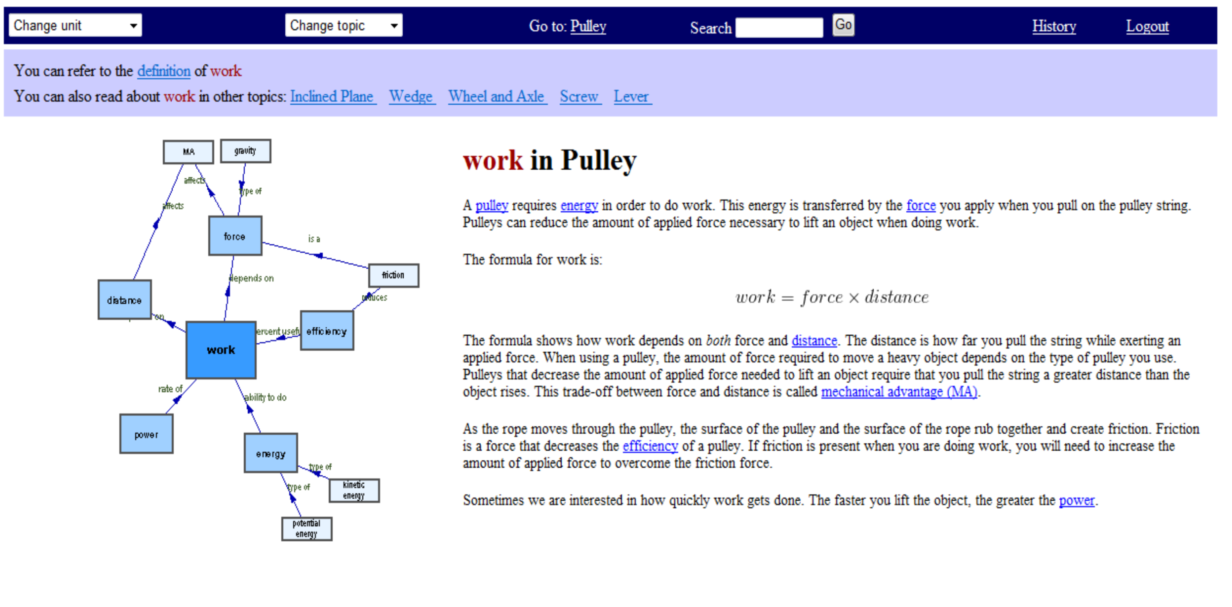


FIGURE 1. *CoMPASS, dynamic concept maps and hypertext-based environment.*

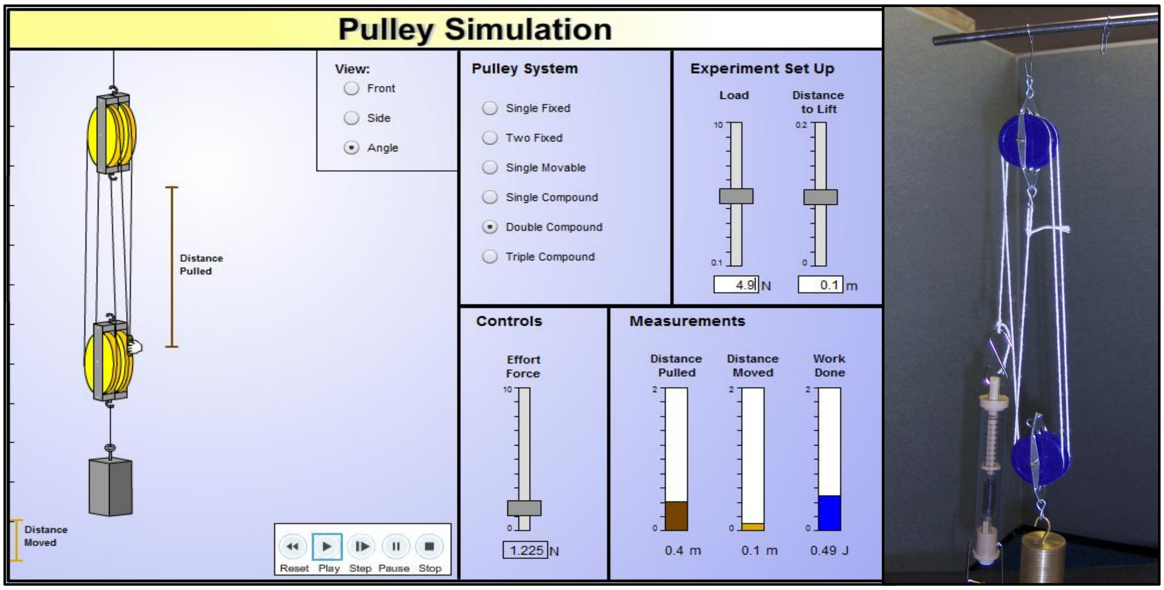


FIGURE 2**.** *Virtual manipulative (computer simulation) and physical manipulatives (pulleys, spring scale, string and mass).*

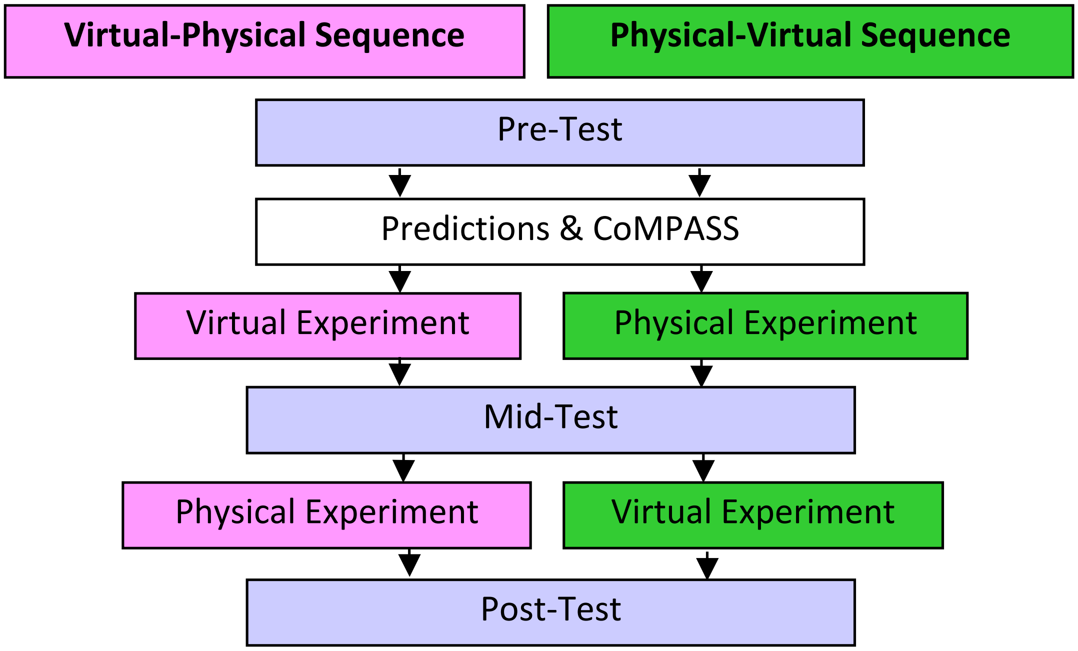


FIGURE 3. *Activities performed by treatment groups.*

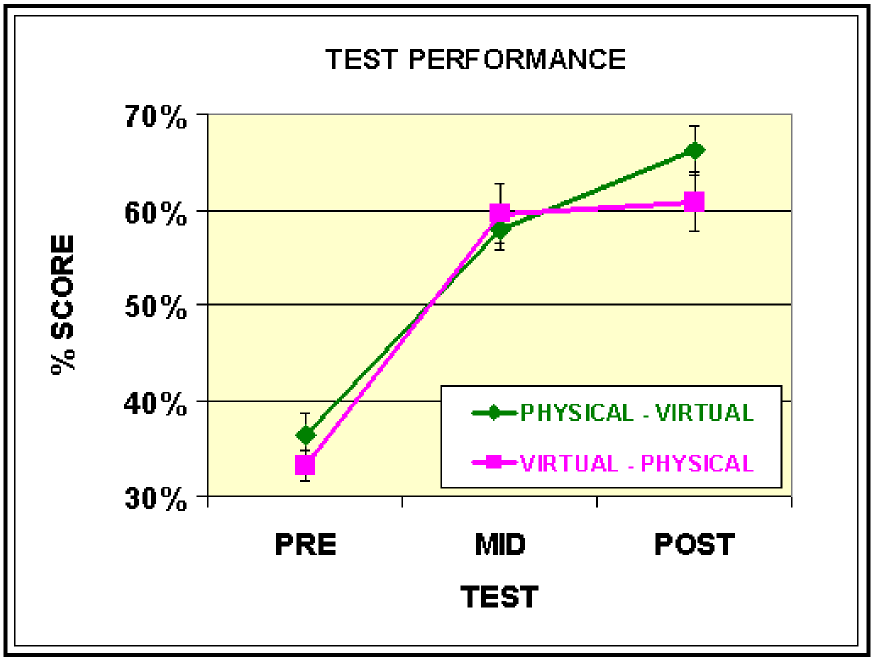


FIGURE 4. *Mean score on pre-, mid- and post-tests of physical-virtual and virtual-physical groups. The error bars represent the standard error.*

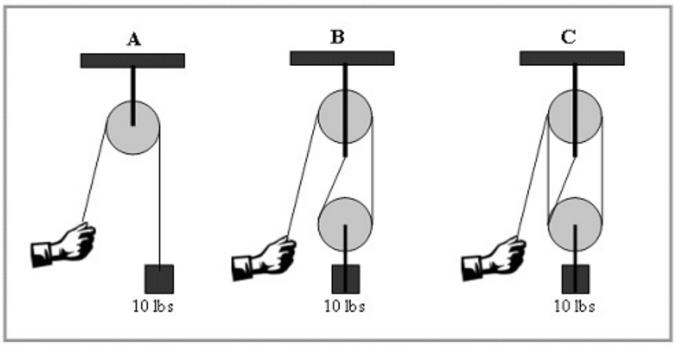
9) Alice is using pulley set-up A, Brenda is using B, and Carl is using C. What can you tell about the *work needed* to lift the load by each of them, if friction is not a factor?

A.) Alice (using pulley system A) is doing more work

B.) Brenda (using pulley system B) is doing more work

C.) Carl (using pulley system C) is doing more work

D.) The work done in all three situations is the same



13) 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?

A.) The work is *more* than the potential energy

B.) The work is *less* than the potential energy

C.) The work and potential energy are the same

D.) Not enough information

FIGURE 5. *Question 9 and question 13 from pre-, mid- and post-test.*

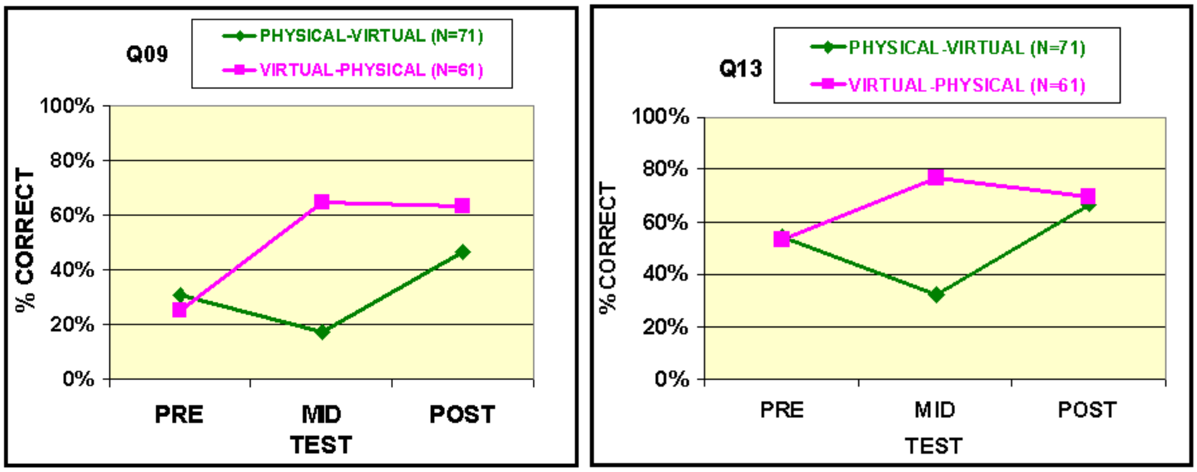
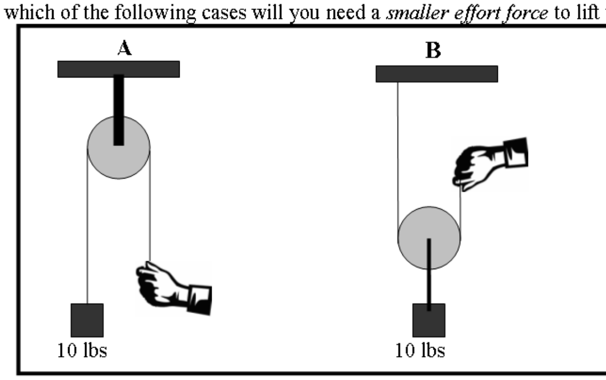


FIGURE 6. *Performance on test questions 9 and 13.*

1) In which of the following cases will you need a *smaller effort force* to lift the load?



A.) Pulley A

B.) Pulley B

C.) Both A & B are equal

D.) Not enough information

2a) You used a fixed pulley to lift a watermelon to your tree house. If you changed it to a movable pulley…
the *distance* pulled would:

Circle one:

A.) Increase

B.) Decrease

C.) Stay the same

D.) Not enough information to decide

FIGURE 7. *Question 1 and question 2-1 from pre-, mid- and post-test.*

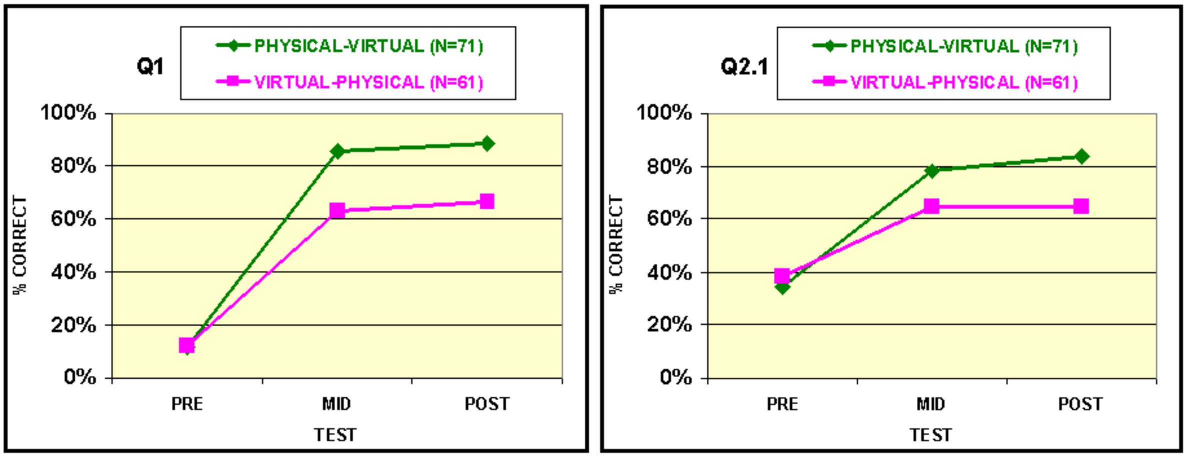


FIGURE 8. *Performance on test questions 1 and 2-1.*

TABLE 1

Pre-, mid-, and post-test mean ± standard error.

Test	Physical-Virtual (n=71)	Virtual-Physical (n=61)
Pre-	37 ± 2	33 ± 2
Mid-	58 ± 2	60 ± 3
Post-	63 ± 3	61 ± 3

TABLE 2

Mauchly's Test, Greenhouse-Gessier Estimates of Sphericity, and Repeated Measures Test for overall score.

Effect	Mauchly's Test		Sphericity	Repeated Measures Analysis of Variance	
	$\chi^2(2)$	p	ε	F	p
Total Score	67.28	<.001	.71	F(1.42,184.87) = 173.57	<.001
Total Score*Treatment				F(1.42,184.87) = 2.33	0.12

TABLE 3
Contrast comparisons.

Effect	Comparison	F(1,130)	p
Total Score	Pre-Mid	170.94	<.001
	Mid-Post	22.33	<.001
Total Score* Treatment	Pre-Mid	1.71	.19
	Mid-Post	12.04	.001