Haptic Perception in Multimodal Virtual Environments - the Haptic Paradigm for Teaching and Learning -

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ABSTRACT
Multimodal Virtual Environments (MVEs) interface between humans and computers using multiple human modalities. A multimodal interface conveys information in a more naturalistic fashion. The user manipulates and experiences the environment through multiple sensory channels. Out of the interfaces for our five senses, the visual and auditory ones have been used most extensively however, interfaces already exist that allow us touch (haptic devices), and technologies for taste and smell may be the next step. Such interfaces give birth to new paradigms for human computer interaction (HCI).

Involving students in the learning process has been a challenge for educators for many years. MVEs may contribute to raising interest and motivation in students, improving their learning and retention. In addition, MVEs provide an alternative method of presenting complex concepts during the educational process.

In this paper we review MVEs and their use in K-16 education, with the emphasis on the potential combinations of audio, visual, and haptic modalities. We provide a brief historical perspective of MVEs and review their evolution in parallel with education. We present the results of an investigation into the potential benefits of incorporating haptic feedback into an MVE intended for college and high school physics curricula. Our HaptEK16 application helps students understand the difficult concepts underlying hydraulics and Pascal's Principle. HaptEK16 has the potential to augment or replace traditional laboratory instruction with an approach offering enhanced motivation, retention and intellectual stimulation.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation (e.g. HCI)]: User Interfaces: Haptic I/O, Interaction styles (e.g., commands, menus, forms, direct manipulation)

General Terms
Experimentation

Keywords
Haptics, Multimodal Virtual Environments, Haptic Technology in Education

1. INTRODUCTION
Multimodal Virtual Environments (MVEs) are computer generated environments that may increase the user's level of perception. MVEs take advantage of different sensory channels (e.g. visual, auditory, and haptic).

Educators are continually challenged to increase the communication bandwidth and help students understand complicated ideas. As some first time concepts are puzzling to students, MVEs are helpful in developing a student's ability to connect theory with reality. The addition of multiple senses can reduce the distance between the concept that a student has formed about a certain phenomena of the physical world, and the reality [7].

Previously, the lack of availability of adequate technology was a roadblock for development of MVEs. Recently the technology has become both available and economically feasible for widespread use. An early implementation of an MVE, the Sensorama Simulator (1957), provided the illusion of a motorcycle ride through New York using a 3-D motion picture with smell, stereo sound, vibrations of the seat, and wind in the hair. The Sensorama is now acknowledged as one of the first MVEs, but years later, most MVEs still fall short of this prototype [4].

A large number of existing MVE applications have focused on vocationally based training in surgery, dentistry, and flight navigation. However, there are particular advantages for the visually impaired and other people with disabilities (e.g. physical, sensory, or learning). Real opportunities exist for learning and the design of educational materials, particularly for science applications where 3D visualization is critical for understanding concepts, such as molecular structure or anatomy [6]. Furthermore, MVEs provide new paradigms for the study of human behavior and performance in the psychology field [13].

The paper is organized as follows: we discuss the use of visual, audio, and haptic modalities in Section 1. Previous work involving haptics technology in educational applications is reviewed in Section 2. In Section 3 we discuss HaptEK16, our haptically augmented application. In Section 4 we focus on the efficiency assessment from the student's learning perspective. Finally, in Section 5, we conclude and provide an insight to future work.

1.1 The Visual and Audio Component

For years there has been an increase in the availability of quality multimedia materials and these have become widely available as teaching resources. Multimedia materials consist of audio and visual delivered via the Internet, VHS, DVD, multimedia presentation tools (such as Microsoft PowerPoint), and text (library). Multimedia has provided the means for accessing large amounts of information with interfaces that are appealing and user friendly, encouraging student involvement. The combination of audio and visual modalities in multimedia technology also made possible the production of memorable, illustrative explanations of concepts, breaking the barriers of verbal communication [2].

The current content and mechanics of delivery lack:

- *Interactivity* – Interactivity is influenced by the amount of control available to the user, as well as the availability of features that encourage users to actively process information [9, 14]. In most current multimedia applications, the student is merely an observer. He is not considered to be an active part of the system and is unable to take control and guide himself through the system. Interaction is usually limited to either mouse clicks or commands for navigational purposes. His engagement is affected, which may lead to a lack of interest and understanding.

- *Communication Bandwidth* – Without the haptic channel, the quality and quantity of information conveyed through the interface may be decreased, resulting in a narrower communications bandwidth - making difficult concepts harder to understand. MVEs provide a medium to learn by doing, through first-person experience. Confucius's ancient Chinese proverb -, "I hear and I forget. I see and I remember. I do and I understand", suggests ways in which we learn. *Doing* tasks to learn abstract principles instead of reading or hearing about them, significantly impacts a student's interest in learning the subject at hand.

- *Three-Dimensional Representations* - Multimedia materials are useful in giving us reference material, or applications that require simple visual representation. Subject areas with complex concepts that have high visualization needs lack appropriate content delivery methods. Most multimedia tools don't take advantage of 3D visualization techniques. Taking advantage of 3D techniques has the potential to widen the communication bandwidth and increase interactivity. For example, depth perception is an important factor in understanding the composition of molecules in biology or theorems in 3D geometry.

- *Assessment* – Current methods of assessment consist primarily of paper based multiple-choice or true-false questions and standardized tests. These methods test facts and skills in isolation, seldom requiring students to apply what they know in real-life situations. Even with the advances in multimedia technology, student assessments using multimedia technology are typically the traditional tests in an electronic format. As instruction of students is changing, so must the assessment of student achievement [3].

As the world changes, students need to understand the basic principles, but also to think critically, analyze, and to make inferences. By incorporating the haptic modality, MVEs can address several of the previously mentioned limitations of current learning materials (e.g. lack of interactivity, communication bandwidth, assessment) and help facilitate the learning process.

1.2 Haptics

The word "haptics" is derived from the Greek *haptikos*, which means "to touch". Haptics is the science of applying tactile sensation to computer applications, enabling users to receive feedback they can feel, in addition to auditory and visual cues.

Several different types of haptic devices are commercially available on the market today. A number of haptic devices, such as the PHANTOM® Omni™ (Figure 1a), can apply small forces through a mechanical linkage (e.g. a stylus in the user's hand) [1]. Devices like haptic gloves (Figure 1b), allow the user to feel the shape and form of virtual objects. Others, like the Screen Rover (Figure 1c), enable visually impaired users to access computers almost as easily as users without visual impairments.

Figure 1a: PHANTOM® Omni™ - *Courtesy of SensAble Technologies*

Figure 1b: CyberGlove® II – Courtesy of Immersion Corporation

Figure 1c: ScreenRover - *Courtesy of Betacom*

Now let's take a look at some of the ways MVE's can address the limitations given in the previous section.

- *Interactivity* - Educators often talk about advantages of hands-on experiences in learning. One aspect of the haptic experience is active manipulation as opposed to passive learning. Active manipulation adds elements of choice, control and conscious movement, making learning tasks more engaging and motivating to students [6]. Haptics aids retention by making concepts more memorable, while increasing interaction by encouraging the use of the environment itself.

- *Communication Bandwidth* - By using MVE interfaces, the communication bandwidth with students is increased as they interpret visual, auditory and haptic displays to gather information while navigating and controlling objects in the virtual environment [11]. Such multisensory stimulation promotes learning and recall. The issue of increasing communication bandwidth is particularly important when applied to students with disabilities, such as visual impairment.

  When eyesight is lost or impaired, the communication bandwidth through vision is narrowed. While the visual channel is narrowed, communication bandwidth through other senses such as tactile may increase dramatically. This shift in perception modalities will affect the communication bandwidth. When this shift occurs, we want to be prepared to present the same information through a different channel, for example haptic instead of visual. We have to adapt learning materials to increase the communication bandwidth of the students with disabilities and present the same materials through alternate channels.

For example, the use of haptics in MVEs can give blind or visually impaired students access to graphical information on a webpage. According to the Phantom haptic interface designer, the device can provide an alternative display to a vision-impaired user [10].

- *Three-Dimensional Representations* - MVEs inherently support 3D modeling. Students with haptic feedback were significantly more likely to express greater interest in investigations of viruses were more likely to make 3D models than students who did not receive haptic feedback [6]. With tactile feedback, students can not only view the 3D models, but touch and feel surface textures, increasing their interest level, motivation, and understanding of basic principles.
- *Assessment* – New methods of assessment are needed to allow students to demonstrate desired performance through real-life situations. Haptics opens up new possibilities. An example of an innovative use of haptics in student assessment using a haptic pad to assess student's handwriting skills.

Recent advances in technology allow the addition of haptic feedback to a wide range of software applications. Although the use of haptics has not made inroads into K-16 education, we feel there is a lot of potential. Up to this point there are few applications or research literature available for the K-16 educational field. Some haptics is used at the graduate level, but primarily as part of robotics courses or as a research topic [8].

2. EXISTING MVEs FOR K-16 EDUCATION

Initial pilot demonstrations with biology students using augmented graphical models and haptic feedback to explore complex molecular structures support the hypothesis that this method provides an intuitive and natural way of understanding underlying working principles and phenomena [12].

The subject area of Physics is a logical fit for the use of haptically augmented activities. A haptic paddle has been developed to teach dynamics systems in an undergraduate Physics course. Students were surveyed concerning their perceived value of the labs and their opinions on the haptic paddle. The qualitative impact was positive. Many students fully understood these concepts for the first time [8].

A group at the University of Patras in Greece is involved with designing MVEs to aid children in comprehending ideas concerning several subject areas of Science, such as Newtonian Laws, Space Phenomena and Mechanics Assembly [7]. The initial tests show that haptics technology improves the level of perception due to the increased level of immersion it provides.

National Aeronautics Space Administration (NASA) has shown interest in the potential use of haptics in educational technology. The Learning Technologies Project at Langley Research Center is concerned with innovative approaches for supporting K-16 education. Pilot study results from the use of haptics-augmented simple machines have yielded positive feedback with 83% of the elementary school and 97% of the college students rating the software from "Somewhat Effective" to "Very effective" [15, 16].

3. HaptEK16

Researchers in physics education have demonstrated that students typically enter and leave high school and college level physics courses with faulty mental models [5]. HaptEK16 (Haptic Environments for K16) is designed to help students understand the difficult concepts underlying Pascal's Principle and its application to hydraulics. Students have trouble understanding the basic theory behind these concepts and then turning that knowledge into problem solving skills.

A multiplication of force can be achieved by the application of fluid pressure according to Pascal's Principle, which states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container. This allows the lifting of a heavy load with a small force. Practical applications of this principle include car lifts, hydraulic jacks, artesian wells, and forklifts.

HaptEK16 will enable students to work with a number of arrangements and sizings of the components involved in the activities in order to gain a deeper understanding of the laws of hydraulics.

3.1 Hardware and Software Components

SensAble's PHANTOM® Omni™ (See Figure 1a) is the haptic device being used with HaptEK16 due to its flexibility. Haptic feedback and user interactivity is achieved through this device.

The HaptEK16 program is being deployed using the Python scripting language, SenseGraphics' H3D API (www.sensegraphics.com) and X3D. X3D is an open standards file format and run-time architecture used to represent 3D scenes. It is the successor to Virtual Reality Modelling Language (VRML). The H3D API is a GPL (open source) software development platform for multi-sensory applications. In addition to using the open standards X3D and OpenGL , the H3D API leverages haptic technology from SensAble. With its haptic extensions to X3D, the H3D API is an excellent tool for writing hapto-visual applications that combine the sense of touch and vision.

3.2 Haptics-Augmented Hydraulics Activities

The technology described in the previous section was used in creating the software for several haptics-augmented high school physics activities involving Pascal's Principle and its applications to hydraulics. These activities and the figures shown are in various stages of development. The background material used for developing these activities was provided by the Science Department at Richmond Hill High School (RHHS) located in Richmond Hill, Georgia. We began this process by interviewing three teachers from 9th and 10th grades. The teachers provided us with information on how the topic had been covered in the curriculum and worked with us closely to develop the User Requirements for the application.

HaptEK16 includes three different activities (Pressure, Hydraulic Machines, and the Hydraulic Car Lift) to reinforce concepts taught in a standard high school or university physics curricula. These activities augment the lessons taught in the students' class. The focus is on what the student should be learning from the activity and not from the technology itself.

The three activities are designed to guide the students from the simple concept of pressure depending on two things: Force and Area, to the more complex system of a hydraulic car lift. The students can work through the activities at their own pace, experimenting with different configurations and parameters for increased interaction and learning. Each activity is augmented in various ways by haptic feedback so the student can feel what he is learning. It is our belief that students seeing and feeling such differences will lead to more effective learning.

HTML tutorials with diagrams will also be available to explain the relevant science and math concepts. This section briefly describes the three activities to demonstrate what our product does.

3.2.1 Activity 1: Pressure

In the case of hydraulics, the concept of pressure and its dependency on force magnitude and area is a crucial topic. Pressure is defined as force per unit area. It is usually more convenient to use pressure rather than force to describe the influences upon fluid behavior. The standard unit for pressure is the Pascal, which is a Newton per square meter.

For an object sitting on a surface, the force pressing on the surface is the weight_of the object, but in different orientations it might have a different area in contact with the surface and therefore exert a different pressure (See Figure 2). Also, a large force might only create a small pressure if it’s spread out over a wide area and a small force can create high pressure if the area is very small.

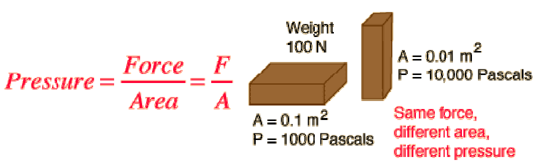

Figure 2: Pressure = Force/Area

In this activity, the student places different weights in different orientations on a bench to demonstrate this concept. Figure 3 shows a scene from this activity.

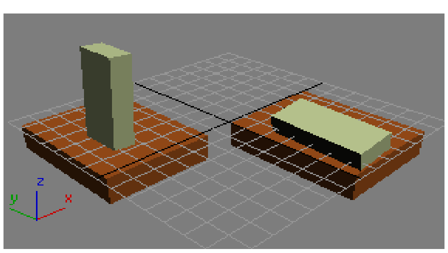

Figure 3. Activity 1 Demonstrates same force, different area, different pressure

3.2.2 Activity 2: Hydraulic Machines

Hydraulic jacks and many other technological advancements work on the basis of Pascal's Principle. The principle states that the pressure in a closed container is the same at all points. As the student sees in the previous activity, pressure is described mathematically by a Force divided by Area.

Therefore, if you have two cylinders connected together, a small one and a large one, and apply a small Force to the small cylinder; this would result in a given pressure. By Pascal's Principle, the pressure would be the same in the larger cylinder, but since the area of the cylinder base is larger, the force produced by the second cylinder is greater. This is represented by rearranging the pressure formula P = F/A, to F = PA. The pressure stays the same in the second cylinder, but Area is increased, resulting in a larger Force. The greater the differences in the areas of the cylinders, the greater the potential force output of the larger cylinder

In this activity the student is presented a small cylinder connected to a larger cylinder as illustrated in Figure 4. Haptically applying different forces on the small cylinder, the student experiences the resulting force on the second cylinder

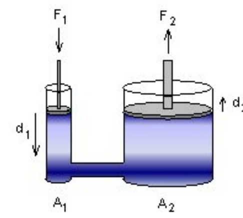

Figure 4. Activity 2 demonstrates the forces that result on the larger cylinder from using different forces on the small cylinder.

3.2.3 Activity 3: Hydraulic car lift

A hydraulic car lift is simply two cylinders connected as described above. Pressure applied to the small cylinder is transferred through the fluid to the large cylinder. Because pressure remains constant throughout the fluid, more force is available to lift a heavy load by increasing the surface area.

The third activity shows how Pascal’s principle is used to raise a car using a hydraulic car lift. Using the haptic device the student tries different car weights as illustrated in Figure 5, experiencing the different pressures exerted on the small cylinder.

The fluid in the small cylinder must be pushed much further than the distance the car is lifted.

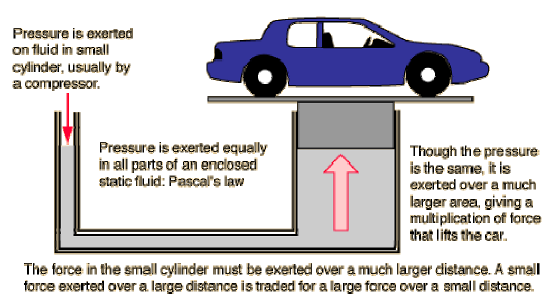

Figure 5. Activity 3 shows different pressures exerted on the small cylinder in a hydraulic car lift move different car weights.

4. ASSESSMENT

A pilot study is underway to collect feedback from students and teachers in order to further develop the project. Students are monitored during the activities and information is collected for learning efficiency evaluation. Before the activities they are asked to make predictions, and then describe what they observe while performing the activity, and finally compare predictions to their observations. These comments and users' reactions are logged.

After completion of the HaptEK16 activities, each participant is asked to fill out an evaluation questionnaire. Please see Appendix A. These questionnaires and the interviews are used to gather students' perceptions about their learning experience.

After all of the students in the pilot study group had the opportunity to evaluate HaptEK16, they are given the same assessment test (similar to that found in Appendix B) as the students in the group not using HaptEK16. Questions for the assessment were designed by the RHHS science teachers.

The student evaluations, comments, and assessments are all designed to examining various aspects of the study – the learning experience, the project process and the learning outcome.

5. CONCLUSION AND FUTURE WORK

In this paper we briefly reviewed MVEs, their use in education and the potential benefits of incorporating haptic feedback into MVEs. We have also summarized the HaptEK16 project, its technology and goals. HaptEK16 is intended to reinforce concepts underlying hydraulics and Pascal's Principle. HaptEK16's haptics-augmented activities allow students to interact and to feel the effects of their different choices. We believe that seeing and feeling these concepts will lead to more effective learning and that this project has significant educational potential.

The software and haptic interfaces will be delivered and installed for the pilot project at RHHS in Richmond Hill, Georgia during the spring 2007 semester. The students will be from the 10th grade Physical Science classes. One class will receive the traditional classroom lecture on Pascal's Principle and the other class will receive the traditional classroom lecture, plus instruction using HaptEK16.

Following the pilot study at RHHS, the student interviews, the results of the students' responses to the evaluation questionnaire and their assessment tests will be analyzed. Additional questions will be addressed such as: Is this approach one that will be welcomed by both students and instructors? What improvements are necessary? How can teachers benefit from our results?

These results will be used to perform any needed improvements to HaptEK16 and the process used in the study. The project will then be expanded beyond this small sample of participants to other participating high schools in the Savannah, Georgia area.

6. ACKNOWLEDGEMENTS

Our thanks to the Science Department at Richmond Hill High School for their assistance.

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APPENDIX A: Evaluation Questionnaire

1. Check one: Student ___ , Grade ___ or Teacher ____

2. From 1 to 5, rate the ease of use of HaptEK16 with 1 being *Very Difficult* and 5 being *Very Easy*.
   1 ___ 2 ___ 3 ___ 4 ___ 5 ___

3. Give any specific suggestions as to how the software can be improved.

4. Please rank the software activities from Best(1) to Least Effective (3).
   Activity 1: Pressure: _____
   Activity 2: Hydraulic Machines _____
   Activity 3: Hydraulic Car Lift _____

5. From 1 to 5, rate how helpful the software was in your learning of the Hydraulics principles, with 1 being Not Effective and 5 being Very Effective.
   1 ___ 2 ___ 3 ___ 4 ___ 5 ___

6. Any additional comments:

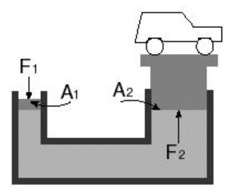
7. Are there any other concepts (can be other subject areas besides Physics) you would like to see programs such as HaptEK16 used for?

APPENDIX B: Sample Student Assessment

1. According to ________, pressure applied to a fluid is transmitted unchanged throughout that fluid.
   a. Bernoulli's principle b. Pascal's principle
   b. Charles' law d. Archimedes' principle

2. Hydraulic machines work by:
   a. Decreasing the amount of friction in a machine
   b. Transferring a small force in a small area through a fluid to create a large force over a large area
   c. Transferring a large force in a large area

   small area
   d. Increasing the amount of work put in to the _machine



A B

Figure 1

3. Use Figure 1 to solve the following problem. A car with a weight of 16,170N is placed on piston B of a hydraulic lift. Piston B has a surface area of 5,005 cm^2, and piston A has an area of 65 cm^2. What force must be applied to piston A to lift the car?