HAPTICS-AUGMENTED HIGH SCHOOL PHYSICS TUTORIALS

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ABSTRACT

This article describes a unique project using commercial haptic interfaces to augment the teaching of high school physics. Since force is central to the teaching of physics, we believe that the use of haptics in virtual reality physics 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 high school physics. Pilot study results are reported, which yielded positive feedback and suggestions for project improvement from high school physics students and teachers.

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 high school physics.

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). 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).

Two new articles published in physics journals show that K-12 educational goals (including science education) set by 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).

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 "feel" concepts presented in class. In this way, learning and retention will be enhanced. 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 at supporting K-12 education in this nation. The objective of the current project was to develop haptics-augmented computer simulations to enhance teaching high school physics. The goal was maximum accessibility for all U.S. schools, which dictated the use of the Internet to distribute the program and tutorials, and a reasonably-priced, commercially-available haptic interface.
The project resulted in free software, available from:

http://www.ent.ohiou.edu/~bobw/html/NASAHap/main.htm

The program includes seven different haptics-augmented activities to reinforce concepts presented throughout a standard high school physics course. In addition to distributing the executable code (including help files), the project website contains HTML tutorials for each activity to further strengthen concepts taught in class. Part of the effort is for the high school students to use the technology themselves to increase computer literacy. This includes evaluating the project on-line via the website. A pilot study was conducted in three physics classes from two local Ohio high 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 useful feedback from students for project improvement.

This article first presents the requisite technology behind this project, followed by a description of the HTML tutorials and haptics-augmented software activities. The pilot study results are presented (including evaluation by the three high school classes and the Robotics/Haptics class at Ohio University). Lastly, future work plans are discussed based on pilot study results.

2. Project Technology

This section presents the technology behind the project. Included is the commercially-available haptic interface, force and graphical programming, website development, and the help facilities.

2.1 COMMERCIAL HAPTIC INTERFACE

At the project inception, the Microsoft Sidewinder® (Fig. 1) was the best choice in terms of availability, low cost (less than $100), 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. 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].

The Microsoft Sidewinder® (Fig. 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). Though this axis is limited in motion range and has no associated force feedback, it proved useful in the project software. 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 this project demonstrates its potential for education as well.

Figure 1. Microsoft Sidewinder®

Figure 2. Logitech Wingman®

2.2 DIRECTX/OPENGL PROGRAMMING

The Haptics-Augmented Physics 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.

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

2.3 INTERNET WEBSITE DEVELOPMENT

The Haptics-Augmented Physics Simulation Website (the URL address is given in the Introduction) was created by 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.

2.4 HELP

This section 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 (FAQs).

2.4.1 Program help window

The help window for the Haptics-Augmented Physics Simulation program provides answers for how to use the Haptics-Augmented Physics Simulation program on a user PC. It can also connect to the Haptics-Augmented Physics Simulation Website and the user can operate the Physics Simulation program and read the Internet tutorials concomitantly.

2.4.2 Internet tutorials

In the Haptics-Augmented Physics Simulation Website (the URL address is given in the Introduction), there are several tutorials that contain concepts and formulas related to the Physics Simulation program. They will help high school students understand physics. More details regarding the project tutorials is given in Section 3.

2.4.3 Internet FAQs

In the Haptics-Augmented Physics Simulation Website, there is a frequently-asked-questions (FAQs) section. This lists several potential problems or questions about the requirements of the Haptics-Augmented Physics Simulation program, plus how to download and install this program.

2.5 INSTALLING AND RUNNING THE PROGRAM

Upon downloading the executable ***HpSetup.exe*** from the project website (downloading requires approximately 10 minutes using a 56.6 kByte modem), double-click on this file under the 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 directions instruct the user to click on 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 physics (see Section 3.2). Each physics activity is enabled by clicking on the appropriate program icon.

3. Haptics-Augmented Software and Tutorials

The technology described in the previous section assisted in preparing the primary project results: a software executable for haptics-augmented high school physics activities, tutorials explaining the mathematics and physics behind each of these activities, and the related help files and FAQs. This section briefly discusses the seven activities in the program and how each may be used. Please see the website for more information.

3.1 HAPTICS-AUGMENTED HIGH SCHOOL PHYSICS ACTIVITIES

Seven activities have been programmed with haptic feedback to augment the teaching of standard high school physics concepts. The seven activities in the downloadable executable program are:

Sliding frictions
Spring forces
Magnetic simulations
Block sliding on inclined plane
Projectile motion
Robot joint control
Paddle ball

All activities are augmented in various ways by haptic feedback so the students can feel what they are learning. Five of the executable activities are accompanied on the website by HTML tutorials complete with text, figures, and equations, explaining the relevant concepts and mathematics. The reader is referred to the project website for these tutorials. Tutorials have not been developed for the Magnetic simulations (due to simplicity) or the Robot joint control (this activity is generally not in the scope of high school physics) activities. The five tutorials are not intended to replace textbooks. The next section briefly describes the functionality of each of these activities.

3.2 HIGH SCHOOL HAPTICS-AUGMENTED PHYSICS PROGRAM

This subsection describes each of the seven haptics-augmented physics simulations and how to use each. To enable one of the activities, click on the desired icon from the toolbar. Moving the mouse pointer along the toolbar without clicking will identify which activity each icon represents. Alternatively, activities can be activated from the *Effects* pull-down menu. Two of the activities are presented as games: Projectile motion and Paddle ball; in three of the activities students can change simulation parameters for enhanced learning: Block sliding on inclined plane, Projectile motion, and Paddle ball.

3.2.1 Sliding frictions

This activity allows the user to feel different levels of sliding friction: coarse, medium, fine, and ice. The joystick is used to move the cursor to the different zones. A Coulomb sliding friction model is used. The resistance due to friction is felt in the horizontal screen direction only. Figure 3 shows the window for this activity.

3.2.2 Spring forces

This activity allows the user to feel different spring force effects: a single spring, two identical springs in parallel and two identical springs in series (each identical to the single spring). The joystick is used to move the cursor to compress the different spring arrangements. The parallel setup feels twice as stiff as the single spring, while the series setup feels less stiff than the single spring. In each case, the greater the deflection imparted by the user via the joystick, the greater the restoring force felt (according to the linear Hooke's Law). At the neutral spring position, no force is felt. This simulation only works in compression. Figure 4 shows the window for this activity.
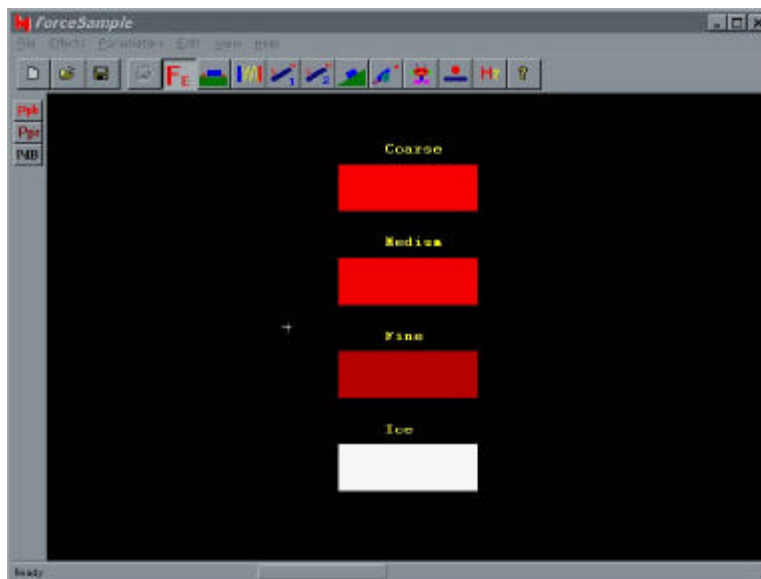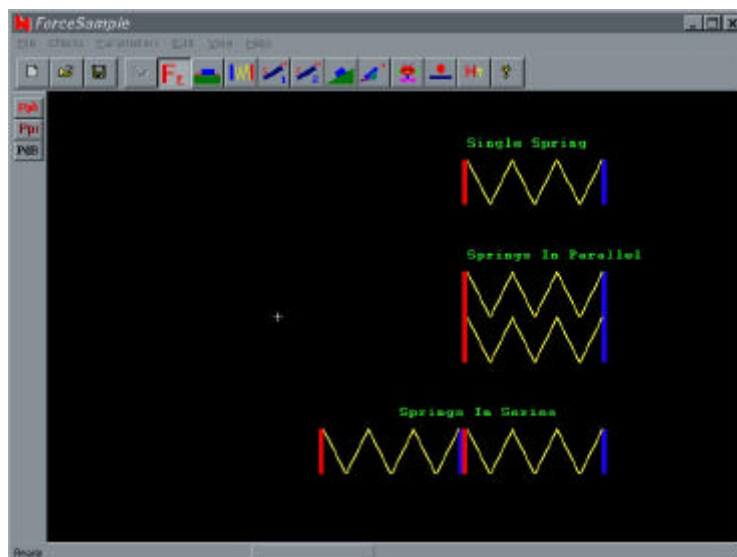

Figure 3. Sliding Friction Window

Figure 4. Spring Forces Window

3.2.3 Magnetic simulations

There are two magnetic simulations. Magnetic 1 demonstrates the attractive force between a cross-hair magnet and a concentric square of iron (the cross-hair could be iron and the square the magnet, alternatively). All four sides of the square attract and a realistic magnetic effect is produced as the user moves the cross-hairs via the joystick. Figure 5 shows the window for this activity. Magnetic 2 features a fixed magnet with fixed north and south poles. A second "active" magnet can switch poles when the user twists the joystick (in the real world, rotating the magnet by 180 *degrees*). In the horizontal screen direction only, the user can then feel the attractive/repulsive forces (depending on the "active" magnet alignment) as the "active" magnet is translated relative to the fixed magnet via the joystick. Figure 6 shows the window for this activity.
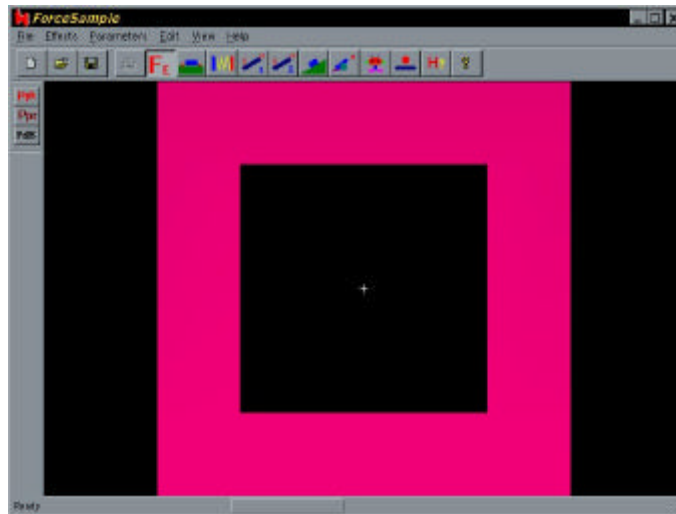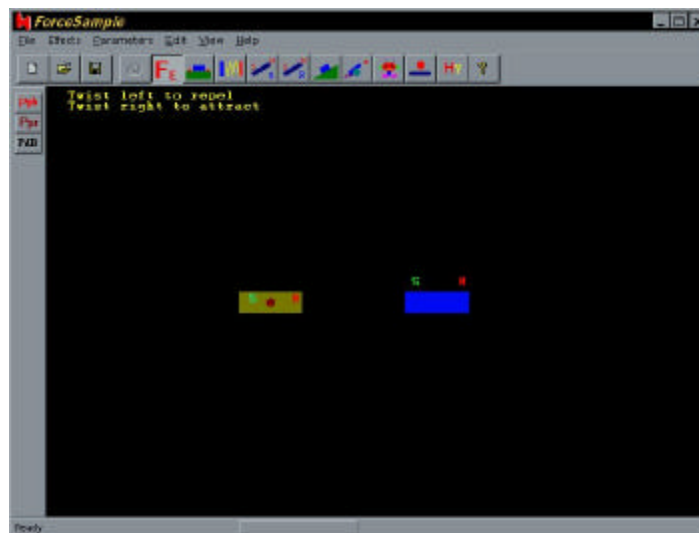

Figure 5. Magnetic 1 Windo0w

Figure 6. Magnetic 2 Window

3.2.4 Block sliding on inclined plane

This activity allows the user to push a block up an inclined plane via the joystick (feeling the weight at an angle and friction), release it, and then watch the ensuing simulated motion down the plane. By clicking *Ppb* from the sidebar (alternatively, using the *Parameters* pull-down menu and choosing *Block Sliding on Inclined Plane*), the user can change the block mass, plane inclination angle, and block/plane coefficient of friction and feel what effect each has in the simulation. As outlined in the associated HTML tutorial on the project website, a free-body diagram is used with Newton's Second law to solve this problem. Analytical solutions can be compared qualitatively with observed and felt results from the simulation. Figure 7 shows the window for this activity.
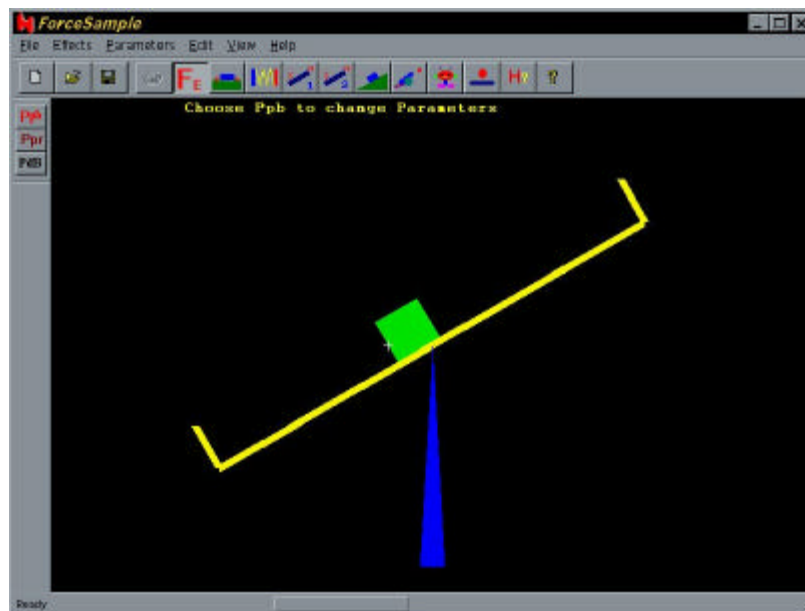

Figure 7. Block on Inclined Plane Window

3.2.5 Projectile motion

This activity is arranged as a game to shoot at the target flag in an attempt to blow it up. In this case the joystick is used only to pull the trigger to launch the projectile. However, haptic feedback is used to feel the recoil of the cannon shot and to feel vibrations when the projectile explodes. The vibrations are small for a miss and large for a hit. By clicking *Ppr* from the sidebar (alternatively, using the *Parameters* pull-down menu and choosing *Projectile Motion*), the user can change the initial cannon muzzle velocity, time of flight, range to the target, and cannon inclination angle. The user must click LOAD CANNON to try the new set of parameters. As outlined in the associated HTML tutorial on the project website, the solution to this problem is a parabolic trajectory. Analytical solutions can be compared qualitatively with observed results from the simulation. Figure 8 shows the window for this activity.
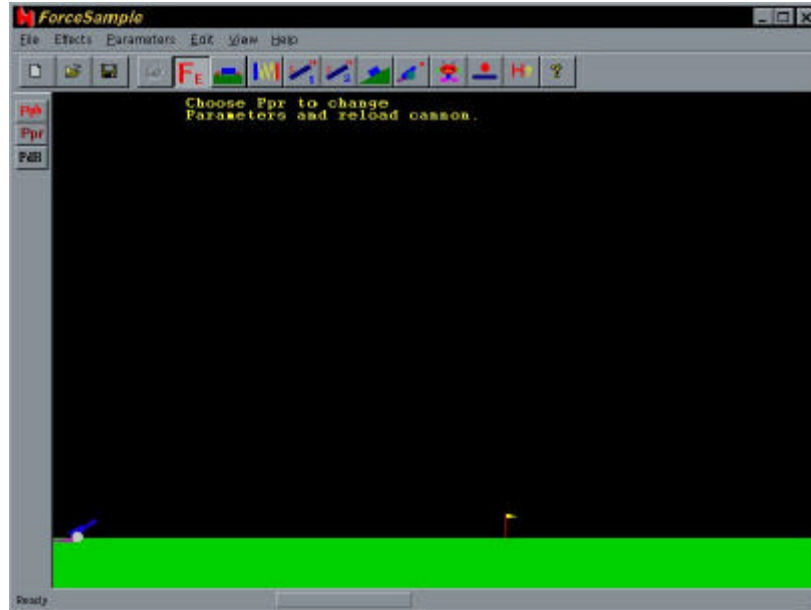
Figure 8. Projectile Motion Window

3.2.6 Robot joint control

This activity allows the user to drive a six-axis robot arm joint-by-joint using the joystick. The program help file explains how each joint is controlled. The haptic feedback in this activity is limited to feeling vibrations as each joint operates. There is no associated HTML tutorial for the robot on the project website since the mathematics behind this activity are not part of a standard high school physics course. Figure 9 shows the window for this activity.
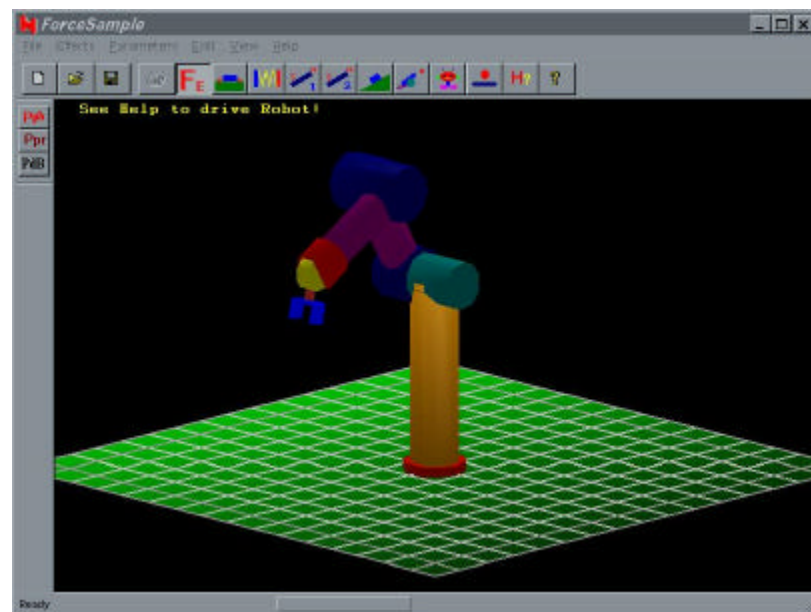

Figure 9. Robot Window

3.2.7 Paddle ball

This activity is arranged as a game to toss a ball into the air by manipulating an elastic paddle with the joystick and then trying to continue bouncing the ball. The paddle can be inclined in real-time by twisting the joystick for more varied motions. While the resulting trajectories are parabolas as in the cannon game case, the HTML tutorial associated with this activity is more advanced (generally corresponding to a university sophomore dynamics course) since it involves elastic collisions and coefficients of restitution. The joystick is used to toss and bounce the ball and for feeling the effects of the motion and collisions. By clicking *PdB* from the sidebar (alternatively, using the *Parameters* pull-down menu and choosing *Paddle Ball*), the user can change the ball mass, the initial ball velocity, and the paddle elasticity. The joystick trigger is used to start this activity. Figure 10 shows the window for this activity.
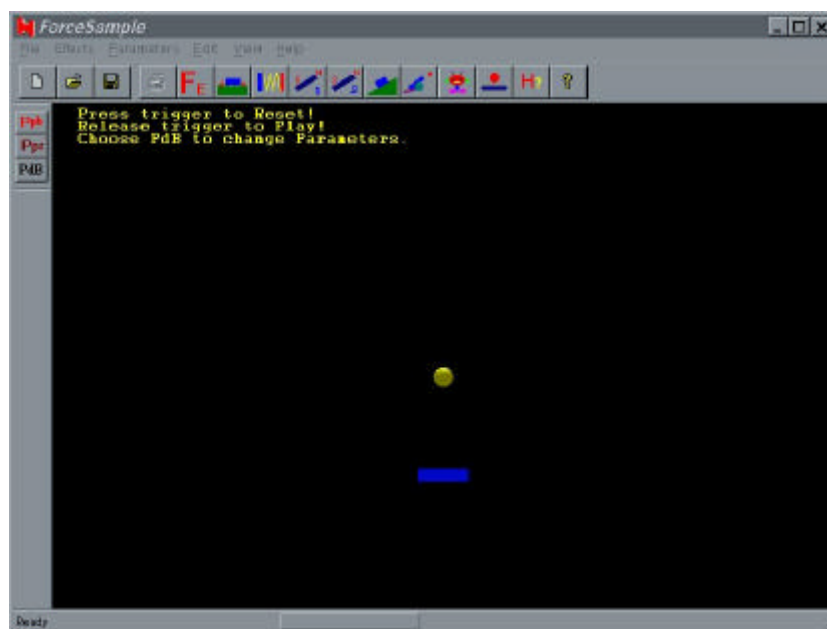

Figure 10. Paddle Ball Window

4. Project Results

This section presents pilot project results. These results are not intended to be a rigorous statistical study, but rather a presentation of high school students' and teachers' opinions to guide our future development in this area. The results presented were collected on-line via the project website from students in three physics classes from two high schools local to Ohio University: two physics classes of 12 and 17 students at Athens High School, led by Physics and Computer Science teacher Tom Stork; and one physics class of 5 students at Alexander High School, led by Physics teacher Gary Dunfee. A Microsoft Sidewinder® haptic interface was donated to each school for participating in the pilot project. 26 students replied, 100% of the Alexander High School students, and 72% of the Athens High School Students.

The first two authors visited each school to deliver the haptic interface, to present a five-minute introduction to the project, and to give the project website. The students were asked to install on their own the haptic interface and the haptics-augmented software developed in the project, freely available from the project website. Each student was asked at their leisure to go through the on-line tutorials and to evaluate the project software with regard to efficacy for augmenting their physics class. During the pilot project we received other responses as well (one individual from India and 37 students in the Ohio University EE/ME Robotics/Haptics class), but the data presented in this section is exclusively from the three local high school physics classes, lumped together. This section will conclude by comparing the Ohio University student responses with the high school responses. Given below is the set of nine evaluation questions each student was asked to fill in via the project website:

1. I am a :

    Student; Grade:

    Teacher; Course:

    Other:

2. How effective are the Tutorials and Haptics Software in augmenting your physics learning?

    Very effective

    Effective

    Somewhat effective

    Not effective

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

    Sliding frictions

    Spring forces

    Block sliding on inclined plane

    Projectile motion

    Paddle ball

4. Please rank the haptics-augmented software activities from best (1) to least effective (7):

    Sliding frictions

    Spring forces

    Magnetic simulations

    Block sliding on inclined plane

    Projectile motion

    Robot joint control

    Paddle ball

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):

    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:

    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 meet your needs in physics education. Also suggest additional tutorials you would like to use and/or existing tutorials which should be dropped:

8. Give any additional comments below:

9. Optional: Enter your name, phone number, address (including e-mail), school name.

We now summarize results of the high school students' responses to the pilot project evaluation questionnaire. As shown in Fig. 11, all students rated our overall project as either *effective* or *somewhat effective*. No student chose the *very effective* or *not effective* ratings.
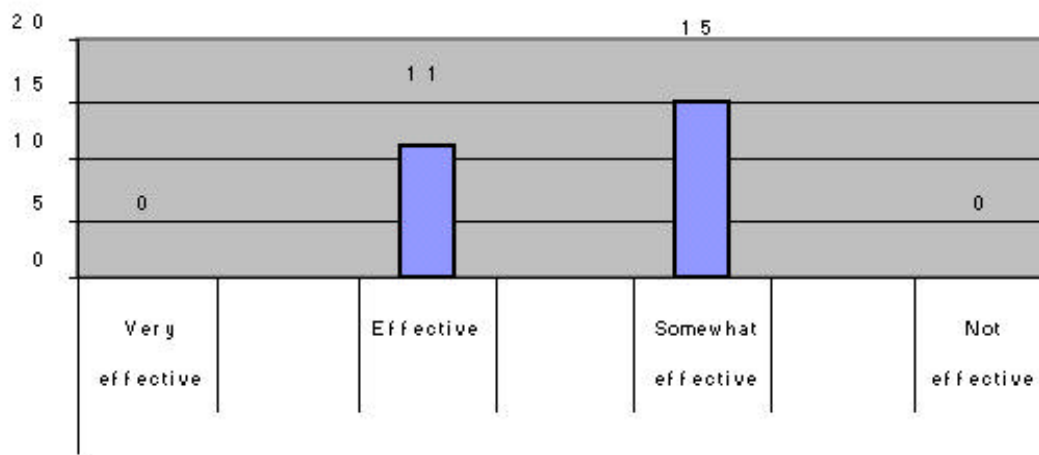

Figure 11. Question 2 Responses

Table 1 gives the students' rankings for the five web-based HTML tutorials we developed to accompany the software (no tutorial was given for the magnetic simulations or the robot joint control). The results were clear, with the Sliding Frictions tutorial ranked as the best (1) and the Paddle Ball tutorial ranked as the least effective (5). This Paddle Ball ranking is not surprising since the level of the tutorial is more advanced than the others, aimed more at the sophomore dynamics student at the university level. The three intermediate tutorials were ranked in the order that they appeared in Question 3.

Rank Tutorial	1	2	3	4	5
Sliding Frictions	18	0	1	3	4
Spring Forces	1	16	3	3	3
Block on Plane	0	3	16	5	2
Projectile Motion	6	2	3	14	1
Paddle Ball	1	5	3	1	16

Table 1. Question 3 Responses (1 best, 5 least)

Table 2 gives the students' rankings for the seven haptics-augmented software activities developed in the project. The results were not as clear as those given in Table 1. This may actually be good since this means all software activities are roughly on par concerning effectiveness, all good. The Projectile Motion software activity was clearly rated as the best, while the Sliding Frictions software activity was clearly rated as least effective (though its tutorial was most effective). Also, the Magnetic Simulations and Block Sliding on Inclined Plane software activities were ranked between best and least effective. The rankings for the remaining software activities were more widely distributed.

Rank Software Activity	1	2	3	4	5	6	7
Sliding Frictions	4	0	0	1	3	4	14
Spring Forces	5	5	5	2	3	6	0
Magnets	1	6	5	8	2	4	0
Block on Plane	0	4	5	7	7	1	2
Projectile Motion	13	1	4	0	3	5	0
Robot Control	1	4	4	4	3	5	5
Paddle Ball	2	6	3	4	5	1	5

Table 2. Question 4 Responses (1 best, 7 least)

According to the results of Question 5, shown in Fig. 12, the use of the project technology (Sidewinder® installation, accessing tutorials, downloading and installing the haptics-augmented software) was straightforward, which is crucial for our target audience.
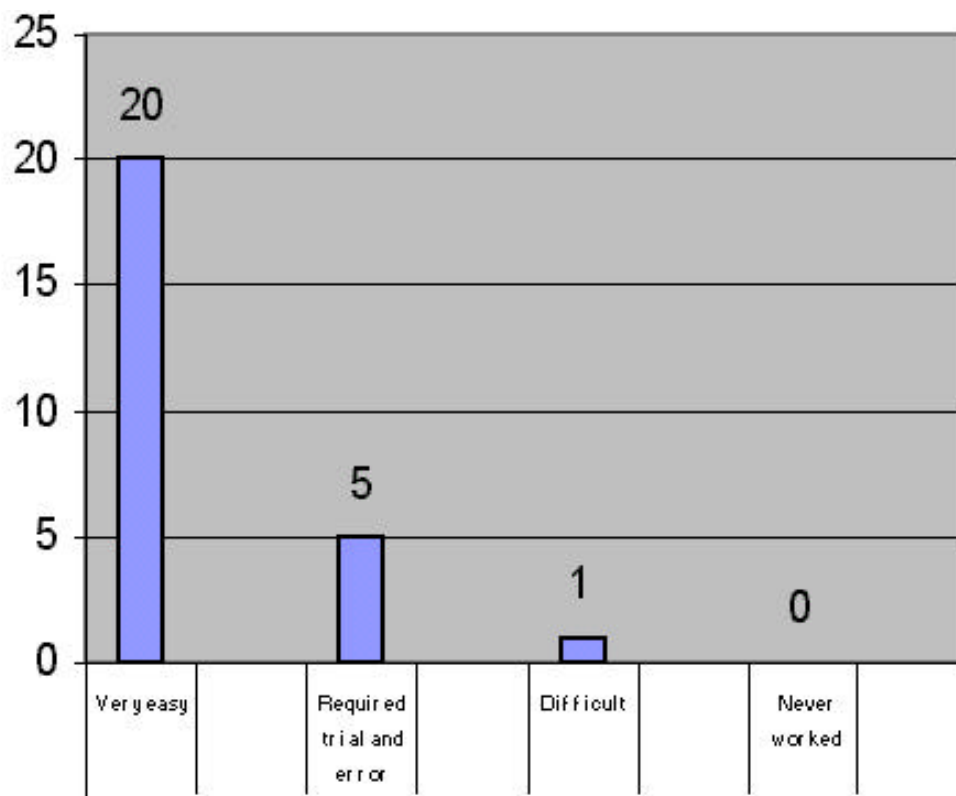

Figure 12. Question 5 Responses

Figure 13 shows the responses to Question 6, which demonstrates most students found the Sidewinder® interface to be effective, considering its relatively low cost.
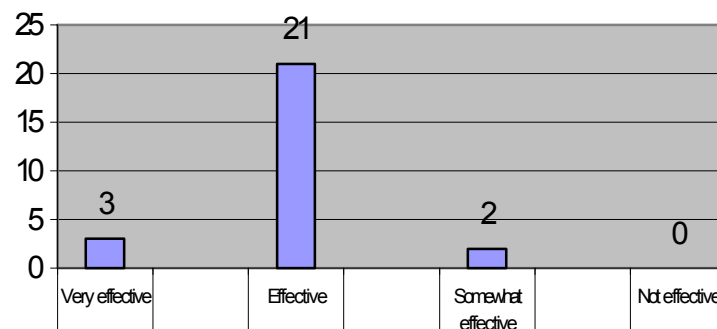

Figure 13. Question 6 Responses

In addition to the quantitative data presented above, student and teacher comments (Questions 7 and 8) greatly aided our project evaluation. Most respondents praised the project and the overall feeling was quite positive. Here we focus on the constructive criticism comments given, often by more than one respondent, to improve project results.

Many mentioned the crude nature of the software graphics might detract from effectiveness. An Ohio University student said: "Basically the tutorial could be enhanced with better graphics and more interesting scenarios. The haptic interface is nice for the cost. High school students are used to state-of-the-art gaming . . . but this is a great step in the right direction!" Others mentioned that the animation should be improved and the activities should be turned into goal-oriented games to hold the students' interest. A high school physics teacher said: "Make objectives to the levels (like a game). I was very disappointed when I got the block up the inclined plane and it didn't fall." Some called for a wider variety of activities, coordinated more closely with their high school physics curriculum. Others suggested an environment where the student can change the configuration of the haptics-augmented demonstration at hand, e.g. changing the number, stiffness, and arrangement of the springs to feel the differences. One student recommended making all HTML-based tutorials interactive (the Sliding Frictions tutorial is already partially interactive, which may account for why it was clearly chosen as the best tutorial, see Table 1). Many respondents requested that the robot be given objects to interact with, rather than just moving the joints. Finally, some students pointed out software bugs to be fixed, such as the toolbar tips not appearing after force reflection is enabled, and simple typographical errors. These and other comments were a great aid in project improvement via the pilot study.

As mentioned in the beginning of this section, the Ohio University EE/ME Robotics/Haptics class was also asked to evaluate project results, to give a different perspective. Most of these senior undergraduate and first-year graduate students would have been in high school physics at least four years previously. Though no data is given, we now compare the Ohio University student responses to the high school student responses given above. The overall project effectiveness rating is not greatly different from Fig. 11, except 6 responded *very effective* and 2 *not effective*. Also, the *effective* responses (18) outnumbered the *somewhat effective* ones (11). The Question 3 responses were very consistent with Table 1, i.e. the HTML-based tutorial ranking was clear and in the same order as the high school students chose. Once again, in response to Question 4, the Ohio University students clearly rated the Projectile Motion software activity as the best, while the Sliding Frictions software activity was clearly rated as

least effective. The remaining software activities' rankings were even more distributed than the high school data. Question 5 does not apply to the Ohio University students since the project software and haptic interface was already loaded on a lab computer. The shape of Fig. 13, giving Question 6 responses for the effectiveness of the Sidewinder® haptic interface, is similar for the Ohio University students; *effective* is still the clear choice, with 6 *very effective* and 2 *not effective* ratings. In summary, the Ohio University student project evaluations are very similar to the high school student evaluations, though conducted independently and at a different academic level.

5. Future Work

Based on pilot project results, we are encouraged to extend and open this project to science curricula in 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 setting 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.

- Develop game-like activities to better engage students' attention for deeper learning.

- Develop software activities where the user can 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.

- Develop interactive tutorials to support the software. Investigate inclusion of haptic feedback via the server hosting the tutorials, rather than the local computer.

6. Conclusion

This project focused on developing Internet tutorials and freely-downloadable haptics-augmented software activities for assisting the teaching of high school physics. This project is intended to reinforce concepts learned in high school physics by allowing the students to feel the various concepts the teacher presents. It is in no way intended to replace textbooks or teachers. Seven activities are provided, with HTML tutorials for five of these on the project website. 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 great educational potential for the future, based on pilot project results. Future objectives and plans for this project have been presented.

7. Acknowledgement

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Sidewinder® haptic interface homepage:
   http://www.microsoft.com/products/hardware/sidewinder/ force-feedback/default.htm

DirectX homepage: http://www.microsoft.com/DirectX

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

BIOGRAPHIES

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