Comparing Benefits of Hypertext Exploration versus Virtual Experimentation on Students' Analysis of Physical Experiments

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Abstract

In this study, we explore whether students who had a prior experience with a virtual experiment make the same types of interpretations of data from a physical experiment as students with no prior virtual experience. One group of students ('Hypertext', N=67) explored the science concepts related to inclined planes using a hypertext-based concept mapping system before beginning the physical experiment. A second group ('Hypertext+Sim', N=58) used the hypertext system and performed a virtual experiment with a simulation before beginning the physical experiment. We analyzed students' responses to written open-ended analysis questions answered by both groups after performing the physical experiment. We ask, do students who have a prior experience with a virtual experiment provide different interpretations of data from a physical experiment than students who have not? We find that students with the prior virtual experience focus on more scientifically useful aspects of the physical data, such as the similarity between the amounts of work needed to lift a load with different machines and between work and potential energy. However, students who did not have the prior virtual experience provided more scientifically correct explanations of how the length of the inclined plane affected the applied force and mechanical advantage.

Background and Introduction

In this study, we seek to build on our research comparing the effectiveness of experimentation with physical and virtual manipulatives in the introductory conceptual-based physics laboratory. Previous studies on this topic have shown mixed results. Many studies (e.g. Zacharia, Olympiou & Papaevripidou, 2008; Finkelstein *et al*., 2005) have found students' learning is enhanced by experimentation with virtual rather than physical manipulatives. Other studies (e.g. Klahr, Triona & Williams, 2007; Zacharia & Constantinou, 2008), however, have shown no difference in students' learning between groups who used physical or virtual manipulatives. Our research in the context of the science concepts related to simple machines (Gire, *et al*., 2010) has shown that students' understanding of force may be better supported by physical manipulatives, while virtual manipulatives may offer better support for their understanding of work and energy.

In addition to comparing the physical and virtual manipulatives in isolation, we are interested in whether the sequence in which physical and virtual manipulatives are used affects students' learning. Zacharia and Anderson (2003) have shown that simulations prepare students to make more scientifically correct predictions and explanations of phenomena in physical experiments. This suggests that performing a virtual experiment may prepare students for learning in a physical experiment.

In this study, we explore whether students who had a prior experience with a virtual experiment make the same types of interpretations of data from a physical experiment as students with no prior virtual experience. Before performing the physical experiment, one group of students had the opportunity to explore relevant science concepts in an online hypertext system, while the second group used the hypertext system and performed experiments with a computer simulation. We will compare students' responses to written open-ended analysis questions to which both groups of students responded after performing the physical experiment. We ask, do students who have a prior experience with a virtual experiment provide different interpretations of the data from a physical experiment than students who have not?

Theoretical Underpinnings

We hold a constructivist view of learning which posits that students construct their own understanding. Triona and Klahr (2003) have pointed out that while constructivist theory suggests students must be actively involved in the process of learning, active involvement does not require physical manipulation.

We discuss our results in light of two theoretical frameworks. Chinn and Brewer (1993) have described the possible stances one can take towards anomalous data that does not fit the individual's existing theory. When faced with anomalous data, an individual can: ignore the data; reject the data; exclude the data; hold the data in abeyance; reinterpret the data while maintaining the existing theory; make peripheral theory changes; or change the theory. Chinn and Brewer explain that the properties of the anomalous data may affect the stance one takes towards that data. Thus, this framework has promise for explaining students' responses to data from the physical experiment. They suggest that if the data is not viewed as credible, it can be easily rejected, and our previous work (Chini, 2010) has shown that students find the virtual experiment to be more trustworthy than the physical experiment. In addition, Chinn and Brewer predict that ambiguous data can be easily reinterpreted. The physical experiment often generates "messy" data due to frictional effects and measurement errors. Thus, the data from the physical experiment may appear ambiguous to students.

Schwartz, Varma and Martin (2008) have described how the learning environment may support students as they develop new conceptions, a process they call “dynamic transfer.” The authors distinguish between similarity transfer, involving application of well-formed concepts to a new situation, and dynamic transfer, involving application of component competencies in an environment to yield new concepts. In similarity transfer the environment cues the retrieval of intact prior knowledge, while in dynamic transfer the environment coordinates different components of prior knowledge. The environment may support dynamic transfer by allowing for distributed memory, affording alternative interpretations and feedback, offering candidate structures by constraining and structuring actions, or providing a focal point for coordination of disconnected pieces of knowledge. This framework is promising as it is possible that the learning environments created by the physical and virtual manipulatives will offer different support for the development of new ideas.

Curriculum

All students in this study used the CoMPASS (Concept Mapped Project-based Activity Scaffolding System) (Puntambekar, Stylianou & Hübsher, 2004) curriculum to learn about inclined planes. The curriculum makes use of a hypertext concept map that allows students to explore the concepts related to inclined planes, as shown in Figure 1. Students click on a concept in the map, and the text describes how that concept is related to inclined planes. The map is arranged so that the concepts most closely related to the chosen concept are larger and closer to the chosen concept. The navigation bar at the top of the screen allows students to read about the selected concept in the context of other simple machines.

In the physical experiment, students used boards to build inclined planes. They were provided with different lengths of boards with different surfaces as well as a brick to change the inclined planes' height. Students used meter sticks and spring scales to make measurements of distance, load and effort force. They calculated work, potential energy, and mechanical advantage.

In the virtual experiment, students used an inclined plane simulation, shown in Figure 2. Students varied the length, height and surface of the inclined plane by adjusting the corresponding sliders in the simulation. They adjusted the force until the load began to slide up the ramp. The force, work done, potential energy and mechanical advantage were calculated by the simulation and shown both on bar charts and numerically.

After performing each experiment, students responded to the same set of written open-ended analysis questions. These questions focused on how changing aspects of the inclined plane (length, height and surface) affected force, work, potential energy and mechanical advantage.

Methodology

This study was conducted at a large research university in the American Midwest. The participants were enrolled in a conceptual-based physics laboratory and completed the experiments as part of their course. The participants were enrolled in one of four lab sections, taught by several undergraduate teaching assistants. A member of the research team was present at each meeting to ensure that the sections were run uniformly. Some students ('Hypertext' group, N=67) explored inclined planes using the hypertext based concept mapping system before beginning the physical activity. Other students ('Hypertext+Sim' group, N=58) used both the hypertext system and the simulation before beginning the physical activity.

Our analysis for this study focuses on comparing the two groups (Hypertext vs. Hypertext+Sim) in terms of students' responses to the open-ended analysis questions after the physical experiment. A chi-square test for independence was used to determine if there was a difference between the types of responses given by students in the two groups. When a statistically significant result was found, adjusted residuals were examined to determine which cells contributed to the significant result (Haberman, 1973).

Results

Students responded to 18 analysis questions. The questions were broken into groups of three that focused on six main themes: force needed to lift the load; work needed to lift the load; change in the load's potential energy; comparison of work and potential energy; ideal mechanical advantage; and actual mechanical advantage. For each set of questions about a single physical quantity (force, work, potential energy, ideal mechanical advantage and actual mechanical advantage), students were asked to explain how changing a parameter (length, height and surface of the inclined plane) affected that quantity. For the comparison of work and potential energy, students were asked to describe how the work and potential energy compared for different types of surfaces (friction, less friction, no friction). The questions are described by the "Physical Quantity" and "Parameter" columns in Table 1. The results of the chi-square test for independence for each question are also presented in Table 1.

Prior Virtual Experience Supported Dynamic Transfer

Students in the Hypertext+Sim group gave more correct or more useful interpretations of the data to many questions as shown in Table 1. In Question 4, the students were asked to compare work and potential energy for three different types of surfaces. The responses given by students in the Hypertext and Hypertext+Sim groups were significantly different for all three questions. In Q4A, students were asked how work and potential energy compare when there is friction present. With friction present, the work required to lift the load is greater than the change in the load's potential energy. Students' responses fell into the categories "work is greater than potential energy", "work is equal to potential energy", "work increases and potential energy stays the same" and "other." Students in the Hypertext+Sim group were more likely to respond that work would be greater than or equal to the potential energy, while students in the Hypertext group were more likely to respond that work would increase and potential energy would remain the same.

In Q4B, students were asked how work and potential energy compare when the surface gets smoother. As friction is reduced, less work is required to lift the load so the work value becomes closer to the change in the load's potential energy. Students' responses fell into the categories "work and potential energy get closer", "work is equal to potential energy", "work decreases and potential energy stays the same" and "other." Students in the Hypertext+Sim group were more likely to respond that work and potential energy would get closer or be equal, while students in the Hypertext group were more likely to respond that work would decrease and potential energy would stay the same.

In Q4C, students were asked to compare work and potential energy for a frictionless inclined plane. This is the ideal situation for which work and change in potential energy are equal. Students' responses fell into the categories "work is equal to potential energy", "work decreases and potential energy stays the same", and "other". Students in the Hypertext+Sim group were more likely to respond that work and potential energy would be equal, while students in the Hypertext group were more likely to respond that work would decrease and potential energy would stay the same.

Across all three work and potential energy comparison questions, students in the Hypertext+Sim group were more likely than students in the Hypertext group to give responses about how work and potential energy related to each other. On the other hand, students in the Hypertext group were more likely than students in the Hypertext+Sim group to give responses that discussed work and potential energy separately. This difference can be explained by how the two environments support dynamic transfer or the development of new ideas. In the simulation, work and potential energy were displayed side-by-side as bar charts, as shown in Figure 1. One way an environment can support dynamic transfer is by providing a “focal point for coordination”. The bar graphs may help students construct ideas about how work and potential energy compare, leading students in the Hypertext+Sim group to provide more productive responses. Importantly, the students in the Hypertext+Sim group continued to make these more productive responses when they performed the physical experiment without the extra support from the environment.

Hypertext+Sim Group Provided More Favorable Responses to Anomalous Data

Q2L asked students to describe how increasing the length of the inclined plane affected the work needed to move the load. Under ideal (i.e. frictionless) conditions, the work required to lift the load does not depend on length. In the physical experiment, the required work increases slightly with length due to frictional effects; however, we would like students to focus on the similarity of the work values rather than the small-scale changes. Students’ responses fell in the categories “work would increase”, “work would stay the same”, and “work would decrease.” It seems the prior virtual experience allowed students in the Hypertext+Sim group to make a more useful interpretation of the physical data. Students in the Hypertext+Sim group were more likely to respond that changing length would not affect work, while students in the Hypertext group were more likely to respond that increasing length would increase or decrease the work needed.

Students in the Hypertext+Sim group were more likely than students in the Hypertext group to interpret the physical data to indicate that work was constant or nearly constant across machines (Q2L)and that work and potential energy were equal or nearly equal (Q4C, discussed in the previous section). This difference can be explained by Chinn and Brewer's (1993) framework of possible responses to anomalous data. When data does not agree with an individual's current theory, the individual can have one of several responses, described above. Properties of the data may affect the stance one takes towards that data. For example, data that is not viewed as credible can be easily rejected and ambiguous data can be easily reinterpreted

In the Hypertext+Sim group, students have the opportunity to explore work and potential energy in a frictionless environment before encountering the physical experiment, where it is impossible to run a trial in the absence of friction. Thus, students first encounter data that is easily interpreted to indicate that the work needed to lift a load does not depend on length and that work and change in potential energy are equal in the absence of friction. Students then encounter ambiguous data in the physical experiment. Chinn and Brewer's framework suggests students may reinterpret the data from the physical experiment to fit the theory they developed from the virtual experiment. In addition, our previous work (Chini, 2010) has shown that students trust the simulation more than the physical equipment. Chinn and Brewer's framework suggests that students may reject the data from the physical experiment because they view it as less credible than the data from the virtual experiment.

Hypertext Group Performed Better on Questions about Length

Students in the Hypertext group provided more correct interpretations of the physical data in Questions Q1L, Q5L and Q6L as shown in Table 1. In Q1L, students were asked to describe how increasing the length of the inclined plane would affect the force needed to lift the load.

Students' responses fell into the categories "force would decrease", "force would stay the same", and "force would increase". Significantly more students in the Hypertext group stated that the force would decrease, while significantly more students in the Hypertext+Sim group indicated that the force would increase.

In Q5L, students were asked to describe how increasing the length of the inclined plane would affect the ideal mechanical advantage. Students' responses fell into the categories "ideal mechanical advantage would increase" and "other". Significantly more students in the Hypertext group stated that the ideal mechanical advantage would increase, while significantly more students in the Hypertext+Sim group provided a different response.

In Q6L, students were asked to describe how increasing the length of the inclined plane would affect the actual mechanical advantage. Students' responses fell into the categories "actual mechanical advantage would increase", "actual mechanical advantage would stay the same" and "actual mechanical advantage would decrease". Significantly more students in the Hypertext group responded that increasing the length would increase the actual mechanical advantage, while significantly more students in the Hypertext+Sim group said that increasing the length would decrease the actual mechanical advantage.

All three questions where students in the Hypertext group gave more correct interpretations of the physical data than students in the Hypertext+Sim group asked students to consider varying the length of the inclined plane. It is possible that students are more aware of the length of the inclined plane in the physical experiment because they physically replace shorter boards with longer boards. Also, force and mechanical advantage can be "felt" in the physical experiment, which may help students understand the changes better than the simulation where force is displayed as a meter or bar chart.

Alternate Interpretations

We have presented the results in light of how two theories, Schwartz, Varma and Martin's theory of dynamic transfer and Chinn and Brewer's theory of responses to anomalous data, can explain why the order in which students used the manipulatives led to difference in responses to the analysis questions. However, it is possible to suggest other reasons for these results. For example, the Hypertext+Sim students had more time on task before responding to the physical experiment analysis questions than the Hypertext students did. This additional exposure time may have led to their more scientifically correct explanations of relationships involving work and potential energy, which are often difficult concepts for students to understand.

Conclusions and Implications

We have demonstrated that prior virtual experimentation does influence the responses students provide to open-ended analysis questions after performing a physical experiment. Using the simulation before performing the physical experiment appears to help students make useful comparisons between work and potential energy, while students whose only prior experience was hypertext exploration tended to discuss work and potential energy separately. This result supports the findings of Zacharia and Anderson (2003). However, in our study, students who completed only the hypertext exploration and not the simulation before the physical experiment provided more scientifically correct responses about how length affected force and ideal and actual mechanical advantage.

This study expands on the existing research about the comparative effectiveness of experiments performed with physical and virtual manipulatives. Rather than focusing on the manipulatives in isolation, we have begun to compare the benefits of using the manipulatives in sequence. We argue that performing the virtual experiment first may prepare students to make more productive interpretations of some of the data from the physical experiment. These issues are important for education researchers as well as those who are making decisions regarding the use of physical (e.g. hands-on) and virtual (e.g. simulations) manipulatives in science teaching in their classrooms. This study suggests reasons for using a virtual experience to help students be more successful in a physical experiment.

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Table 1

The Results of the Chi-Square Test for Independence

Q#	**Physical Quantity**	**Parameter**	**$\chi 2$**	**p-value**	**Effect Size**
Q1L	Force	Length	$\chi 2(2, N=108) =13.2$	**.001**	.35
Q1H*	Force	Height	$\chi 2(2, N=109) =4.1$	.162	.20
Q1S	Force	Surface	$\chi 2(1, N=108) =.7$	.404	.08
Q2L	Work	Length	$\chi 2(2, N=108) =20.1$	**<.001**	.43
Q2H*	Work	Height	$\chi 2(2, N=108) =.7$	.753	.08
Q2S	Work	Surface	$\chi 2(1, N=108) =1.5$	.221	.12
Q3L*	Potential Energy	Length	$\chi 2(1, N=107) =1.3$	.437	.11
Q3H*	Potential Energy	Height	$\chi 2(1, N=107) =1.1$	.363	.10
Q3S*	Potential Energy	Surface	$\chi 2(1, N=106) =1.3$	.438	.11
Q4A*	Work/Potential Energy	Rough	$\chi 2(3, N=108) =21.2$	**<.001**	.44
Q4B	Work/Potential Energy	Smoother	$\chi 2(3, N=108) =29.4$	**<.001**	.52
Q4C	Work/Potential Energy	No friction	$\chi 2(2, N=107) =31.4$	**<.001**	.54
Q5L	Ideal Mechanical Advantage	Length	$\chi 2(1, N=107) =7.0$	**.008**	.26
Q5H	Ideal Mechanical Advantage	Height	$\chi 2(1, N=107) =.6$	.426	.08
Q5S	Ideal Mechanical Advantage	Surface	$\chi 2(1, N=103) =3.1$	.079	.17
Q6L	Actual Mechanical Advantage	Length	$\chi 2(2, N=108) =10.7$	**.005**	.31
Q6H*	Actual Mechanical Advantage	Height	$\chi 2(2, N=108) =2.9$	.280	.17
Q6S*	Actual Mechanical Advantage	Surface	$\chi 2(2, N=108) =6.0$	.063	.24
Note: Asterisk indicates exact test was used. Bold indicates significant at the p <.005 level.					

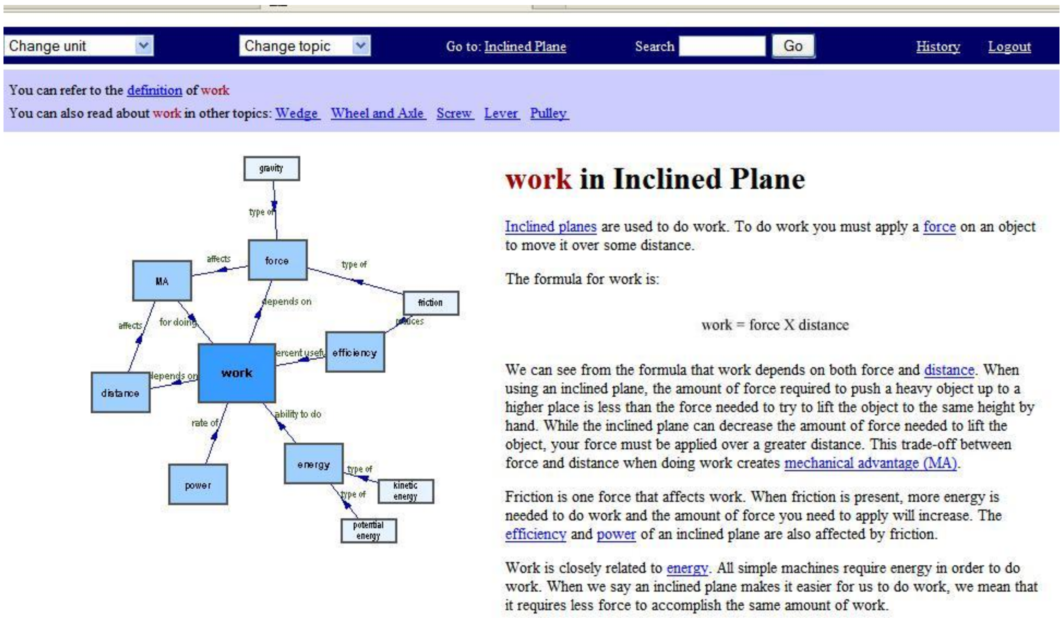

Figure 1. The CoMPASS hypertext system.

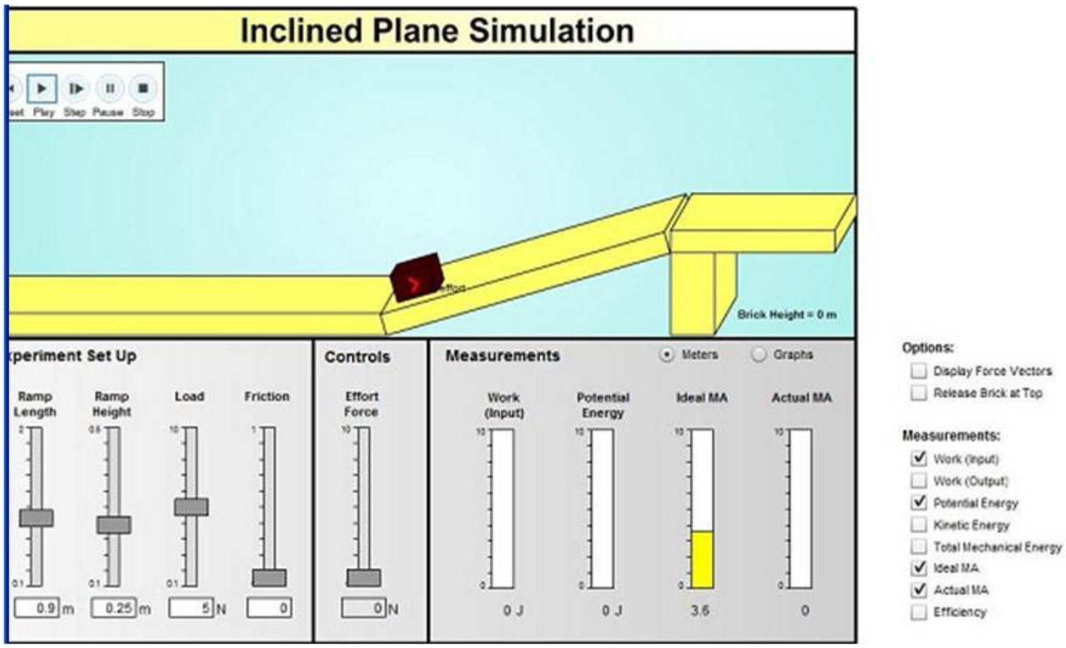

Figure 2. Inclined plane simulation.