Students' Understanding of Inclined Planes Using the CoMPASS Curriculum

Jacquelyn J. Haynicz[1], N. Sanjay Rebello[1] and Sadhana Puntambekar[2]

[1]*Department of Physics, 116 Cardwell Hall, Kansas State University, Manhattan, KS 66506-2601*
[2]*Dept. of Educational Psychology, 693 Educational Sciences, University of Wisconsin, Madison, WI 53706-1796*

Abstract. In this paper, we discuss how students enrolled in a conceptual physics class for future elementary school teachers progress through the CoMPASS (Concept Map Project-based Activity Scaffolding System) curriculum for inclined planes. The curriculum challenges students to design the best inclined plane to lift a pool table into a van. We have found that students typically predict the correct type of board (long and smooth) to complete the challenge, but their responses include evidence of both physics and everyday reasoning. After working through the materials, the majority of students understand the relationship between distance and force in the inclined plane as well as why the inclined plane is useful to lift heavy objects. However, students have difficulty both relating a plane's steepness to the force required to pull an object and discussing work in a scientifically correct manner.

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INTRODUCTION

The CoMPASS (Concept Map Project-based Activity Scaffolding System) curriculum combines design-based and project-based activities with an interactive hypertext system [1]. Thus, the designers have merged the benefits of hands-on activities with an adaptable concept presentation system. The CoMPASS hypertext system (see Fig. 1) combines interactive concept maps with textual descriptions for students to navigate through the information.

In this mixed methods study, we examined how students enrolled in an introductory physics course for future elementary school teachers progressed through the CoMPASS curriculum on inclined planes. The curriculum uses the context of simple machines to help students develop their understanding of mechanical science concepts, such as force, work, mechanical advantage and force-distance tradeoff.

Hawkins and Pea have discussed some issues related to student explanations [2]. They explain that the necessary precision of an argument depends on the norms of the community to which the argument is addressed. Likewise, the range of variables that should be considered depends on the community.

Our research questions for this study were:

Q1) Before instruction, what factors did students consider while making predictions about the length and surface of a ramp that would best complete their design challenge?
Q2) After instruction, to what extent did students learn about the relationship between force and distance?
Q3) After instruction, to what extent did students understand the usefulness of inclined planes?

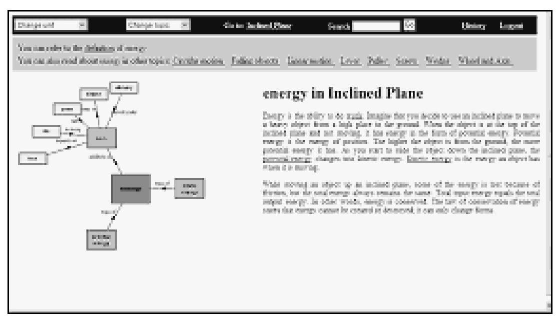

Figure 1. Screenshot of the CoMPASS interface

METHODOLOGY

We investigated how 85 students enrolled in a conceptual physics class for future elementary school teachers progressed through the CoMPASS inclined plane materials. The large majority of students (93%) were female. Most (92%) were between the ages of 18 and 22. Our sources of data include videos of students working through the materials and their worksheets.

The materials challenge students to design a ramp to help them load a pool table into a van (modeled by blocks). In our study, students began by answering a pre-test and anticipation guide. Then they brainstormed about inclined planes and made predictions about the length of board and surface they would need. These predictions were used to gauge students' initial understanding about inclined planes.

Next, students used the CoMPASS hypertext system to learn about inclined planes. A screenshot of the system is shown in Figure 1 above. Students chose their own path through the system by clicking on links in either the concept map or text. We recorded the concepts that the students clicked on, the order in which they clicked and the time they spent on each concept. Then students experimentally explored the relationship between the length or surface of the board and the effort force (applied force) needed to pull their "pool table" into the "van." Finally, students answered open-ended summary questions and a multiple choice post-test.

We used a phenomenological approach to analyze students' predictions and open-ended responses to the summary questions [3]. In addition, we analyzed students' performance on the pre- and post-tests. The inter-rater reliability, before discussion, is 80%.

RESULTS & DISCUSSION

Prediction: Length

The students were asked to predict the length of board they would need to complete the challenge of getting a heavy pool table into a van. The most common responses are shown in Figure 2 below (along with the responses for surface predictions). The majority of students (43/85) responded that a *long board* would best complete the challenge. For example, one student wrote, "I think we will need a long board since the pool table is so big and heavy, it will be better to use a longer board because it will make the effort small." We examined the responses of students supplying answers of *long board* to identify the reasons they gave for this choice. The most popular reason (24/43) was that a long board would have a *small incline*. For example, one student noted, "A long length of board will be the best way to complete the challenge so the incline won't be so big." Other popular responses were that a long board would need *less effort* (6/43) or *less force* (5/43). Some students (4/43) used *everyday physical reasoning* to justify their answer, stating reasons such as the table being wide or heavy.

The next most popular set of responses (33/85) involved students who gave a *specific length* of board that would best complete the challenge. For example, one student wrote, "15 ft because I feel it would go well from the porch or whatever the table is coming off of to the door of the van." As with *long board*, a popular reason that students gave a *specific length* was that it would create a *small incline* (4/33). Equally popular (4/33) was that it would need *less effort*. A few students (3/33) used *everyday physical reasoning* and one student (1/33) said it would take *less work.*

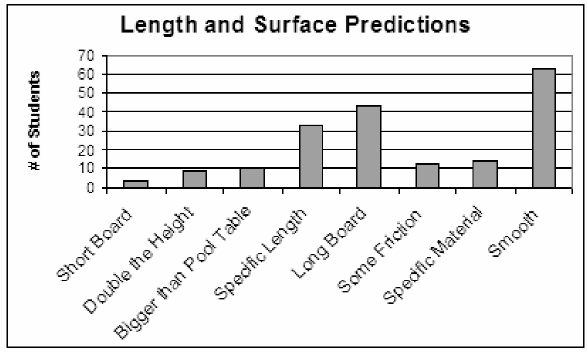

FIGURE 2. Categories of Length and Surface Predictions

As shown in Fig. 2 above, the next most popular response was that the board must be *bigger than the pool table* (10/85). Some students (9/85) responded that the board's length should be *double the height of the pool table*. A few students (3/85) stated that the board should be *short*. For example, one student wrote, "Shorter because the longer the board the more of it will bend a lot in the middle."

Prediction: Surface

The students were also asked to predict the surface of board they would need to complete the challenge. The most common responses are shown in Fig. 2 above (along with the length predictions).

The majority of students (63/85) responded that a *smooth surface* would be the best way to get the pool table into the van. For example, one student responded, "Smooth so there will be nothing interfering with it." We examined students' responses of *smooth* to identify the reasons they gave for this choice. The majority of students answering *smooth* (32/63) said that it would result in *less friction*. For example, one student wrote, "Smooth, because there is less friction on smooth surfaces." Some students (9/63) used everyday physical reasoning, such as the table is heavy. One student noted, "Smooth surface. Because the pool table is heavy, we have to have as little friction as possible." A few students (2/32) said a smooth surface would minimize the energy needed.

Some students (14/85) stated a *specific material* that they thought would best complete the challenge. The materials included wood, plastic, carpet, metal and diamond plate. A nearly equal number of students (13/85) responded that the surface should have *some friction*. For example, one student wrote, "Surface with some kind of friction so you won't slide on the smooth surface." Students choosing a surface with *some friction* either stated that some friction would keep the person from slipping or that it would keep the pool table from sliding back down the plane.

Effort Force and Distance

Open-ended Responses

In an open-ended summary question, students were asked to explain what they had learned about the relationship between effort force and distance in an inclined plane. We coded students' responses for relationships they described. The most common responses are shown in Fig. 3.

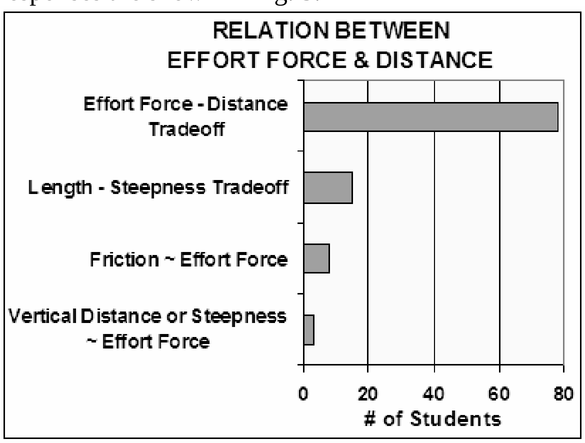

FIGURE 3. Students' relating Effort Force and Distance

As shown, the most common relationship given by students (78/85) described a *tradeoff between effort force and distance*. For example, one student wrote, "The greater the distance the less effort force that is needed." The next most common response (15/85) described a *tradeoff between length and distance*. One student wrote, "The longer a plane, the less steep it is, so the less force required." As this quote demonstrates, some students combined the effort force-distance tradeoff with the length-steepness tradeoff. Some students' responses (8/85) included statements about the *relationship between friction and effort force*, although that was not the focus of this summary question. Finally, a few students' responses (3/85) focused on the *relationship between vertical distance and effort force*.

Pre-test/Post-test Results

The students were given a five-question multiple choice test about inclined planes both before and after completing the instructional activities. On the pre-test, the students' average score was 3.5/5, while on the post-test their average score was 4.3/5. A two-tailed t-test showed this difference is significant at the level $p=3.44\times10^{-8}$.

Over 90% of students chose the correct answer on four of the five post-test questions. However, on Question 5, shown in Fig. 4 below, only 45% of students chose the correct response on the post-test.

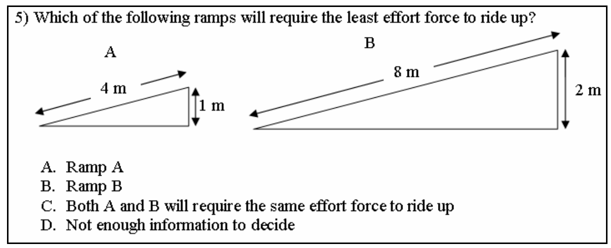

FIGURE 4. Post-test Question 5

Forty percent of students chose Ramp A, with a shorter height and distance, as the ramp which required the least effort force. Since the question does not explicitly state that the ramps are frictionless, Ramp A could be the technically correct choice, but students' responses on the other questions indicate they assumed the ramps to be frictionless. Thus, we feel it is likely this question indicates students have difficulty relating the required effort force to the steepness of the inclined plane. Rather, they focus only on the height or the length of the plane and not on steepness, which is influenced both by height and length.

Usefulness of Inclined Planes

In a second open-ended summary question, students were asked to explain why it is helpful to use an inclined plane when moving heavy objects. The most common reasons given by students for why the inclined plane is helpful are shown in Fig. 5 below.

As shown in the figure, students' responses were more varied on this question than the previous questions. The most common response (58/85) indicated that the inclined plane used *less effort force* than other means of moving the object. For example, one student wrote, "It's helpful because it takes less effort force to use an inclined plane than it takes to lift something up." The next most common response (17/85) indicated that one would do *less work* moving an object with an inclined plane. One student wrote, "The work for lifting something is usually more than using the ramp." Additional reasons given for the usefulness of an inclined plane include *spreads force over greater distance* (9/85), *transfers force/load to ramp* (6/85), *less energy* (6/85), *less time* (4/85), and *gravity acts over greater time* (2/85).

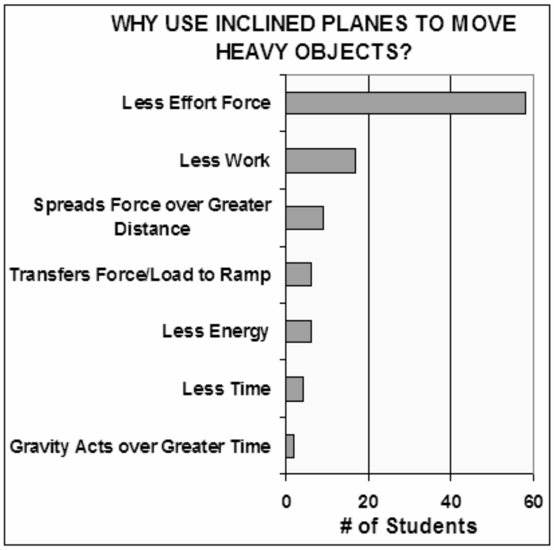

FIGURE 5. Response to Summary Questions

CONCLUSIONS

We address each research questions below.

Q1) *Before instruction, what factors did students consider while making predictions about the length and surface of a ramp that would best complete their design challenge?*

A long, smooth board was most commonly predicted by students to be the best way to complete the challenge. Many students also predicted a specific length of board or type of surface that they thought would be best. In students' responses, we see evidence of everyday physical reasoning, such as the weight or width of the pool table affecting the type of surface they will need. We also see possible evidence of their physics' knowledge influencing their responses, especially with regards to their surface predictions. This influence may be due to the mismatch between variables considered by the physics community and the lay community, as described by Hawkins and Pea. Students simply considered variables that are important in everyday life, but usually ignored in the "physics view" of inclined planes. Some students indicated that they would need friction on the surface so that they would not slip and the table would not slide back on them, while other students used "physics words" such as work and friction.

Q2) *After instruction, to what extent did students learn about the relationship between force and distance*?

Nearly all of the students (78/85) were able to explain that a longer board would require less effort force. We also saw a statistically significant increase in their post-test scores. However, a smaller number of students (15/85) were able to relate the difference in effort force to the steepness of the inclined plane. This inability to relate steepness to effort force appeared to have caused difficulty with Question 5 on the post-test.

Q3) *After instruction, to what extent did students understand the usefulness of inclined planes?*

Most students (58/85) related the usefulness of inclined planes to the smaller effort force required to pull an object up the plane than to vertically lift the object. However, a significant number of students (17/85) stated that the inclined plane is useful because it requires less work than a vertical lift. This response is consistent with our results in previous research on simple machines in which students tend to use the terms work and effort interchangeably, the same way they would in everyday language [4]. This confusion may be due to the difference in precision required by the physics and lay communities, as described by Hawkins and Pea. In the everyday world, it is fine to use "force" and "work" interchangeably, but in physics they have specific definitions.

Overall, our findings indicate that the CoMPASS curriculum is largely successful in helping students to understand the concepts related to inclined planes. However, it is possible that more attention should be given to helping students understand *why* a long board requires less effort. Another area of deficiency is students interchanging the word 'effort force' with the word 'work' as they would in everyday language. We recommend that students need to be provided concrete experiences to understand this difference in terminology.

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