Web-Based Touch Display for Accessible Science Education

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ABSTRACT
Inaccessibility of instructional materials, media, and technologies used in science, engineering, and mathematics education severely restricts the ability of students with little or no sight to excel in these disciplines. Curricular barriers deny the world access to this pool of potential talent, and limit individuals' freedom to pursue technical careers. Immersion has developed a low-cost force-feedback computer mouse. This haptic display technology promises fundamental improvements in accessibility at mass-market prices (sub-$100). This paper presents the results of an investigation into the potential benefits of incorporating haptic feedback into software intended for college and high school physics curricula.

Keywords
Science education, accessibility, blindness, low vision, haptic feedback, force feedback

INTRODUCTION
Physics, chemistry, engineering, and mathematics curricula are full of abstract principles and physical concepts, many of which are inherently dynamic in nature. Examples cross all disciplinary boundaries in the sciences and engineering, and include gravity, inertia, springs, damping, friction, momentum, fluid flow, pulleys, centrifugal force, gyroscopic motion, chemical bonding, and magnetism. Our interaction with such systems is most often mediated by direct physical contact (lifting objects against the force of gravity, rotating tools and feeling inertial forces, etc.) As such, our understanding of many dynamical systems is coupled to our haptic senses, which in turn are finely tuned to interpret dynamic properties in our environment.

This work explored the feasibility of making force-feedback simulations available to blind and visually impaired students over the World Wide Web as part of science education curricula. This included the development of enabling software technology to take advantage of a new low-cost force-feedback mouse (manufactured by Logitech under license from Immersion Corporation) and a demonstration curriculum module. A panel that included both educational experts and blind students was then recruited for a pilot study to assess this module.

Figure 1: Logitech Wingman Force Feedback Mouse

RELATED WORK
Though haptic feedback is a relatively new modality for HCI, its potential for providing access to GUIs for blind computer users was recognized early on and has been explored by many researchers. Broadly speaking, these efforts can be divided into two strands, projects which have concentrated on rendering the components of the 'environment', the GUI itself (Dufresne et al, 1995; Ramstein et al, 1996; O'Modhrain and Gillespie, 1996) and those which have focused on rendering 'content', the non-text information that might be produced by applications such as mathematical packages etc. (Asgher et al, 1998; Grabowski et al, 1998; Fritz et al, 1996A; Fritz et al, 1999.) Two further studies (Ramstein and Century, 1996; Hardwick et al, 1998) have specifically addressed issues related to haptic rendering of objects and images on the World Wide Web. However, both differ from the present

study in that they concentrate on the rendering of web page layout and address only in passing the possibility of rendering content haptically as well.

Two studies that have implications for both strands of research have focused on questions of shape and texture discrimination. Colwell (Colwell et al, 1998.) studied the perception of virtual textures, shapes and objects by both blind and sighted subjects. Fritz and Barner (Fritz et al, 1996B) developed a method to synthesize perceptually distinct haptic textures using stochastic modeling techniques. Their goal was to create a variety of textures that could then be used to display complex data plots.

ACCESSIBLE SCIENCE EDUCATION CURRICULUM DEVELOPMENT

The present project focused on the development of a prototype instruction module (curriculum module) organized around a set of didactic goals. The key features of the curriculum module were that it was accessible and Web-deployed. It used force feedback in a way that was meaningful and necessary for the blind student to understand the material presented (in conjunction with corresponding text-to-speech information).

The development and implementation of the curriculum module were carried out by the Science Access Project at Oregon State University, with Immersion Corporation providing guidance regarding force feedback paradigms. The evaluation phase of the project was conducted by Immersion, which provided evaluators with haptic devices and technical support. Finally, to collect feedback from the evaluators, educators from Oregon State University collaborated with Immersion to design a user evaluation survey.

Topic of Curriculum

Our team chose introductory electric fields as the most appropriate instruction topic for the feasibility study because it lends itself naturally to education using a force display. The purpose of the curriculum module was to demonstrate to the student experimentally the electric field due to a uniformly charged (non-conducting) sphere and to require the student to measure and analyze experimental data to find the charge on the sphere. It is a demanding laboratory suitable for advanced undergraduate physics majors or for introductory graduate students in the physical sciences.

Curriculum Module Design

The curriculum Module was designed as a sequence of tutorial web pages that guided the student through both the experimental and data analysis stages of the laboratory. The goal of the experimental phase of the module was to allow the student to gain an understanding of the behavior of electric charge on the surface of a sphere. Using the Logitech Wingman Force Feedback Mouse, the student controlled the position of a test charge "attached" to the cursor while feeling the resulting force either attracting or repelling their hand from the surface of the sphere. By clicking the mouse button at any point, the student can record data - the force at a particular radius.

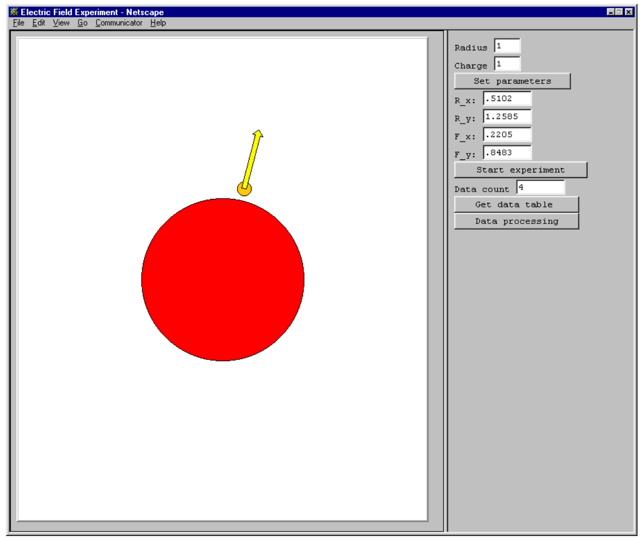

Figure 2: Screen shot of the Experiment Mode of the electric field laboratory.

Next, the students enter an analysis mode. In this mode the students can explore their collected data, select curve-fitting parameters, and feel the fit curves. This environment is designed to help the student gain a quantitative and qualitative understanding of the physical phenomena, to literally get a "feel" for the character of the data they have collected.

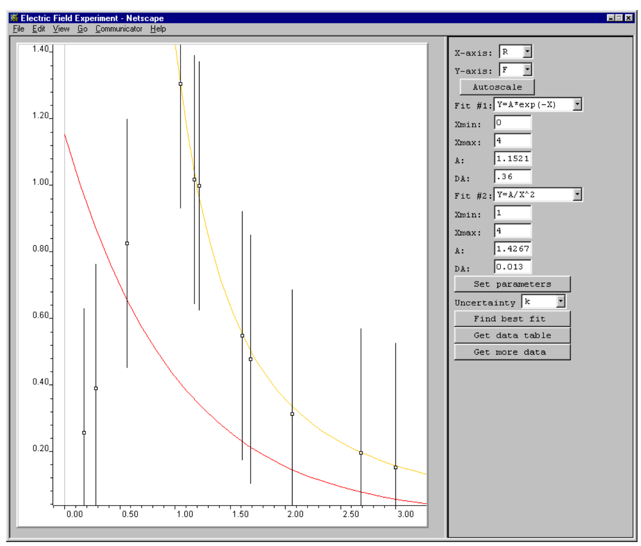

Figure 3: Screen shot of the Analysis Mode of the electric field laboratory.

Interface Design

The principal components of the laboratory are presented as two screens, the experimental screen and the data analysis screen. In both experimental and data analysis phases, considerable care was taken to ensure that the force feedback associated with interface objects (environment) was clearly distinguishable from that associated with the electric field experiment (content) (See Appendix). The design included two frames – an interface frame (on the right side of the screen) and a content frame (on the left side of the screen). Throughout the entire laboratory, screen-reading software voiced the text and user interface items; however, a screen reader is optional if the student is not blind.

In experiment mode, the force on the test charge could be felt at the mouse pointer position. The force vector was also visible as an arrow. An audible warning indicated the boundaries of the charge field; optionally, an additional force field was available that allowed the student to feel the contour of the charge. Once the experiment phase had been initiated, the student could collect data on charge position and the force on the charge via a simple user interface. This interface provided controls to alter the size and charge parameters of the electric charge, to display the numeric values of the current cursor position and force vector, and to show the number of data points already collected. From the interface frame, the student could also view a table of collected data, or enter data analysis mode.

Having collected their data, the student entered the data analysis mode. Here their data were plotted along with statistical error bars and fitted curves. The student could zoom in on a region of the curve by drawing a rectangle over the region of interest, and could modify fitting parameters. Again, audible and tactile cues defined the workspace boundary. In data analysis mode, several regimes of force feedback were available encouraging the student to explore data from different viewpoints. Data can be displayed as single attracting points, as a curve or as a tour (i.e. the mouse could be made to move from point to point under computer control taking the student's hand along with it.) In this way, the student can ascertain how closely a given curve fits their data. Such exploratory data analysis, which has eluded blind students and researchers for so long, therefore becomes a reality.

FEASIBILITY STUDY

In order to understand the effectiveness of the curriculum, Immersion conducted a two-stage evaluation. In the first stage, an educational expert evaluated the curriculum module design. In the second stage of the project, a panel of four experts and students, all of whom were blind, evaluated the curriculum module. Upon completion of the module, they were asked to answer a carefully designed survey. Using the responses to this survey, Immersion hoped to gather information to enable improvements to both the curriculum module and the hardware. The experience with the evaluators exceeded our expectations. Not only did they validate the use of force feedback for accessible education, they had many useful comments on technical issues that will improve our interactions with blind users in the next phase of the project.

All evaluators were quite enthusiastic about the force feedback aspects of the curriculum. Negative comments were largely focused on other important issues such as the installation procedure, curriculum module instructions, and screen reader problems. This evaluator's responses to the following questions illustrate the positive impact of force feedback:

Q. Did feeling the forces of the electric charge affect your understanding of the physical phenomena? If so, how? Why? If not, what would improve it?
A. Yes. I didn't realize that the charge would always be greatest at the boundary of the sphere. Using the control key while moving through the electric field allowed me to explore this.

Q. Did feeling the data points and the fitted plot affect your ability to interpret the experimental data? If so, how? Why? If not, what would improve it?
A. Yes. I particularly liked the "jump to point" mode, because this gave me a good feel for the relationship between the points on the graph.

Q. Overall, did force-feedback affect your ability to learn the material?
A. Yes. Feeling the behavior of a physical system in this way makes it possible for blind people to understand it, much as a quick-time movie of a simulation might help sighted students.

Q. Do you have any additional comments concerning the experience, or suggestions for the use of force feedback in educational applications?
A. Yes. I think force feedback has great potential in educational applications, particularly where it is necessary to explain dynamically changing behavior of systems.

Another evaluator had this general comment:

I can't even begin to enumerate the possible applications, but I can see this technology being valuable across a wide range of disciplines and to students and professionals with a range of learning styles and capacities. Also, I think that there are many applications where the haptic feedback in combination with aural feedback could be potentially very useful. ... The possibilities seem almost endless -- so much so that it may be more efficient to sort out the applications where there would be limited usefulness for this technology.

An adventitiously blind evaluator felt that force feedback would be valuable regardless of students' vision status:

"When I was in high school (and had 20/20 vision) I would have loved to have something like this available that would allow me to explore various phenomena that would otherwise have been impractical to recreate in a laboratory."

In summary, the responses to the evaluation survey lead us to believe that force feedback can provide information to the blind student not available through traditional access technologies.

CHALLENGES AND LESSONS

Creating an Internet-deployed science education curriculum module presented Immersion with new logistical and technological challenges. Unlike a laboratory environment where hardware and software configuration can be tightly controlled, our evaluators were responsible for installing software and hardware on their own systems. Force feedback software and hardware were still in the prototyping stage, adding to the complexity of the installation process. Moreover, evaluators used different screen reading software packages, which in turn interacted with the Windows operating system in subtly different ways. A large amount of effort was unavoidably devoted to ensuring that the force feedback software and hardware was properly installed on the evaluator's systems. The lessons learned from this experience have influenced the subsequent design of Immersions installation tools. In addition, it was not possible to observe closely how much time evaluators spent on the curriculum activities. Based on these experiences, future studies will take place in more controlled settings with on-site technical support.

Web deployment itself presents challenges for distribution of haptic content. Force-feedback is fundamentally high-bandwidth and computationally intensive, however we need to present complex physical phenomena on weak computers over slow Internet connections. Immersion's TouchSense technology overcomes some of these constraints through the application of an embedded controller. This embedded controller can only display a finite set of low-level primitives. For this study, we were able to leverage this architecture to display more complex effects. Over the course of this project, Immersion created new technologies that allow high-level effects, such as electric fields, to be displayed in the constrained, inexpensive realm of Internet-deployed science education.

SUMMARY AND FUTURE WORK

A key result of this project was the proof-of-concept curriculum module that demonstrated accessible, Web-based science education using force feedback. The curriculum module served as both a test bed for accessibility concepts and as a progressive force feedback application that demanded substantial core technology development.

Responses of evaluators to a post-evaluation survey clearly indicate that haptic feedback was a useful tool for realizing the behavior of a dynamical system and a potentially viable modality for presenting non-text content such as data plots for blind computer users. Encouraged by the results of this pilot study, the authors have begun the second phase of this project, which will include the development of a broader range of science curriculum modules and a large-scale user study with blind high school students.

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APPENDIX: Key Accessibility Features of the Curriculum

Many accessibility features were incorporated into the electric field laboratory. The following list describes the most important of these features. This list serves as the beginning of a design guidebook for the authoring of accessible multi-modal, Web-based multimedia. It is important to note that many of these accessibility features are unrelated to force feedback. Although force feedback is an integral aspect of the curriculum module, accessible design requires a holistic, multi-modal approach. Oregon State and Immersion Corporation were extremely sensitive to these issues.

- Two regimes of forces in experimental mode (electric force or objects) allow a blind student to clearly feel the environment of the experiment and the physical processes involved.
- Several regimes of forces in data processing mode (data points feeling, curve feeling, data point touring) give a blind student the capability to study data in a means similar to that of a sighted student using an image of data plot.
- The Web browser window is resized automatically to occupy the biggest possibly area of user the screen. This offers a bigger area for the experimental field or data plot field in the force-feedback mouse workspace. This lets the student feel force details better.
- Instructions are written in a way that allows a blind student with a screen reader to have access to the mathematical formulas used in text (via ALT text).
- User interface forms are designed for clear reading and easy navigation using a screen reader (e.g., one input field with associated caption per line).
- All essential user interface commands are available via keyboard. In particular, data collection is done via the keyboard because it was found to be too hard for a student to click the mouse button while keeping the mouse steady under external forces.
- Different sounds (when mouse pointer crosses experimental field boundaries, charged sphere boundary, or data plot boundary) allow the blind student to know where the mouse pointer is located.
- Confirmation sounds (during data point collection and during data point enumeration) help the student to be sure about a correct program response.
- Collected and processed data are represented in editable text tables, which are accessible and allow simple navigation.