Investigating Change and Consistency in Introductory College Students' Understanding about Pulleys

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Abstract

In this study we investigate how introductory college students' conceptions change after completing physical and virtual experiments focused on learning about the concepts underlying pulleys. Students were asked to take a pre- and post-test before and after completion of activities. We also investigated the effect of context on student reasoning. Twelve individual semi-structured interviews were conducted in which the students were asked questions similar to those on the test, but different in terms of context. While there was overall improvement in test scores, some questions exhibited a decline in the number of correct responses. Through our semi-structured interviews we further investigated students' reasoning on these questions. Our results showed that after completing an experiment, students often refer back to that experience when reasoning. The reasoning resources that are activated during the learning experience can at times lead students to incorrect responses that suspend physical intuition resulting in degraded performance on the post-test on these questions.

Introduction

The issue of conceptual change is an important issue which has been of interest (Vosniadou, 2008). There are several models of conceptual change including those of Piaget (1964) and Vygotsky (1978) which suggest that students construct their own knowledge. However, according to Triona & Klahr, "Constructivist theory emphasizes the importance of children taking an active role in their own learning, but it does not specifically require physical manipulation" (2003).

The CoMPASS curriculum is a design-based curriculum that integrates concept maps and hypertext which students explore prior to performing physical or virtual experiments as shown in Figure 1 (Puntambekar & Stylianou, 2005).

Our preliminary research has shown that there is no statistically significant difference in the overall test scores of students who perform virtual and physical experiments in a pulley curriculum. We investigate how the activity a student performs influences the way they reason and also investigate how the context of a question affects student responses. Our research questions (RQ) were:

RQ1) How do conceptions change from before to after the activity and what elements contribute to the change?

RQ2) How does the context of the question influence students' conceptions?

Theoretical Underpinnings

It is widely accepted that students use prior knowledge to construct new knowledge. Our theoretical framework is based on Hammer's (2000) idea of student resources. Unlike some others' theoretical framework that assume consistency, robustness and larger coherence of learners' knowledge, Hammer views the process of reasoning as the activation of resources –

typically small grain sized knowledge elements that might be unstable and in some cases idiosyncratic. Hammer proposed that students' conceptual resources, if properly activated during learning, can lead to a deeper understanding. Students cannot be treated as blank slates, nor can they be assumed to possess well-formed ideas on underlying concepts. As a byproduct of living in a physical world, students possess knowledge based on everyday experiences. This previous knowledge contains the building blocks to construct new knowledge. Despite pulleys not being emphasized in the physics course taken by the participants, the students are likely to have some resources from their everyday lives that they activate while reasoning about pulleys. In this research we adopt the perspective that students construct their reasoning by activating conceptual resources.

Methodology

The participants in our study included 12 students, all of whom were enrolled in an introductory algebra-based physics course. The students individually completed the activity on pulleys, with six students performing the physical experiment and the other six students performing the virtual experiment.

In both cases, the students first completed a multiple-choice pre-test consisting of 12 questions. Previous versions of the test consisted of more questions, although some items were removed due to unsuitability. However, the numbering of the questions was not changed in order to keep consistent with previous studies.

Following the pre-test, students participated in an individual semi-structured interview. For every question on the test, an interview question was created with an identical underlying physics concept. Two questions on the test contained two multiple choice parts, both of which were addressed in a single interview question. The interview question was open-ended and presented in a different context than the one on the test. Six of the 12 questions were asked in the pre-test interview. Each interview question had a set of follow-up questions designed to further probe student thinking and understanding of key terms.

Next, students performed either the virtual or physical experiment and completed an accompanying worksheet of summary questions. Figure 1 shows a screen shot of the computer screen for the virtual experiment as well as the setup for the physical experiment. Following either experiment, the students completed a post-test which was identical to the pre-test. The students were interviewed again after the post-test during which they were asked the questions that were not asked in the previous interview.

The interview questions were asked an equal number of times in each of the following categories: pre-test/virtual, pre-test/physical, post-test/virtual, and post-test/physical. The interview responses were analyzed using a phenomenological approach (Marton, 1986). As per this approach, we categorized the students' responses as per the meanings conveyed by the students. The categories of students' responses were not predetermined, rather they emerged from the data itself. The pre- and post-test scores were also analyzed.

Analysis & Findings

The test scores were used as an overall measure of improvement of student understanding. As illustrated in Figures 2 & 3, there was no significant difference in improvement of both the physical and virtual groups.

In addition to examining the overall improvement, the consistency between students' test and interview answers was also investigated. There was again, no significant difference in the number of consistent responses given by students in the different groups as shown in Figures 4 & 5. Due to there being two test questions having two separate parts, it is possible for a student to give a response in the interview that is only partly consistent with their response to the test question. An example of this can be seen in Table 1

In taking a deeper look at the test responses question by question, we observed some interesting trends. While the overall scores improved, Questions 8, 9 and 13 did not follow the same trend. These questions previously showed a statistically significant difference in the test scores of those who performed the physical and virtual activities. The text of the pre/post-test and interview questions for Questions 8, 9 and 13 can be found in Table 2 and the diagrams accompanying Q9 and the corresponding interview question are shown in Figure 6.

Question 8 asked students how increasing the height to which an object is lifted affects the amount of work that must be done to lift that object. Figure 7 shows the responses given by the students. In both the physical and virtual treatments the number of correct responses decreased.

The responses the students gave to the interview question corresponding to Question 8 were coded using a phenomenological approach (Marton, 1986). In both the virtual and physical treatments, 4/6 students connected an increase in height with an increase in work done.

The interview responses were also used to investigate the effect of context on student reasoning. This investigation was done by looking at the number of consistent responses between the test question and a similar interview question. In pre-test interviews 3/6 students gave a response consistent with their test answer while 5/6 were consistent in the post-test interview.

Question 8 can be answered on the basis of physical intuition which could account for the high number of correct responses in the pre-test. While a majority of students answered correctly, only half of the interview responses were consistent with the pre-test answer. In the post-test students attempted to reason based on the experiment that they performed going so far as to suspend physical intuition and answer incorrectly.

This suspension of physical intuition can be illustrated by a student who performed the virtual experiment. When asked the interview question equivalent to Question 8 the student responded, "The force I use to get [the mattress] to the third floor is going be more than [the work needed] for [the sixth floor] because [the sixth floor] has the ability to spread the work … over a greater distance." In response to a follow-up question asking how the student thought the height an object is lifted to could affect the work done to lift it the student added, "I'm trying to think back over this experiment… [the objects] all [get lifted to] the same distance but the distance pulled is different… I think I would be doing less work being on the sixth floor."

Question 9 asked the students how the work needed to lift identical objects to the same height compares when using three different frictionless pulley systems: a single fixed pulley, a single compound pulley and a double compound pulley. As can be seen in Figure 8, the students who performed the physical experiment did worse on the post-test than on the pre-test while those who performed the virtual experiment showed no difference in test scores.

In looking at the consistency between the test and similar interview question responses, 4/6 students gave consistent responses in the interview following the pre-test. The post-test interview also had 4/6 consistent responses.

Unlike Question 8 there was not a single prevailing reasoning provided by students in their interview responses. While varied, the post-test interview responses exhibited two specific types of reasoning. The students who performed the physical experiment gave responses in the post-test interview that were more mechanistic, while the responses given by those who performed the virtual experiment were more covariational (Hung & Jonassen, 2006).

Covariational reasoning is characterized by comparing and contrasting while mechanistic reasoning uses the underlying mechanism to establish a connection.

Question 9 is an example of how students activate different reasoning resources. Students who performed the physical experiment activated deeper reasoning resources to explain their responses. In the post-test interview, a student who performed the physical experiment stated that a double compound pulley would require the least amount of work to operate, reasoning that, “Although pulley C would have more friction… it’s easier to move an object with… a double [compound pulley]… because you’re pulling more distance, but the weight is distributed more.” Students who performed the virtual experiment tended to use superficial reasoning resources for their responses. For example, “The work is [going to] be the same… because we’re all lifting it the same distance… The weight of the object stays the same regardless of how you pull it up.”

While the student who performed the physical experiment gave an incorrect response (the question assumes a frictionless environment), they exhibited a deeper reasoning based on what was observed in the activity they performed. The student who performed the virtual experiment gave a correct response, but had a more superficial reasoning.

Question 13 dealt with the comparison between potential energy and work. Figure 9 shows the breakdown of the student responses. Students in the physical treatment group gave fewer correct answers in the post-test than they did in the pre-test, while the virtual students improved by one. In all groups the highest number of correct responses was 3/6.

Analyzing the post-test interview responses showed that students who performed the physical activity were unable to explain the relationship between work and potential energy saying they “didn’t know.” They all, however, referred to proportionality between work and potential energy that they observed in the experiment. Students who performed the virtual experiment also referred to the activity they performed, but were able to see a similarity between work and potential energy.

Context had a greater influence on student response in Question 13 than in Questions 8 and 9. In pre-test interviews students were consistent with their test answers 3/6 times and in post-test interviews students were consistent 2/6 times. However, the post-test did not have a choice stating that work and potential energy are proportional, as shown by 3/6 of post-test interview responses.

Conclusions

We address our research questions below and then follow with a discussion about how our findings fit with Hammer's (2000) explanation of student resources.

RQ1) How do conceptions change from before to after the activity and what elements contribute to the change?

The experiment a student performs has an influence on the way they conceptualize the related problems. It is important, then, that resources are appropriately activated to ensure the most productive learning outcome. Overall, an increase in correct responses and consistency show that student resources are being activated throughout the activity, but in some cases, as in Questions 8, 9 and 13, the resources that are activated are unproductive.

In the post-test interviews, students tended to refer back to the experiment which they performed when reasoning about a given situation. Those who performed the physical experiment were able to reason at a deeper level, as observed in Question 9, but faced more trouble in explaining energy-work transfer in a frictionless situation, such as those that appear on the tests.

Students who performed the virtual experiment also attempted to refer back to the activity when reasoning. This at times led to the suspension of physical intuition, as in Question 8, in which more abstract concepts like work and effort force can seem interchangeable.

RQ2) How does the context of the question influence the conceptions a student might have?

Overall, the responses to the interview questions tended to be consistent with those given on the pre/post-tests. The number of consistent responses increased from the pre-test interview to the post-test interview, which is not unexpected as the influence of guessing should be lessened once students have formally learned the material.

What is more unexpected is that in some cases an increased consistency in responses also went along with a decrease in the correctness of the responses. That is, students were more consistent, though consistently incorrect, as demonstrated in Questions 8 and 9.

This consistent incorrectness can be related to the activation of unproductive resources during the experiment, whether physical or virtual. Students will go so far as to go against "common sense" reasoning, as in Question 8, if it seems contrary to what they took away from the experiment.

Implications for Instruction

This research demonstrates that instructional experiences can greatly influence the kinds of reasoning resources that students activate when they reason about a situation. These resources are not necessarily stable, rather they can be susceptible to change based upon the context of the question. Sometimes these resources might inhibit the use of "common sense" reasoning that might in fact be more productive in some situations. If curriculum designers and instructors are aware of what resources students tend to activate due to instruction, they can design activities that ultimately lead to the appropriate activation of productive resources.

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Table 1

Example of a "Half Consistent" Response (Bolded Text Indicates Response to Test Question)

Part	Test Question	Interview Question	Interview Response
a)	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: **A. Increase** B. Decrease C. Stay the same D. Not enough information to decide	You used a fixed pulley to lift a futon into your third floor dorm room, if you used a movable pulley instead, what do you think would happen to distance you would have to pull the rope?	"The string and the pulley keeps jerking around as you pull on it. It might cause more distance, but it seems like it just might be the same distance just more effort." (Inconsistent with Test)
b)	and the *effort force* required would: **A. Increase** B. Decrease C. Stay the same D. Not enough information to decide	In the same situation you used a fixed pulley and switched to a movable pulley, what do you think would happen to the effort force required?	"I just thought it would go up … [be]cause … the weight of the pulley and the fact that it's moving every time you pull on it would have a greater affect on the effort required to raise the futon." (Consistent with Test)

Table 2

Comparing Pre/Post-Test Question to Corresponding Interview Question (See Figure 3 for Diagrams Corresponding to Question 9)

Q#	Pre/Post-Test	Interview
8	Jacob is using a fixed pulley to separately lift two boards of the exact size and mass up to two different heights. He lifts one board 10 meters and then lifts the second board 20 meters. When lifting the board 20 meters, Jacob is doing _____________ work as/than when lifting the first board 10 meters high? A.) more B.) less C.) the same amount of D.) not enough information to decide	You and your friend have just purchased identical mattresses and use the same pulley to lift them into your rooms. You live on the third floor, and your friend lives on the sixth floor. How does the amount of work you do lifting the mattress compare to the amount of work your friend does?
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	You and two of your friends have all purchased the same refrigerator and have the same pickup truck to move it home. You used pulley A to lift the fridge into the truck. However, Betty used pulley B, and Carl used pulley C. What can you say about the work being done by each of you?
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	Because the elevator in the dorm is too small, you decide to use a movable pulley to lift a futon into your dorm room. How does the work done to lift the futon compare to its potential energy once it is lifted?

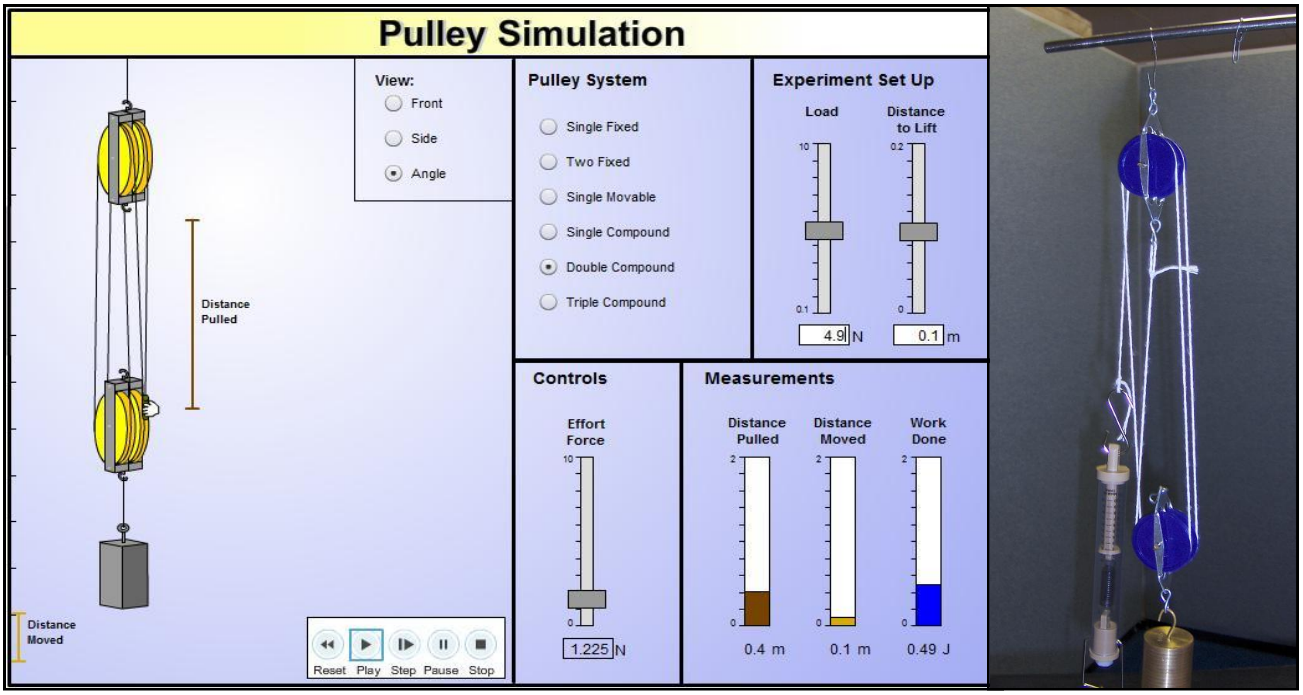

Figure 1. Virtual (L) and Physical (R) activities

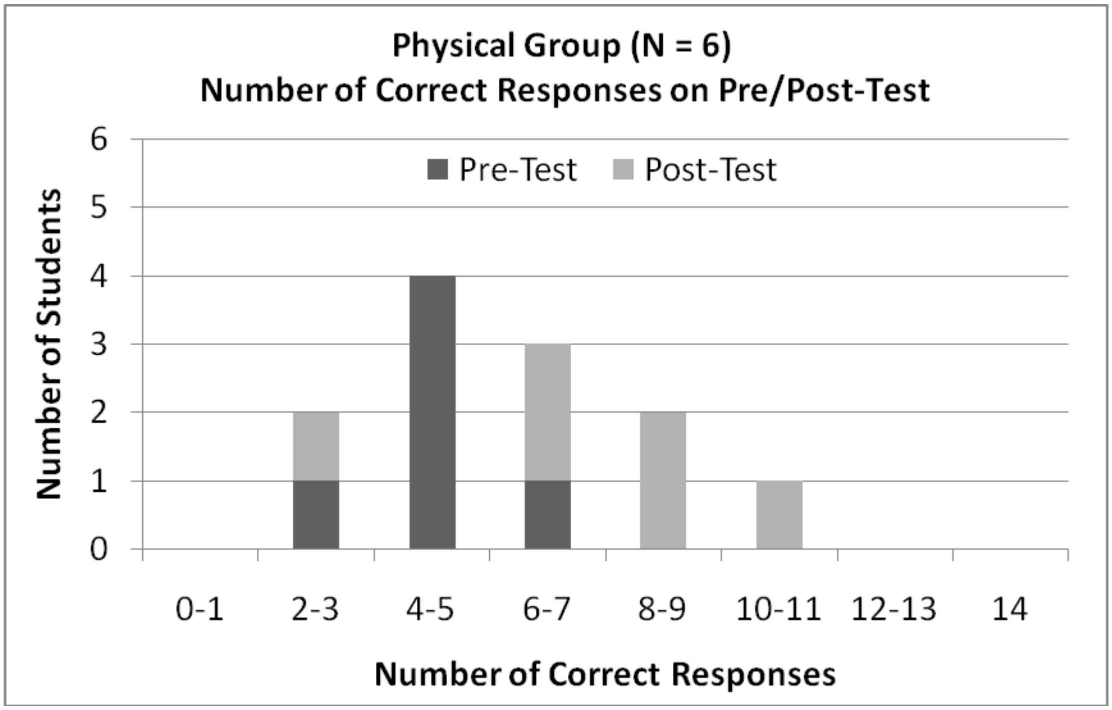

Figure 2. Number of correct responses given on pre/post-test by physical group

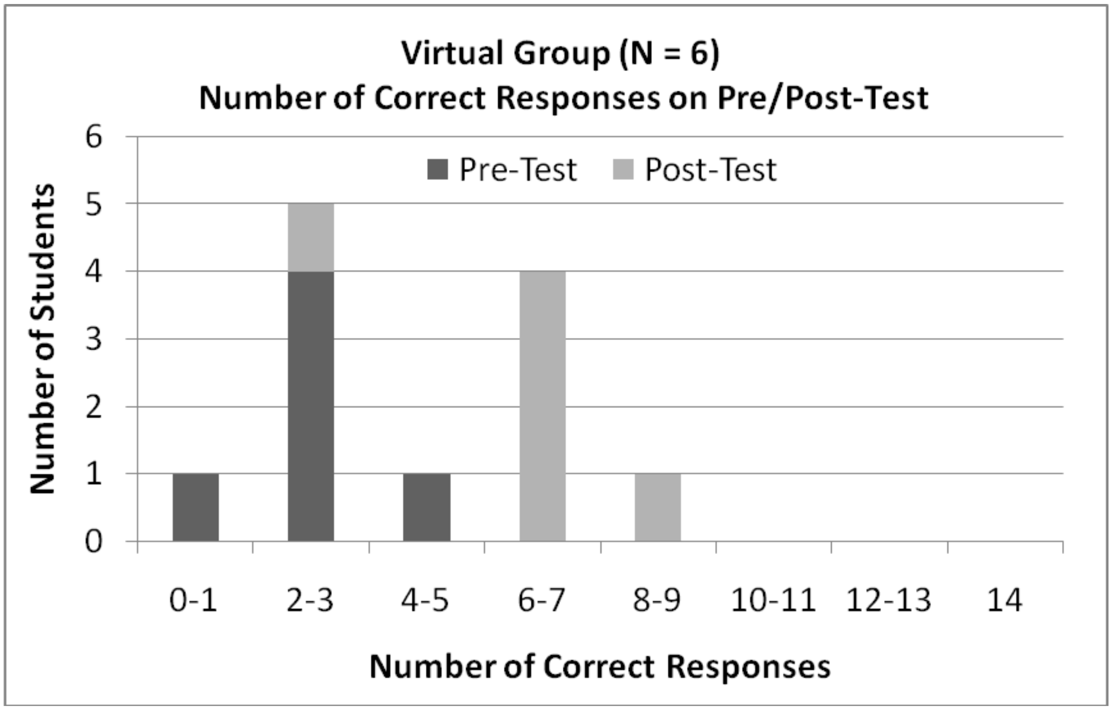

Figure 3. Number of correct responses given on pre/post-test by virtual group

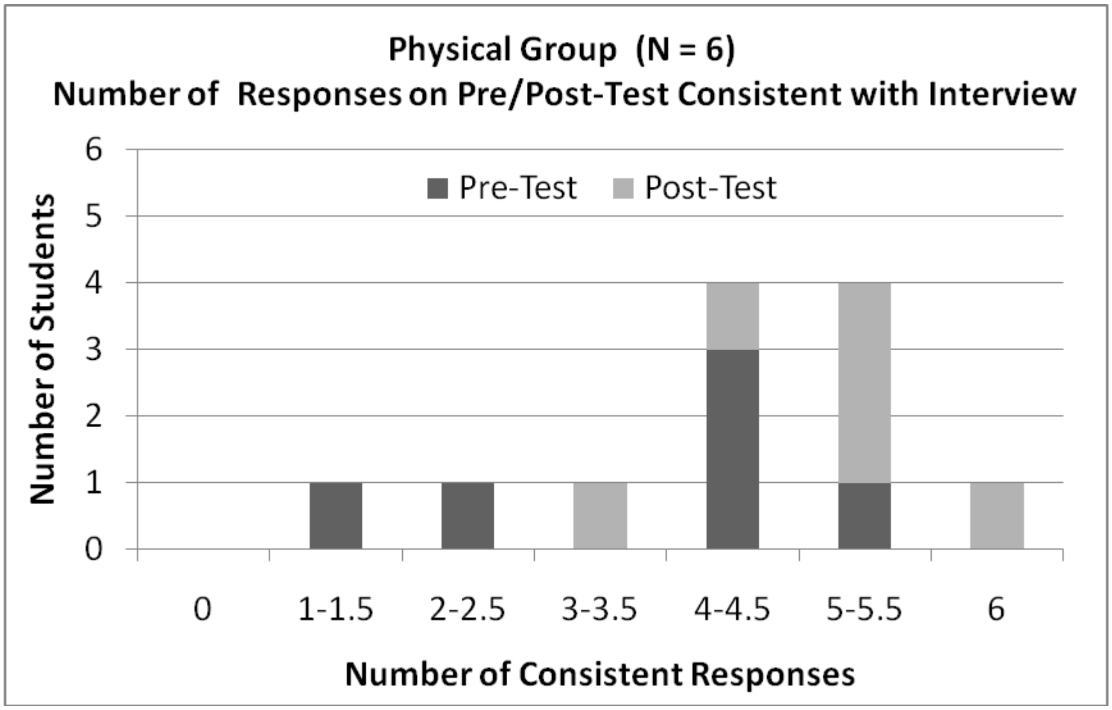

Figure 4. Number of responses given by physical group in interview consistent with answer given on pre/post- test

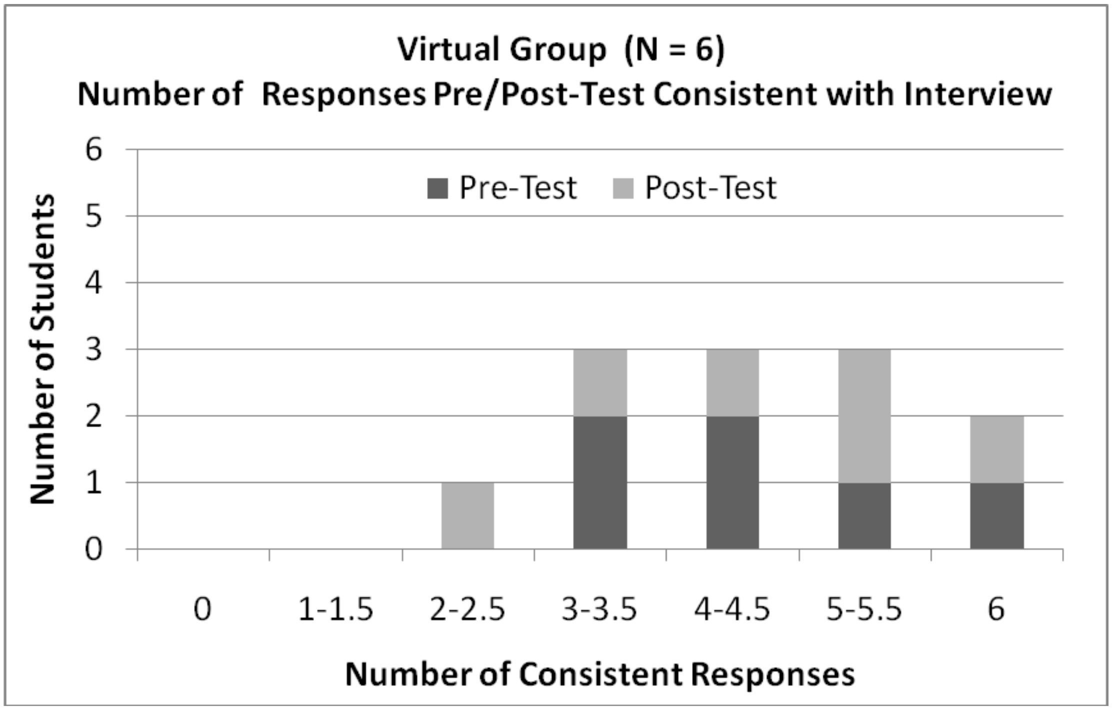

Figure 5. Number of responses given by virtual group in interview consistent with answer given on pre/post- test

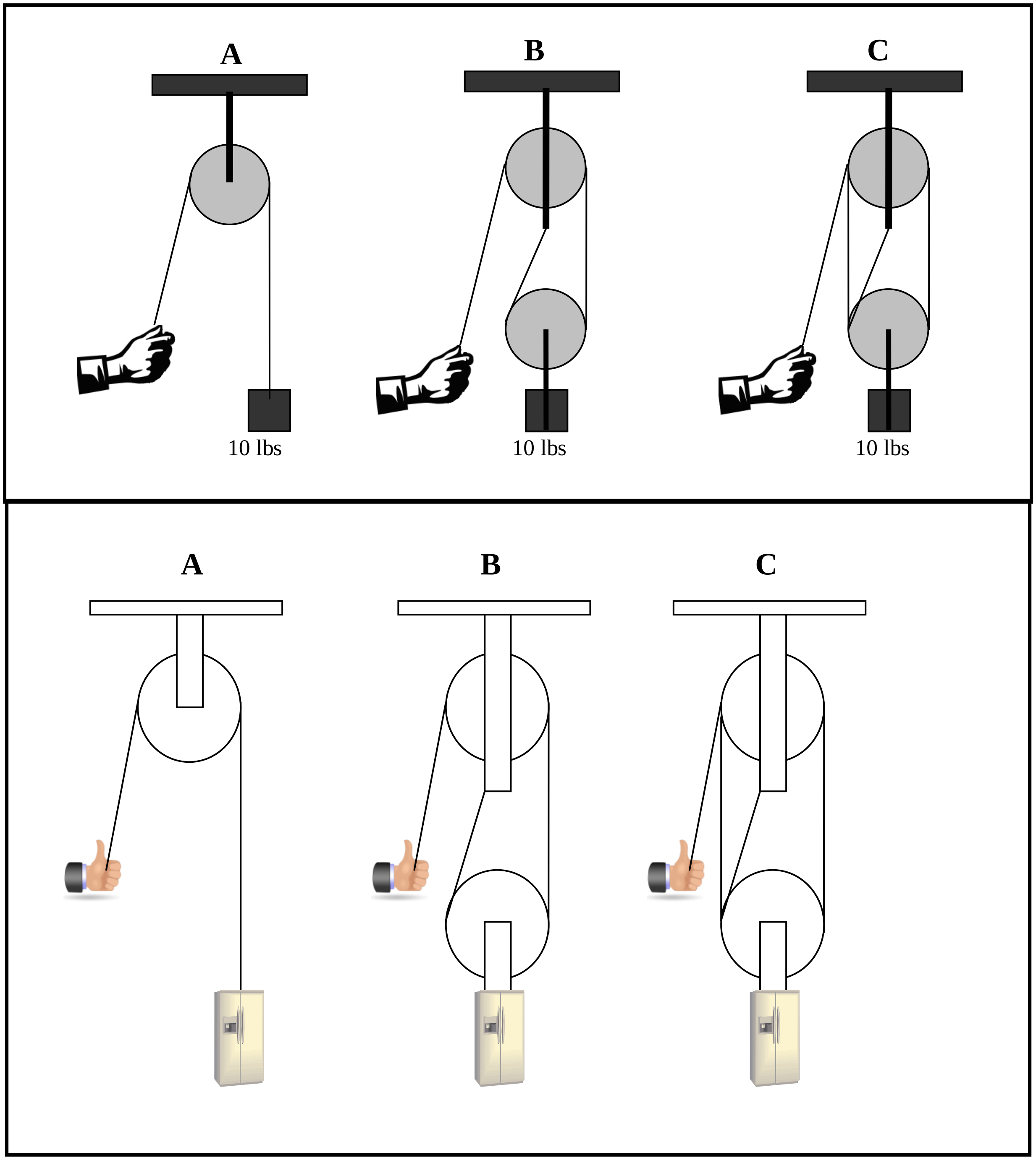

Figure 6. Diagrams accompanying Q9: Pre/Post-Test (Top), Interview (Bottom)

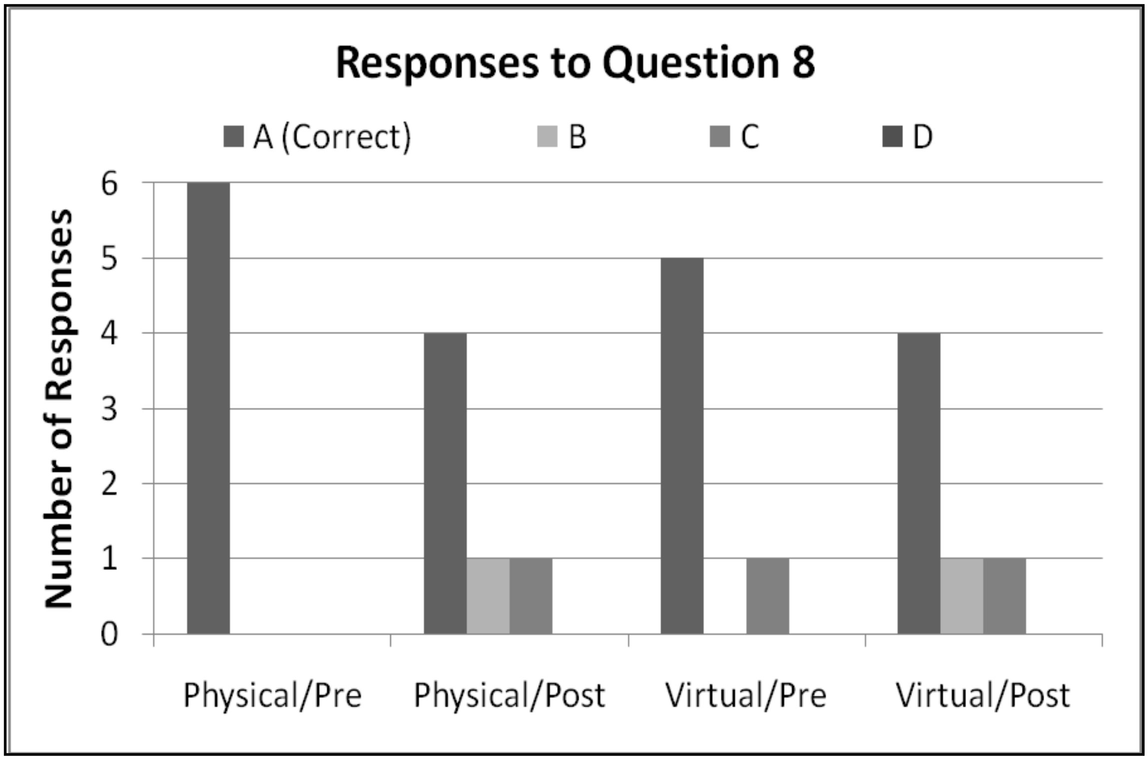

Figure 7. Student responses to test question 8

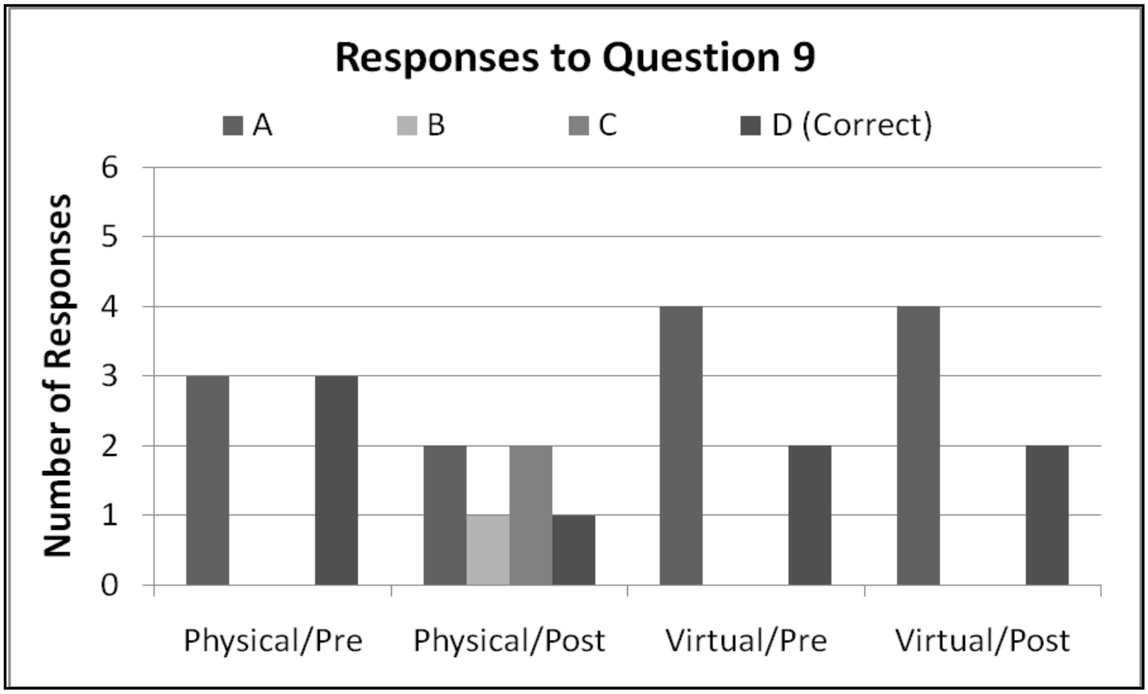

Figure 8. Student responses to test question 9

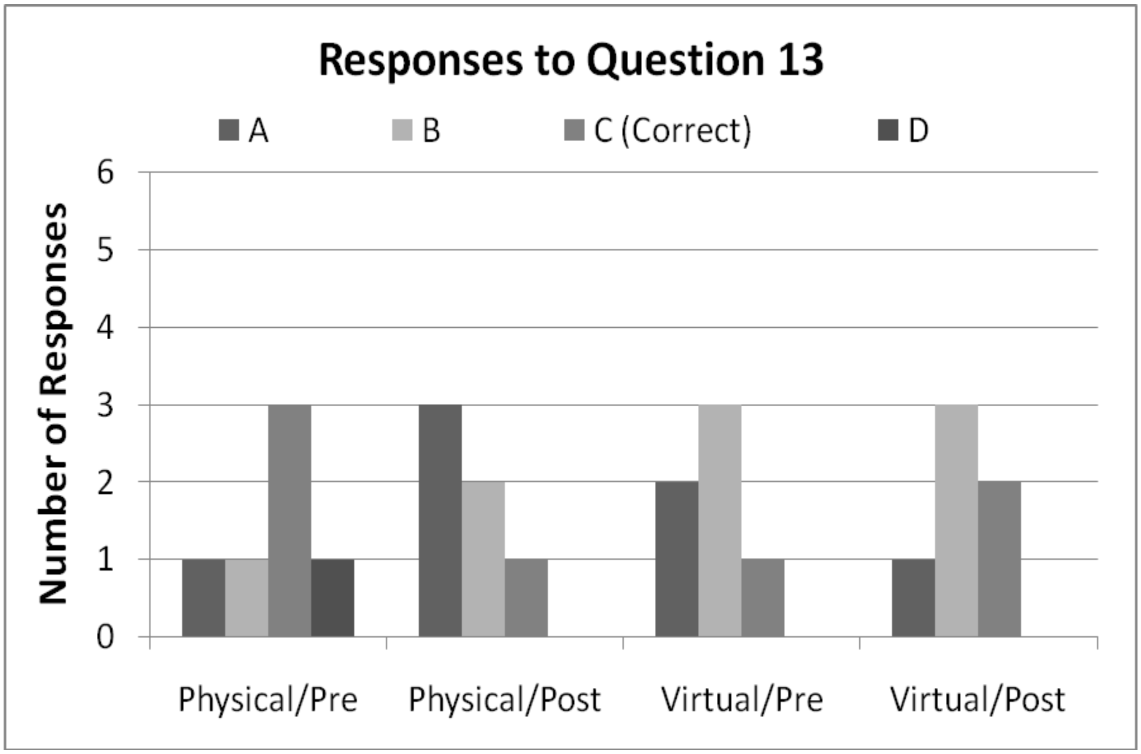

Figure 9. Student responses to test question 13