Effects of a Prior Virtual Experience on Students' Interpretations of Real Data

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Abstract. Our previous work has shown that experimentation with virtual manipulatives supports students' conceptual learning about simple machines differently than experimentation with physical manipulatives [1]. This difference could be due to the "messiness" of physical data from factors such as dissipative effects and measurement uncertainty. In this study, we ask whether the prior experience of performing a virtual experiment affects how students interpret the data from a physical experiment. Students enrolled in a conceptual-based physics laboratory used a hypertext system to explore the science concepts related to simple machines and performed physical and virtual experiments to learn about pulleys and inclined planes. Approximately half of the students performed the physical experiments before the virtual experiments and the other half completed the virtual experiments first. We find that using virtual manipulatives before physical manipulatives may promote an interpretation of physical data that is more productive for conceptual learning.

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INTRODUCTION

Our previous research has focused on how students' learning about the physics concepts related to simple machines is supported by experimentation with physical and virtual manipulatives [1]. We have found that students often score better on conceptual tests after using a computer simulation to perform experiments than after using physical equipment to perform the same experiments. In particular, students' performance on questions about work tends to be better supported by the virtual manipulative than the physical manipulative.

One factor that may contribute to this result is the "messy" data generated by dissipative effects and measurement uncertainty in physical experiments. Analyzing this data may not successfully prepare students to answer questions about the physics of an idealized situation. For example, when students use physical equipment to explore how changing the pulley system used affects the work needed to lift a load to a certain height, the data from their physical experiment may show the work changing. While the difference in work between pulley setups is usually small, students may not be prepared to interpret this data in a meaningful way.

Zacharia and Anderson have shown that students who used a computer simulation prior to performing a physical experiment made better predictions and explanations about the experiment than students who had solved textbook problems [2]. Based on these previous studies, we ask, "Does the prior experience of performing a virtual experiment affect how students interpret the data from a physical experiment?"

METHODOLOGY

Students enrolled in a conceptual-based physics laboratory performed experiments on inclined planes and pulleys using physical and virtual manipulatives. Each laboratory lasted approximately two hours. For the pulley experiment, two laboratory sections (N=67) explored science concepts related to pulleys in an online hypertext experiment before completing a physical experiment ("Hypertext"). The other two sections (N=58) used the hypertext system and completed a virtual experiment before performing the physical experiment ("Hypertext+Sim"). For the inclined plane experiment, two sections (N=53) were in the Hypertext group and two sections (N=57) were in the Hypertext+Sim group.

For both the pulley and inclined plane experiments, the virtual experiment closely replicated the physical experiment. Students performed the same types of trials, collected the same kinds of data, and answered the same analysis questions. The physical experiments used equipment such as pulleys, boards, spring scales, and meter sticks. The pulley and inclined plane simulations are shown in Figures 1 and 2 below. Students completed the experiments and answered the analysis questions during the laboratory session.

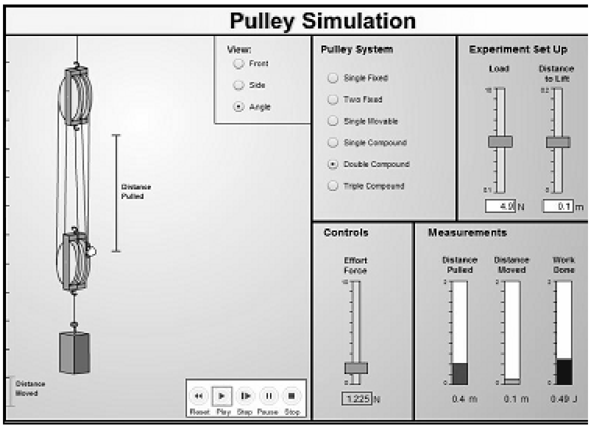

FIGURE 1. Pulley Simulation.

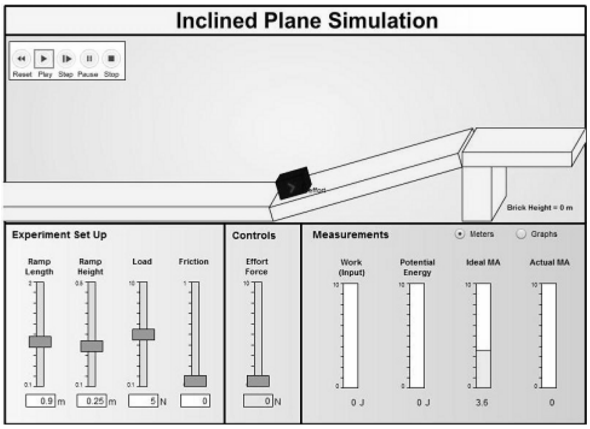

FIGURE 2. Inclined Plane Simulation.

Students' responses to open-ended worksheet questions related to work and potential energy were coded using a phenomenographic approach [3]. These questions were selected since our previous work suggests that the computer simulation may better support students' understanding of work and energy [1]. A chi-square test was used to determine if there was a difference between the responses given by Hypertext and Hypertext+Sim students. Fisher's exact test was used when expected cell counts were less than five. When a statistically significant result was found, adjusted residuals were examined to uncover which cells contributed to the significance [4].

THEORETICAL FRAMEWORK

Chinn and Brewer have described the possible responses one can have towards anomalous data [5]. 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. This framework will be used to explain students' responses to physical data.

Schwartz, Varma, and Martin have described how the learning environment can support dynamic transfer, or the development of new conceptions [6]. The environment may allow for distributed memory, afford alternative interpretations and feedback, offer candidate structures by constraining and structuring actions, or provide a focal point for coordination. It is possible that the learning environments created by the physical and virtual manipulatives will offer different support for the development of new ideas.

ANALYSIS

Pulley Analysis Questions

After performing the physical pulley experiment, students answered two open-ended analysis questions related to work. The first question asked, "Based on your data, when you changed the pulley setup, how did it affect the work required to lift the object?" Table 1 shows the categories of responses and occurrence frequency for each category within the two sequences.

TABLE 1. Responses to Pulley Work Question.

	H	H+S
Work constant	3	24
Work nearly constant	2	13
Work got easier	43	3
Work changed	16	12
Other	3	2

There is a statistically significant difference between the types of responses given by the Hypertext and Hypertext+Sim students, $\chi^2(4, N=121)=65.8$, $p<.001$, $V=.737$. Hypertext students were more likely to interpret the data from the physical experiment to indicate that the work needed to lift the object decreased as the pulley system got more complex. Hypertext+Sim students were more likely to interpret the physical data to indicate that the work was constant or nearly constant across pulley setups.

The second pulley analysis question related to work asked, "Based on your data, how does work compare to potential energy for a given pulley system?" Table 2 shows the common categories of responses and occurrence frequencies of each.

TABLE 2. Responses to Pulley Work/Potential Energy Question.

	H	H+S
Work = Potential Energy	5	8
Work & Potential Energy similar	1	18
Work > Potential Energy	6	4
W < Potential Energy	6	4
Work changed, Potential Energy did not	18	8
Work & Potential Energy not related	15	0
Work & Potential Energy both constant	5	4
Other	11	7

There is a statistically significant difference between the types of responses given by Hypertext and Hypertext+Sim students, $\chi^2(7, N=120)=39.5$, $p<.001$, $V=.574$. Hypertext students were more likely to state that the work and potential energy were not related, while Hypertext+Sim students were more likely to state that work and potential energy were similar.

Inclined Plane Analysis Questions

After performing the physical inclined plane experiment, students responded to nine open-ended analysis questions related to work and potential energy. Four questions will be discussed here. The first question asked, "How does the work (input) needed to move the load change as the length of the ramp increases (for a constant height)?" Table 3 below displays students' responses and the occurrence frequency for each.

TABLE 3. Responses to Inclined Plane Work Question.

	H	H+S
Work increased	40	18
Work stayed the same	4	25
Work decreased	10	11

There is a statistically significant difference between the types of responses given by Hypertext and Hypertext+Sim students, $\chi^2(2, N=108)=23.6$, $p<.001$, $V=.467$. Hypertext students were more likely to interpret the physical data to indicate that work increased as the length of the ramp increased, while Hypertext+Sim students were more likely to interpret the physical data to indicate that work stayed the same as the length increased.

In another question, students were asked, "How do the work (input) and potential energy compare when there is friction?" Table 4 below displays students' responses and the occurrence frequency.

TABLE 4. Responses to Inclined Plane Work/Potential Energy Question: Friction Present.

	H	H+S
Work > Potential Energy	10	26
Work < Potential Energy	1	8
Work increases, Potential Energy constant	29	12
Other	14	8

There is a statistically significant difference between the types of responses given by Hypertext and Hypertext+Sim students, $\chi^2(3, N=108)=21.3$, $p<.001$, $V=.444$. Hypertext students were more likely to respond that work would increase and potential energy would stay the same, while Hypertext + Sim students were more likely to state that work was greater than or less than potential energy.

In the next question, students were asked, "How does the relationship between work (input) and potential energy change as the surface gets smoother?" Table 5 below displays students' responses and the frequency with which each type of response occurred in each treatment.

TABLE 5. Responses to Inclined Plane Work/Potential Energy Question: Less Friction Present.

	H	H+S
Work & Potential Energy get closer	8	24
Work = Potential Energy	3	12
Work decreases, Potential Energy constant	30	6
Other	13	12

There is a statistically significant difference between the types of responses given by Hypertext and Hypertext+Sim students, $\chi^2(3, N=108)=29.4$, $p<.001$, $V=.522$. Hypertext students were more likely to state that the work would decrease and the potential energy would remain the same, while Hypertext+Sim students were more likely to state that the work would get closer to or equal to the potential energy.

The next question asked students, "How do the work (input) and potential energy compare when there is no friction?" Table 6 below displays the common categories of responses and occurrence frequency.

TABLE 6. Responses to Inclined Plane Work/Potential Energy Question: No Friction Present.

	H	H+S
Work = Potential Energy	17	43
Work decreases, Potential Energy constant	21	1
Other	16	9

There is again a statistically significant difference between the types of responses given by Hypertext and Hypertext+Sim students, $\chi^2(2, N=107)=31.4$, $p<.001$, $V=.542$. Hypertext students were more likely to state that the work would decrease and the potential energy would remain the same, while Hypertext+Sim students were more likely to state that the work would equal the potential energy.

DISCUSSION

For both the pulley and inclined plane experiments, Hypertext+Sim students were more likely to interpret the physical data to indicate that the work was constant or nearly constant across different machines (when lifting the object to the same height). It appears that the experience with the computer simulation may have better prepared students to interpret the physical data about work. While students in both sequences saw work values that varied slightly from machine to machine, Hypertext students focused on the difference while Hypertext+Sim students were more likely to focus on the similarity.

This result can be explained in terms of Chinn and Brewers' framework of possible responses to anomalous data [4]. Hypertext+Sim students are first presented with data that is easily interpreted to indicate that (in the absence of frictional effects) the work required to lift the object does not vary between machines. Students are likely to develop, at least tentatively, the idea that the work will not change between different pulley systems or different lengths of frictionless inclined planes. Students then encounter ambiguous data in the physical experiment. Due to the ambiguity, Chinn and Brewer's framework suggests students may reinterpret the physical data to fit the theory developed from the virtual experiment. In addition, Chinn and Brewer propose that students may reject data from a source they do not view as credible. Our previous work has found students trust the computer simulation more than the physical experiment [7].

Hypertext and Hypertext+Sim students also made different types of comparisons between work and potential energy in both the pulley and inclined plane experiments. In the pulley experiment, Hypertext students were more likely to state that work and potential energy were not related, while Hypertext+Sim students were more likely to state that the work and potential energy were similar. In the inclined plane experiment, Hypertext students were more likely to talk about work and potential energy separately while Hypertext+Sim were more likely to make comparisons between work and potential energy.

This result can be explained in terms of the different support for dynamic transfer offered by the physical and virtual environments [6]. In both virtual experiments, work is represented both as a number and as a bar graph. In the inclined plane experiment, both work and potential energy were represented with bar graphs. These graphs may provide a "focal point for coordination" and help students construct ideas about how work and potential energy compare, leading Hypertext+Sim students to provide more productive responses.

SUMMARY

In both the pulley and inclined plane experiments, students' interpretations of data about work from a physical experiment were affected by whether they had a previous experience exploring work in a computer simulation. Specifically, Hypertext+Sim students were more likely to focus on the similarity between the values of work across different machines, while Hypertext would focus on the small variations in work. In addition, Hypertext+Sim students were more likely to make comparisons between work and potential energy than were Hypertext students. Thus, it appears the prior virtual experience prepares the students to make more productive interpretations of the physical data than the hypertext exploration.

It is important to note that the Hypertext+Sim students spent more time learning work and energy than the Hypertext students did before answering these analysis questions. In the future, we plan to analyze the reasoning students provided for their responses to help determine whether students were repeating the answers they saw in the simulation or were thinking more explicitly about measurements and error.

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REFERENCES

1. E. Gire, A. Carmichael, J. J. Chini, A. Rouinfar, N. S. Rebello and S. Puntambekar, "The Effects of Physical and Virtual Manipulatives on Students' Conceptual Learning about Pulleys," in International Conference of the Learning Sciences, in press.
2. Z. Zacharia and O. R. Anderson, *Am. J. Phys.* **71**(6), 618-629 (2003).
3. F. Marton. *Journal of Thought* **21**, 29-39 (1986).
4. S. J. Haberman, *Biometrics* **29**, 205-220 (1973).
5. C. A. Chinn and W. F. Brewer, *Rev. of Educ. Research* **63**(1), 1-49 (1993).
6. D. L. Schwartz, S. Varma and L. Martin, "Dynamic Transfer and Innovation," in *International Handbook of Research on Conceptual Change*, edited by S. Vosniadou, New York: Routledge, 2008, pp. 479-506.
7. J. J. Chini, E. Gire, A. Carmichael, N. S. Rebello and S. Puntambekar, "Students' Views of Physical and Virtual Experiments with Pulleys," in *American Association of Physics Teachers Winter Meeting*, Washington D.C., 2010.