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ABSTRACT

This article describes a unique project using commercial haptic interfaces to augment the teaching of simple machines in elementary school. Haptic interfaces provide the sense of touch and force to the human from a virtual model on the computer. Since force is central to the teaching of simple machines, we believe that the use of haptics in virtual simple machines simulations has the potential for deeper, more engaging learning. Software has been developed which is freely-available on the Internet, and HTML tutorials have been developed to support these haptics-augmented software activities in the teaching and learning of elementary school simple machines. Pilot study results are reported, which yielded positive feedback and suggestions for project improvement from elementary school students and teachers.

KEYWORDS

simple machines, haptics, haptic interface, Internet-based education, haptics-augmented education

1. INTRODUCTION

Haptics is related to the cutaneous sense of touch in humans. Haptic interfaces provide force and touch feedback from virtual models on the computer to human users. This article describes an innovative project using haptic interfaces to assist the teaching of simple machines at the elementary school level.

The literature regarding the use of haptics in K-12 education seems to be non-existent. Haptics expert J. Kenneth Salisbury is quoted in a recent Discover magazine article (Lemley, 2000): "I've often wondered if you could teach physics more effectively if your students could feel molecular attraction or planetary motion." Existing papers relating haptics and education are in the medical training field: the Interventional Cardiology Training Simulator (Shaffer et al., 1999) links technical simulation with specific medical education content, and a virtual reality-based simulator prototype for the diagnosis of prostate cancer has been developed using the PHANToM haptic interface (Burdea et al., 1999). The Immersion Corporation (www.immersion.com) has developed haptic interfaces for injection training and sinus surgery simulation; these interfaces are relatively expensive and are special-purpose. The GROPE Project (Brooks et al., 1990) has developed over 30 years a 6D haptic/VR simulation of molecular docking. The SPIDAR haptic interface has been adapted to serve as "the next generation education system" (Cai et al., 1997), although the authors do not elaborate on the type of education intended.

A group at the University of Ioannina in Greece is involved with virtual learning environments including a Power Glove with tactile feedback to "build a theoretical model for virtual learning environments, expanding constructivism and combining it with experiential learning." (Mikropoulos and Nikolou, 1996).

A research group at the Ohio Supercomputing Center has applied haptics in virtual environments to improve tractor safety by training young rural drivers (Stredney et al., 1998).

Haptics has been applied to make virtual environments accessible to blind persons (Jansson et al., 1999). Also, the effectiveness of virtual reality (without haptics) has been demonstrated in the learning process (North, 1996). Härtel (2000) has produced a simulation program (without haptics) to support teaching of high school physics (basic mechanics and electricity).

According to the National Science Education Standards (http://books.nap.edu/html/nses/html/index.html), in future science teaching there should be less emphasis on "Maintaining current resource allocations for books" and more emphasis on "Allocating resources necessary for hands-on inquiry teaching"; there should be less emphasis on "Textbook- and lecture-driven curriculum" and more emphasis on "Curriculum that includes a variety of components, such as laboratories emphasizing inquiry"; there should be less emphasis on "Investigations confined to one class period" and more emphasis on "Investigations over extended periods of time"; there should also be less emphasis on "Knowing scientific facts and information" and more emphasis on "Understanding scientific concepts and developing abilities of inquiry".

Two articles show that K-12 educational goals (including science education) set by the former President Bush have still not been met (Goodwin, 2000) and suggest a physics education reform agenda that must focus on politics and systemic change in addition to classroom innovation (Tobias, 2000).

We have started to address these shortcomings and the National Science Education Standards' philosophy in our work. Williams et al. (2001) present freely-available Internet tutorials and haptics-augmented software activities to support the teaching and learning of high school physics, with pilot project results.

2. PROJECT DESCRIPTION

The current project has the potential for both classroom innovation and nationwide systemic change. Since humans rely on multiple input modes to synthesize sensory information from the real world, haptics can greatly augment Internet-based education tools: "feeling is believing". This project attempts bring science education to life by allowing students to actually feel concepts presented in class. In this way, learning and retention will be enhanced. Also, through experiencing haptics, it is hoped that more students will be excited by and excel in science and mathematics and thus increase our technical base for the future.

The Learning Technologies Project at NASA Langley Research Center is concerned with innovative approaches for supporting K-12 education nationwide. The objective of the current project is to develop haptics-augmented computer simulations to enhance teaching elementary school simple machines. The goal is maximum accessibility for all U.S. schools, which dictated the use of the Internet to distribute the free program and tutorials, and a reasonably-priced, commercially-available haptic interface. The project software and tutorials are available from:

http://www.ent.ohiou.edu/~bobw/

Then choose Haptics-Augmented Education, Haptics-Augmented K-12 Education, and then Haptics-Augmented Simple Machines (for elementary school students). The program includes five different haptics-augmented activities to reinforce concepts presented in standard simple machines curriculum. In addition to distributing the software (including help files), the project website contains HTML tutorials for each activity to further strengthen concepts taught in class. Part of our philosophy is for the elementary school students to use the technology themselves to increase computer literacy. A pilot study was conducted in two local Ohio elementary schools to evaluate project results and identify improvements and future work areas. This pilot study was not intended as a statistically-significant result, but as feedback from students for project improvement.

This article first presents our educational philosophy, followed by a description of the HTML tutorials and haptics-augmented software activities. The pilot study results are presented (including evaluation by two elementary schools and the Robotics/Haptics class at Ohio University). Lastly, future work plans are discussed based on pilot study results. The appendices present the requisite technology behind this project, and the project evaluation questionnaire.

3. EDUCATIONAL PHILOSPOHY

We now relate our educational philosophy. We do this expressly to distance our efforts from those commercial entities, increasingly common in K-12 education, wherein the latest technology is the focus, rather than focusing on improved educational quality. Our team is non-profit; the NASA Langley Learning Technologies Project requires that project results be available free-of-charge via the Internet to all schools. Thus, we do not undertake this work for commercial purposes but to improve science education in the U.S. An important component of our work is evaluation of the usefulness of our results to teachers and students.

We did not develop our existing free tutorial and software products specifically to meet the national and various state science educational standards. However, we acknowledge how important these standards are to practicing teachers. Our work fits two categories of the National Science Education Standards (http://books.nap.edu/html/nses/html/index.html): Physical Science and Science and Technology. Our simple machines (and high school physics, Williams et al., 2001, and middle school pre-physics, available soon) content fits in the former category, while the nature of our Internet-based tutorials and PC software supports the latter category. These categories both extend through all levels, K-4, 5-8, and 9-12. Not only does our work fit the Standards' philosophy, but the content addresses the following needs: *position and motion of objects*, *equilibrium*, *motions and forces*, *transfer of energy*, *conservation of energy*, and *understanding about science and technology*.

Our work to date, focusing first on high school physics and now on elementary school simple machines (and middle school pre-physics in the near future)is just the first step in an ongoing project in attempt to improve K-12 science education. Our initial concept regarding the use of haptics in augmenting existing educational programs has been defined and we have produced alpha-version tutorial and software products, along with initial in-school evaluations. At this point we have raised more questions than concrete results, questions we aim to answer in ensuing work: Is our approach something that teachers and students will welcome in the classroom? What types of improvements will be necessary to strengthen our products? What instructional areas would teachers like to see our project applied to? How can we ensure that teachers will use our results and derive specific benefits from them? Our initial work is giving our ongoing project direction by taking into account the input of students and practicing teachers.

Our focus must be on what the students should be learning from each tutorial and haptics-augmented software activity. We are trying to shift focus away from the educational technology itself. For instance, in the present case of simple machines, work (force times distance) is a crucial topic. A simple machine does not reduce the amount of work required to complete a task, rather it changes the way in which the work is performed. For example, consider a 1:1 pulley and a 4:1 pulley. A 1:1 pulley requires input effort equal to the weight being lifted; a 4:1 pulley requires only one-fourth of the weight being lifted as the input effort. However, with the 4:1 pulley, the weight is only lifted one-fourth the distance that the 1:1 case achieves. Put another way, four times as much rope must be pulled in the 4:1 case. The required work in both cases is theoretically identical; using the 4:1 pulley requires less force while doing the same work. Similar arguments can be made regarding the work, effort, and distance moved in the other simple machines: levers, inclined planes, screws, and wheel-and-axles. It is our belief that students seeing and feeling such differences regarding motion and effort in our software will lead to more effective learning.

Our software allows the student to try different arrangements and sizing of simple machines to learn about work, input effort required, and load motion achieved. Of course, these important concepts can also be effectively taught using traditional hardware laboratories; we do not advocate replacing these necessary activities. Rather, our computer-based educational technology is intended to allow a greater number of potential arrangements and sizing in order to foster deeper and more complete learning, given limited budget and time in the schools.

4. HAPTICS-AUGMENTED SOFTWARE AND TUTORIALS

The project products are: an interactive software program for haptics-augmented elementary school simple machines activities, tutorials explaining the science behind each of these activities, and related help files. The project technology is described in Appendix A. This section discusses the five activities in the software program to demonstrate what our products can do. Please see the project website given in the References for more information and for the tutorials.

4.1 Haptics-Augmented Simple Machines Activities

Five activities with haptic feedback have been produced to augment the teaching of standard simple machines concepts:

1. Lever
2. Pulley
3. Inclined Plane
4. Screw
5. Wheel and Axle

We have not yet included the wedge due to its similarity to the inclined plane and screw. The wedge will be included in future work.

All activities are augmented in various ways by haptic feedback so the students can feel what they are learning. Also, configurations and parameters can be changed for each of the simple machines for increased interaction and learning. These five software activities are accompanied on the website by HTML tutorials with diagrams, explaining the relevant science concepts and mathematics. The next section describes each of the five activities.

4.2 Haptics-Augmented Simple Machines Program

This subsection describes the five haptics-augmented simple machines simulations. In all five simple machine choices, configurations can be changed by the student, as discussed below.

4.2.1 Lever. This activity allows the user to feel the force required to move a load with a lever. All three classes of lever are available: Class 1 (see-saw), Class 2 (wheelbarrow), and Class 3 (human forearm with bicep muscle). For all classes, the fulcrum and applied force locations are fixed, but the user may change the distance from the load to the fulcrum. Moving the haptic interface causes the virtual lever to operate. The student feels the effort required and sees the load distance moved, and can compare the results for varying fulcrum lengths. Figure 1 shows the Class 1 lever.

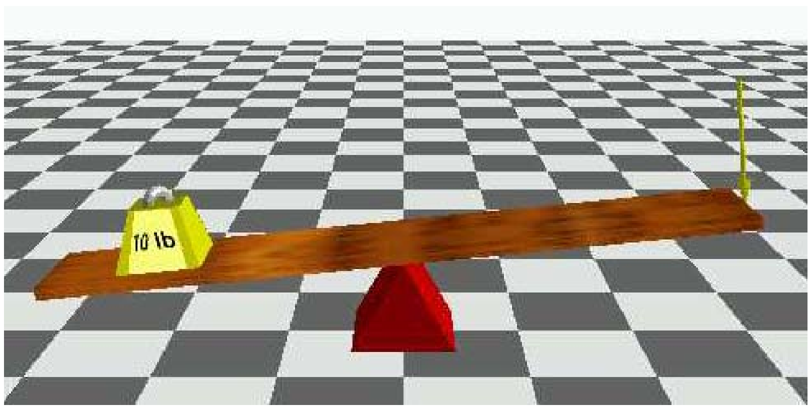

Figure 1. Class I Lever

4.2.2 Pulley. Three different pulleys are available, 1:1, 2:1, and 4:1 pulleys. The student pulls the haptic interface to pull rope down in the virtual world; an arrow indicates the direction of effort. The user sees the vertical motion of the load and feels the effort required. In the 1:1 pulley there is no mechanical advantage; the effort required is equal to the load weight. In the 2:1 pulley, the effort required is half of the load weight, but the load only moves half as much as in the 1:1 case (for the same amount of rope pulled). In the 4:1 pulley, the effort required is one-fourth of the load weight, but the load only moves one-fourth as much as in the 1:1 case. The work (force times distance) required in each case is the same; the user can see and feel this concept. Figure 2 shows the 4:1 pulley.

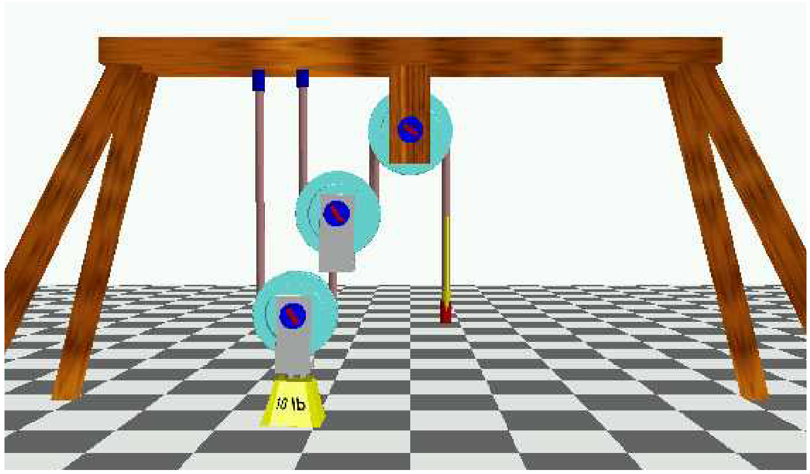

Figure 2. 4:1 Pulley

4.2.3 Inclined Plane. Figure 3 shows a virtual inclined plane used to lift a weight. The student pulls the virtual rope via the haptic interface to move the load up the inclined plane. The user can see the motion of the load and feel the effort required. The user may change the angle of the inclined plane, and then see different motions and feel different input forces. When the plane is vertical, there is no mechanical advantage: the effort required is equal to the load weight. However, the load moves the greatest possible vertical distance. As the plane angle increases, the required effort reduces, but the effective vertical distance the load is raised also decreases. Again, the work required to lift the load a given vertical distance is the same for all inclined plane angles, but it is easier to do this work (with more rope) using inclined planes with smaller angles. The user can see and feel this concept.

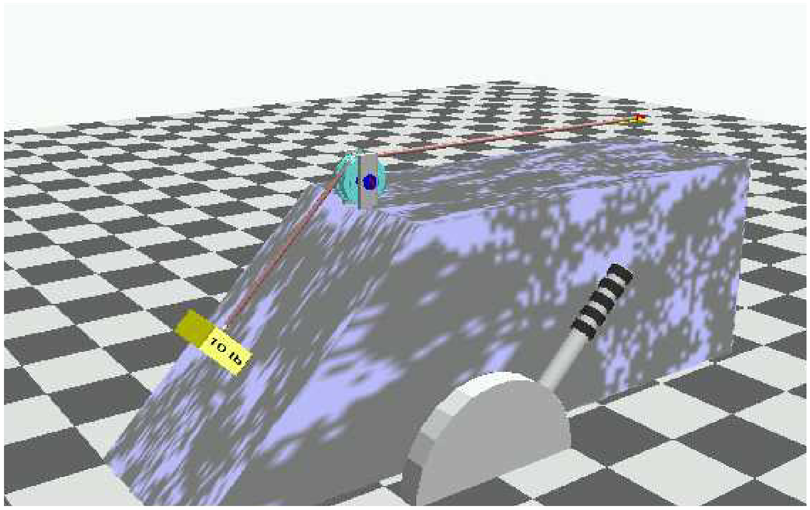

Figure 3. Inclined Plane

4.2.4 Screw. Figure 4 shows the screw simulation. This activity allows the user to turn screws into or out of a virtual board of wood via the haptic interface operating a virtual ratchet. Two screws are available: the right screw has a pitch (distance traveled into the wood per revolution of the screw) that is half the pitch of the left screw. That is, for one revolution of the ratchet, the screw on the left will penetrate twice as far into the wood; this also requires twice as much torque (rotational effort) as a single revolution of the screw on the right. So, the user can see and feel the different ways a screw can do the same amount of work.

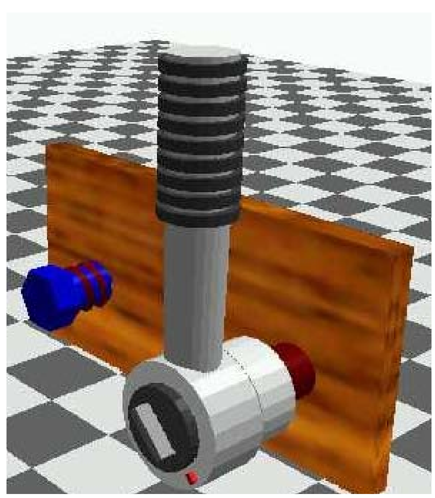

Figure 4. Screws with Ratchet

4.2.5 Wheel and Axle. To demonstrate the wheel and axle simple machine, we chose gears (wheels) rotating on shafts (axles). Three gear ratios are available, 1:1, 2:1, and 4:1. The input gear (chosen by the student) is rotated using the haptic interface. The direction of the input gear is also chosen by the student. The user can watch the resulting simulated motion and feel the torque (rotational effort) required in each case. With the 1:1 gear there is no mechanical advantage; the torque required is the same regardless of which gear is the input gear. Also, the rotational motion of one gear is equal to the other, the direction is just reversed. In the 2:1 gearset, when the small gear is input, the required torque effort is half that of the 1:1 case, but the output gear only rotates half as much. If the larger gear is input, the torque required is double that of the 1:1 case, but the small output gear rotates twice as much. Similar statements can be made for the 4:1 gear ratio, replacing half with one-fourth and twice with four times. Figure 5 shows the 4:1 gear train.

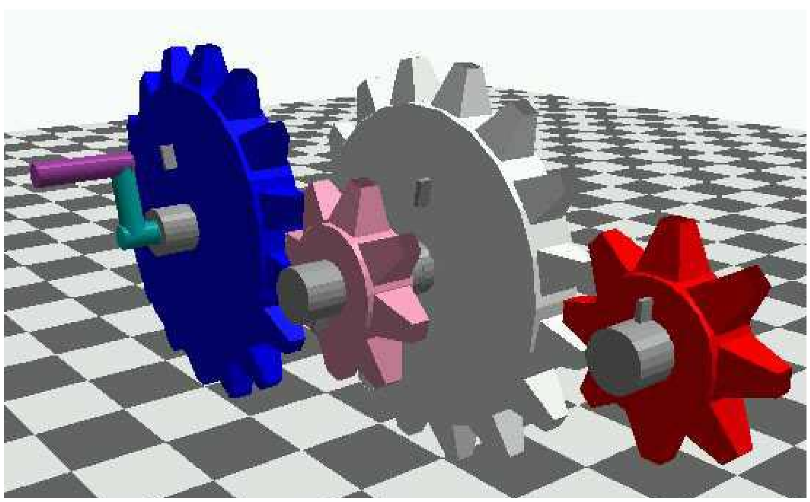

Figure 5. 4:1 Gear Train

5. PROJECT RESULTS

This section presents pilot project results. These results are not intended to be a rigorous statistical study, but rather a presentation of elementary school students' opinions to improve our current software and tutorials and to guide our future development in this area. The results presented were collected via paper surveys given to the students by computer administrators in two elementary schools near Ohio University. The students' levels ranged from second through sixth grades. Two haptic interfaces were donated to one school for participating in the pilot project; the second school bought a haptic interface.

A decision was made by Ohio University personnel not to interfere in the evaluation process in order to obtain fair results. The first two authors visited each elementary school to deliver the haptic interfaces, present a five-minute introduction to the project, give the project website, and deliver enough survey hardcopies. The schools were asked to install on their own the haptic interfaces and the haptics-augmented software developed in the project, freely available from the project website. Each computer administrator was asked to ensure as many students as possible would go through the on-line tutorials and evaluate the project software. Each student filled in the paper survey to determine our project's effects in augmenting their simple machines learning. The project evaluation questionnaire is given in Appendix B.

During the pilot project the Ohio University EE/ME Robotics/Haptics class students were also asked to evaluate the tutorials and software using the same survey, but the data presented in this section is exclusively from the two local elementary schools' students, lumped together. This section will conclude by comparing the Ohio University student responses with the elementary school responses.

We now summarize results of the elementary school students' responses to the pilot project evaluation questionnaire. As shown in Fig. 6, most of the 56 students rated our overall project as either *Effective* or *Somewhat effective*. 5 students chose the *Very effective* and 9 chose the *Not effective* ratings.

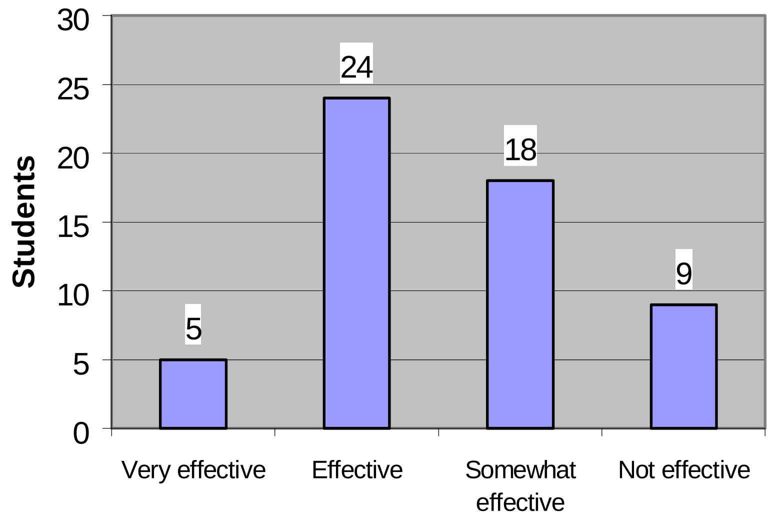

Figure 6. Question 2 Responses: How effective are the Tutorials and Haptics Software in helping you to learn or review simple machines?

Rank / **Tutorial**	**1**	**2**	**3**	**4**	**5**
Lever	6	8	6	4	2
Pulley	9	5	5	2	5
Inclined Plane	6	2	5	7	6
Screw	3	4	5	6	8
Wheel and Axle	2	7	5	7	5

Table I. Question 3 Responses: Please rank the web-based HTML tutorials from best (1) to least effective (5).

Table I gives the students' rankings for the five web-based HTML tutorials we developed to accompany the software. The numbers indicate the number of students who selected a given rank (1-best and 5-least effective) for a given tutorial. The numbers only add up to 26 students; this is explained below. The results were spread fairly evenly. The *Pulley* and *Lever* tutorials seem to be the best, while the *Screw* tutorial is the least effective. In our opinion, a broad spread of data in Table I is desirable since that means the quality of each tutorial is on par with the others.

Rank / **Software Activity**	**1**	**2**	**3**	**4**	**5**
Lever	10	3	4	3	6
Pulley	6	6	4	5	5
Inclined Plane	5	5	5	5	6
Screw	1	6	7	6	6
Wheel and Axle	4	6	6	7	3

Table II. Question 4 Responses: Please rank the haptics-augmented software activities from best (1) to least effective (5).

Table II gives the same 26 students' rankings for the five haptics-augmented software activities developed in the project, for the same simple machines covered in the tutorials. Again, the results are rather widely distributed. It seems that the *Lever* software rated as the best (although 6 students chose it as the least effective) and the *Screw* software ranked as the least effective. Again, the even spread of data indicates that all software activities are of consistent quality.

One unfortunate result of our non-interference policy was apparent only after the quarter-long independent evaluation process ended. Out of 56 total students, only 26 students read the directions carefully enough to fill in valid surveys for Questions 3 and 4. That is, over half of the students did not realize that all the numbers 1 to 5 were to be used, only once each, in Questions 3 and 4. The data presented in Tables I and II above is for the 26 valid student responses (in these, all rows and all columns must sum to 26, the number of students).

Since a larger number of students (30) responded to Questions 3 and 4 by ranking each item individually on a scale of 1 (best) to 5 (least effective), repeating numbers as they wished, we now present these results in the following two tables. Tables III and IV are the same as Tables I and II, for the 30 students who chose this alternate method of ranking. In the tables below, the rows sum to 30 students, but the columns do not sum to 30.

Rank **Tutorial**	**1**	**2**	**3**	**4**	**5**
Lever	7	5	11	4	3
Pulley	8	5	9	4	4
Inclined Plane	5	10	6	5	4
Screw	5	9	7	6	3
Wheel and Axle	2	7	6	10	5

Table III. Question 3 Alternate Responses: Please rank the web-based HTML tutorials from best (1) to least effective (5).

Rank **Software Activity**	**1**	**2**	**3**	**4**	**5**
Lever	11	7	6	2	4
Pulley	12	5	7	3	3
Inclined Plane	6	6	7	6	5
Screw	3	8	9	8	2
Wheel and Axle	4	5	11	5	5

Table IV. Question 4 Alternate Responses: Please rank the haptics-augmented software activities from best (1) to least effective (5).

The 30 students' responses using the alternate ranking method in Tables III and IV again show a wide spread, which is desirable for consistency. In this ranking method, the students tended to be more positive, choosing levels 4 and 5 (least effective) at a rate much less than 30 in most cases. According to Table III there is no clear favorite or least favorite tutorial; in this case it could be said that the *Inclined Plane* is the best and the *Wheel and Axle* the least effective. The *Pulley* and *Lever* tutorials again perform well. As seen in Table IV, the *Lever* and *Pulley* software activities rate the best, while the *Wheel and Axle* or the *Screw* are rated lower. Overall, the alternate ranking method reported in Table III and IV agrees well with our intended ranking method (Tables I and II). The spread of data is very broad in general for all responses on Questions 3 and 4, which indicates consistent quality for our tutorials and haptics-augmented software.

According to the results of Question 5, shown in Fig. 7, the use of the project technology (Sidewinder® installation, accessing tutorials, downloading and installing the haptics-augmented software) was fairly straightforward, which is crucial for our target audience. Only 5 students out of 56 said it was *Difficult*, and 0 students chose *Never worked*.

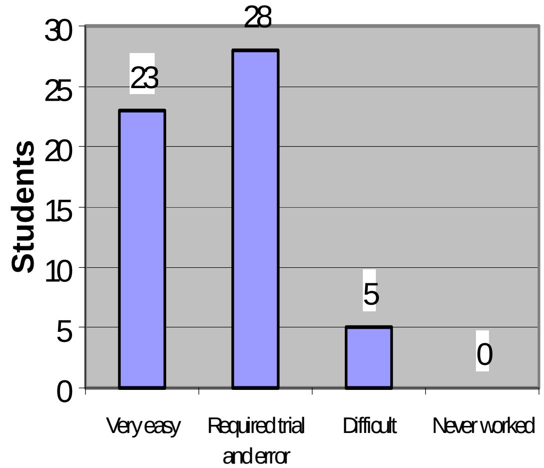

Figure 7. Question 5 Responses: Please rate the ease of use of this technology (accessing the tutorials, downloading the software and running it with the SideWinder haptic interface).

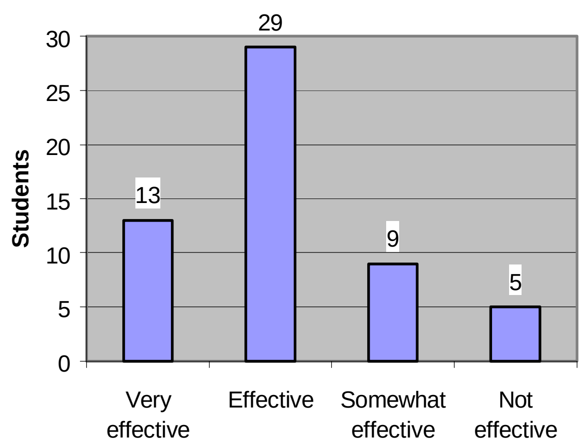

Figure 8. Question 6 Responses: Please rate the effectiveness of the SideWinder haptic interface itself, keeping in mind that it is relatively inexpensive.

Figure 8 shows the responses to Question 6, which demonstrates most of the 56 students found the Sidewinder® interface to be *Effective* or *Very effective*, considering its relatively low cost. The lower ratings are likely due to the low force levels that the SideWinder® allows, for safety.

In addition to the quantitative data presented above, student comments (via the evaluation form, Questions 7 and 8) and teacher comments (verbal) aided project evaluation. Most respondents praised the project and the overall feeling was quite positive. More than one student responded with "It was FUN!" and similar comments. Here we focus on the constructive criticism comments given, often by more than one respondent, to improve project results.

Many mentioned that the software should come with clear directions on how to get started and how to enable the force reflection (we believe these were already provided, perhaps the students did not read the program help files). Students and teachers agreed that the reading level was too advanced for even expert 6th-grade readers and should be written to the target grade levels. It was suggested that the software activities and tutorials be arranged in the form of a multi-level game to keep students engaged and to present more challenge to the student. Many students requested the ability to add more weight and interact more with the simple machines (such as changing the fulcrum locations in the three classes of lever). The software activities already allowed a level of interaction as explained earlier, but there is evidently room for improvement. Some students requested the addition of music and many students recommended the use of a computerized voice to read the tutorials and instructions. These comments are a strong vehicle for project improvement via the pilot study.

As mentioned in the beginning of this section, the Ohio University EE/ME Robotics/Haptics class of Spring 2001 was also asked to evaluate project results using the same questionnaire, to give a different perspective. This class is composed of senior undergraduate and first-year graduate students in two engineering departments. Though no plots are given, we now compare the 37 Ohio University student responses to the elementary school student responses given above.

The overall project effectiveness rating is not greatly different from Fig. 6, except only 1 *Not effective* rating was given. Also, the *Effective* responses (25) greatly outnumbered the *Somewhat effective* responses (8).

The Questions 3 and 4 responses were very consistent with Tables I through IV, i.e. the HTML-based tutorial and software activities rankings were fairly widespread which indicates consistent quality. In the tutorials, the *Lever* and *Pulley* rated the best, while the *Screw* was the least effective, in good agreement with the elementary school student opinions. The same results apply to the software activities: the *Lever* and *Pulley* rated the best, while the *Screw* was the least effective, again in good agreement with the elementary school student opinions. It is interesting to note that the university students also had trouble with the requested format of Questions 3 and 4: 22 students responded as we had intended (numbers 1 to 5 were to be used only once each) and 15 students responded with the alternate ranking method of independently rating each item from 1 to 5. It seems that our questionnaire was ambiguous for Questions 3 and 4; this will be improved for future evaluations. Happily, the two ranking methods did not detract from our pilot project results.

Question 5 does not apply to the Ohio University students since the project software and haptic interface were already loaded on a lab computer. The shape of Fig. 8, giving Question 6 responses for the effectiveness of the Sidewinder® haptic interface, is similar for the Ohio University students; but the *Effective* and *Somewhat effective* choices are more balanced, with 3 *very effective* and only 1 *Not effective* ratings. In summary, the Ohio University student quantitative project evaluations are very similar to the elementary school student evaluations, though conducted independently at a different academic level. The Ohio University students were far more detailed in their comments (Questions 7 and 8). However, the gist of these were all mentioned by the elementary student comments, given earlier. The main difference is that the Ohio University students were very detailed in their suggestions as to how the software activities should look and work; they were also helpful in finding bugs and typos.

6. FUTURE WORK

Based on pilot project results, we are encouraged to extend and open this project to science curricula in elementary schools across the country. A goal is maximum accessibility and another goal is maximum effectiveness; hence, the sixth through eighth-grade levels should be aggressively targeted in the future since these years are influential in determining a student's future study plans. Based on pilot project results, in addition to the bug fixes, future project objectives are to:

- Extend project results to sixth- through eighth-grade science education (available Fall 2002).
- Develop game-like activities to better challenge and engage students' attention for deeper learning.
- Develop software activities where the user can better modify the simulated configuration.
- Enable the use of different economical haptic interfaces that have recently become available.
- Develop improved 3D computer graphics and animation for the haptic-augmented software.
- Continuously evaluate educational effectiveness of project results.

The last bullet above is the most important, given our educational philosophy articulated in Section 3. We have recently begun a collaboration with experts in Instructional Technology and K-12 Teacher Education from the faculty of the College of Education at Ohio University. This collaboration will enhance our educational effectiveness evaluation, with a continued emphasis on meeting teacher needs in the field. Again, we have more questions than answers at this point: How can we improve math and science education in this country? How can we ensure our products are pertinent and useful tools for teachers? How do we ensure we are addressing areas teachers need help in?

7. CONCLUSION

This project focused on haptics-augmented software activities and Internet tutorials for assisting the teaching and/or reviewing of simple machines at the elementary school level. The results of this project are intended to reinforce simple machines concepts learned by allowing the students to feel the various concepts the teacher presents. We feature different simple machine configurations and student interaction to feel the effects of difference choices. This project is not intended to replace textbooks, experiments, or teachers. Five haptics-augmented software activities are provided, with HTML tutorials for each, available on the project website. To date, we skipped the *Wedge* simple machine due to its similarity with the *Inclined Plane* and *Screw*. We will add the *Wedge* in future work. The project goal is to increase student learning, retention, and technical curiosity, for the maximum possible audience. This article summarizes project technology and pilot study results; the reader is referred to the project website for more details. We believe this project has educational potential for the future, based on pilot project results. Future objectives and plans for this project have been presented.

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Immersion Homepage: http://www.immersion.com/.

APPENDIX A. PROJECT TECHNOLOGY

This appendix presents the technology behind the project. Included are the haptic interfaces, force and graphical programming, website development, and the help facilities.

A.1 Commercial Haptic Interfaces

At the project inception, the Microsoft Sidewinder® (Fig. A.1) was the best choice in terms of availability, low cost (about $80), and programmability. The project software executable was developed for this specific device. Since the standard DirectX force programming library was used, in principle any DirectX-compatible device may be used with the project results. However, early tests with the Logitech Wingman® (Fig. A.2) force-reflecting joystick (similar to the Sidewinder®) indicated that while the basic haptics-augmented simulations worked, certain details were different. Hence, our software must be customized for the different commercial haptic interfaces available. Currently our software is tailored to the Sidewinder®, but we are working to extend it to other interfaces[1].

Figure A.1. Microsoft Sidewinder®

Figure A.2. Logitech Wingman®

[1] **Note**: Ohio University is not endorsing the use of any particular commercial product.

The Microsoft Sidewinder® (Fig. A.1) is a two degrees-of-freedom haptic interface arranged like a flight stick. The user can enter two independent motion commands into the computer and feel two independent forces back from the computer via this interface. An infrared optical system is used for stick position sensing and two DC brush motors (with gear trains and linkages) are used for force feedback. In addition to the conventional roll and pitch flight stick motions, the Sidewinder® allows a third axis for input by twisting the stick (yaw). This axis has a limited range of motion and it has no associated force feedback. In addition to the roll, pitch, and yaw inputs, a trigger and various buttons provide additional inputs to the computer. Clearly, this device was developed for the gaming market, but our project demonstrates its potential for education as well.

A.2 DirectX/OpenGL Programming

The Haptics-Augmented Simple Machines Simulation program was created by using Visual C++®, the DirectX® software development kit, and the OpenGL® application program interface (API). One component of DirectX® used to program force feedback is DirectInput. DirectInput provides low-latency input from a broad variety of devices and supports output devices, including force-feedback peripherals. OpenGL® is a 2D and 3D graphic API. OpenGL® was developed by SGI (Silicon Graphic Incorporated). Programmers can use the OpenGL® API to produce workstation-quality graphics and animations on a personal computer.

A.3 Internet Website Development

The Ohio University Haptics-Augmented Simple Machines Simulation Website (see References) was created using the HTML programming language. This website contains some animations; at first we found some compatibility problems between Netscape® and Internet Explorer®. After several tests and experiments, we solved these problems. This website is compatible to both the Netscape® and Internet Explorer® web browsers; however, it was developed for Internet Explorer®, and we found that the latest Netscape® browser is required.

A.4 Help

This subsection briefly describes the three types of help available in conjunction with this project: the program help window, the Internet tutorials, and the Internet frequently asked questions.

A.4.1 Program Help Window. The help window for the Haptics-Augmented Simple Machines Simulation provides answers for how to use this program on a PC. It can also connect to our website so the user can operate the program and read the Internet tutorials simultaneously.

A.4.2 Internet Tutorials. Our website (the URL address is given in the Introduction) gives five tutorials that contain concepts and pictures related to the Simple Machines Simulation program. These are intended to help students understand the science covered. More details on the project tutorials are given in Section 4.

A.4.3 Internet FAQs. In our website, there is a frequently-asked-questions (FAQs) section. This lists several potential problems or questions about the requirements of the Haptics-Augmented Simple Machines Simulation program, plus how to download and install this program.

A.5 Installing and Running the Program

Upon downloading the executable ***SimpleMachinesSetup.exe*** from the project website (the file size is approximately 1.3 MB), double-click on this file under Windows Explorer to install the software. This process will upgrade the PC's DirectX libraries if necessary, but OpenGL must already be available to Windows. The program runs in stand-alone mode on the PC, with HTML-type help files. An Internet connection is required for reading the tutorials.

A desktop icon for the executable program is created during the installation process. Upon running this executable, the user must click on $\boldsymbol{F_E}$ to enable force reflection. The parameters for certain activities can be set by the user to see and feel their effects on the simple machines. Each simple machines activity is enabled by clicking on the appropriate program icon (alternately, via pull-down menus).

APPENDIX B. PROJECT EVALUATION QUESTIONNAIRE

The project evaluation questionnaire is given below.

1. I am a:
   ___Student; Level:
   ___Teacher; Level and Course:

2. How effective are the Tutorials and Haptics Software in helping you to learn or review simple machines (circle one)?

   Very effective Effective Somewhat effective Not effective

3. Please rank the web-based HTML tutorials from best (1) to least effective (5):

___Lever ______Pulley ______Inclined plane ______Screw ______Wheel and axle

4. Please rank the haptics-augmented software activities from best (1) to least effective (5):

___Lever ______Pulley ______Inclined plane ______Screw ______Wheel and axle

5. Please rate the ease of use of this technology (accessing the tutorials, downloading the software and running it in conjunction with the SideWinder haptic interface) (circle one):

   Very easy Required trial-and-error Difficult Never worked

6. Please rate the effectiveness of the SideWinder haptic interface itself, keeping in mind that it is relatively inexpensive (circle one):

   Very effective Effective Somewhat effective Not effective

7. Below please give specific suggestions as to how the tutorials and haptics software can be improved to better help you learn or review simple machines. Also suggest additional tutorials you would like to use and/or existing tutorials which should be dropped:

8. Give any additional comments on the back of this page.

Optional: Enter your name, e-mail address, school name.