Feel the Pressure: E-learning Systems with Haptic Feedback

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ABSTRACT

Involving students in the learning process has been a challenge for educators for many years. Multimodal virtual environments where visual, auditory and haptic stimulus is present may convey information in a more naturalistic fashion since the user manipulates and experiences the environment through multiple sensory channels.

We present a novel E-learning system that incorporates a multimodal haptic simulator. The haptic simulator facilitates student understanding of difficult concepts (e.g. physics concepts) and has the potential to augment or replace traditional laboratory instruction with an interactive interface offering enhanced motivation, retention and intellectual stimulation.

KEYWORDS: Haptics, E-learning.

Index Terms: H.5.2 [User Interfaces]: Haptic I/O; K.3.1 [Computers and Education]: Computer Uses in Education – Computer-assisted instruction (CAI); I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – Virtual Reality.

1 INTRODUCTION

Multimodal Virtual Environments (MVEs) are computer generated environments that may increase the user's level of perception about the surrounding environment. MVEs take advantage of multiple sensory channels (e.g. visual, auditory, and haptic). Educators are continually challenged to increase the communication bandwidth and help students understand complicated ideas. MVEs are helpful in developing the 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 [1].

Recently the technology has become both available and economically feasible for widespread use. A large number of existing haptic-based applications have focused on vocational 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 development of novel educational materials, particularly for scientific applications where 3D visualization is critical for understanding concepts such as molecular structure or anatomy [2]. In this paper we focus on the development, integration and assessment of a haptic-based E-learning system. We prove empirically that the simulator facilitates student understanding of difficult concepts and offers the advantages of enhanced motivation and intellectual stimulation necessary for learning.

The paper is structured as follows. In Section 2 we provide a brief review of the haptics projects targeted towards educational systems. In Section 3 we elaborate on the problems associated with communication and design a haptic solution as part of an advanced E-learning system. Section 4 describes the experimental setup and challenges encountered during the haptic system deployment. We conclude in Section 5 with the analysis of the experimental results and a brief description of the future work.

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2 HAPTICS IN EDUCATION – A BRIEF REVIEW

Recent advances in haptics technology and the decrease in hardware cost allow the extension of haptic feedback to a wide range of applications. Although the use of haptics has not made a clear path into elementary and higher education, we are among the believers that the potential is enormous.

At the time of this writing there are very few haptic-based prototypes available for education, and none of them have been adopted on a large scale.

In higher education a system has been proposed as part of a robotics course that makes use of a haptic-based joystick [3]. Another prototype, the H3DI program [4], investigates teaching concepts about the solar system through force feedback responses to the planetary gravity fields. Users concentrate on the forces they feel on their fingers and realize different gravity fields of the planets while 3D sound effects help them perceive the volume and the direction of the forces.

Haptic technologies offer a new way of creating and manipulating 3D objects. For instance, in Interactive Molecular Dynamics [5] the users manipulate molecules in a molecular dynamics simulation with real-time force feedback and a 3D graphical display. SCIRun [6] is a problem-solving environment for scientific computing which is used to display flow and vector fields such as fluid flow models for airplane wings.

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 difficult concepts and phenomena [7]. A research group at the University of Patras in Greece is involved in designing simulations to aid children in comprehending ideas concerning several subject areas of Science such as Newtonian Laws, Space Phenomena and Mechanics Assembly [1]. The initial tests show that haptics technology improves the level of perception due to the deeper immersion provided. Fields like mathematics and especially geometry also benefit from haptic interaction. A system was recently proposed allowing a haptic 3D representation of a geometrical problem construction and solution [8]. Initial performance evaluations show that the system is user-friendly and highly efficient compared with the traditional learning approach.

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”[9, 10].

3 E-LEARNING AND HAPTICS – BROADENING THE COMMUNICATION CHANNEL

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 illustrative explanations of concepts, breaking the barriers of verbal communication. A closer look at the current content and mechanics of delivery reveals deficiencies in several areas as follows.

Interactivity – influenced by the amount of control available to the user as well as the availability of features that encourage users to actively process information A student is merely an observer however s/he should be considered to be an active part of the system and be able to take control and guide her/himself through the system. In most E-learning systems interaction is limited to either mouse clicks or commands for navigational purposes. Lack of engagement may lead to a lack of students’ interest and understanding.

Communication Bandwidth – Without the haptic channel, the quality and quantity of information conveyed through an interface is reduced, resulting in a narrower communication bandwidth. Haptics may provide a medium to learn by doing, through first-person experience.

Three-Dimensional Representations – The world around us is 3D. Subject areas with complex concepts that have high visualization needs lack appropriate content delivery methods. 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.

3.1 Hydraulics in High-Schools

An important principle of hydraulics taught in high schools is the Pascal’s law, or Pascal's principle, which states that *for all points at the same absolute height in a connected body of an incompressible fluid at rest, the fluid pressure is the same, even if additional pressure is applied on the fluid at some place.* Moreover, the concept of pressure and its dependency on force magnitude and surface area is a crucial topic.

Students have to understand an array of theoretical concepts without sufficient experimentation. Researchers in physics education have demonstrated that students typically enter and leave high school and college level physics courses with faulty mental models [11]. Students have trouble understanding the basic theory behind these concepts and then turning that knowledge into problem solving skills.

3.2 Hydraulics and Haptics – HaptEK16

We have designed and implemented a module capable of simulating applications of hydraulics. The module is a part of a larger system called HaptEK16 (Haptic Environments for K16). The module is designed to help students understand the difficult concepts underlying Pascal’s principle and its application to hydraulics.

The HaptEK16 module enables students to experiment using the haptic feedback with a number of arrangements and sizing of various physical components. The simulator contains a set of activities. Figure 1 is a screenshot from the Hydraulic Machines activity where a student can apply pressure on the left cylinder and feel the force generated by that pressure. The purpose of this activity is to help students gain a deeper understanding of the laws of hydraulics.

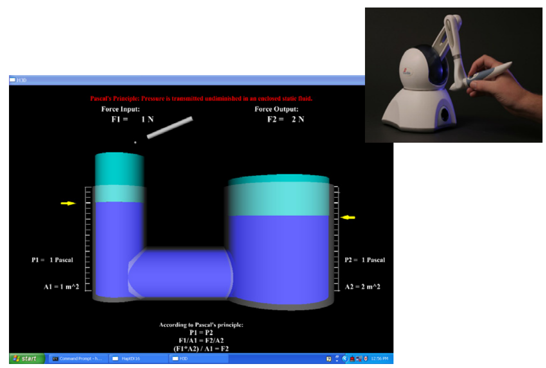

Figure 1: HaptEK16 screenshot and corresponding Phantom® Omni™ device from Sensable Technologies

We have designed and implemented three activities to guide the students through from the simple concept of pressure (depending on two parameters: 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 the haptic system, so the students can feel what they are learning. HTML tutorials with diagrams are also available to explain the relevant science and math concepts.

The following sections describe the activities supported by the HaptEK16 module.

3.2.1 Activity 1: Simulating 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 dynamics (the standard unit for pressure is 1 Pascal, which equals 1 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 the object may have a different area in contact with the surface and therefore exert a different pressure, as illustrated in Figure 2. Also, a large force might only create a small pressure if it is spread out over a wide area while a small force can create high pressure if the area is very small (e.g. a bee when it stings exerts a small force but a high pressure).

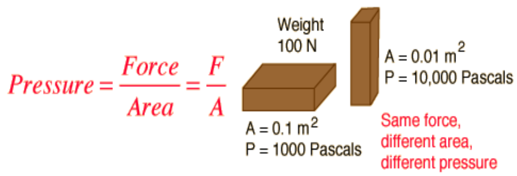

Figure 2: Pressure = Force/Area

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

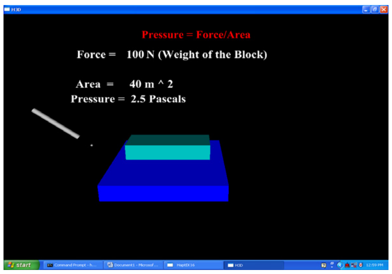

Figure 3: Force, area and pressure relationship

3.2.2 Activity 2: Simulating Hydraulic Machines

Hydraulic jacks and many other technological advancements work on the basis of Pascal's principle. As the student sees in the previous activity, pressure is described mathematically as a force divided by area. Therefore, if we have two cylinders, small and large, connected together 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. The differences in the areas of the cylinders, determine a force output in the large cylinder capable of lifting heavy objects.

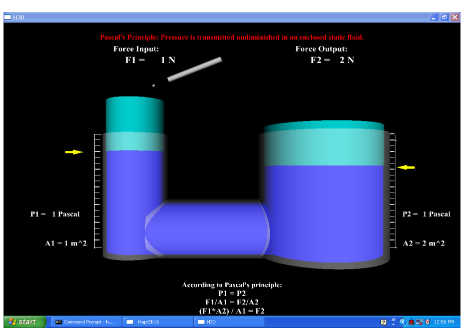

Figure 4: Simulation: cylinders connected through liquid

The activity is presented with a small cylinder connected to a larger cylinder as illustrated in Figure 4. The student may press on the small cylinder (using the haptic device) and feel a reaction to the pressure that is generated.

3.2.3 Activity 3: Simulating Hydraulic Car Lifting

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 lift a car using a hydraulic car jack. Employing the haptic device, the student tries different car weights, as illustrated in Figure 5, experiencing different pressures exerted on the small cylinder. The fluid in the small cylinder must be pushed much deeper than the distance the car is lifted. The force is felt by the user thought the haptic device.

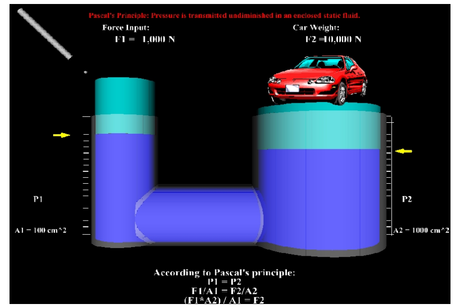

Figure 5: Activity 3 Hydraulic car jack principle.

4 Experimental Setup and Assessment

Haptic feedback and user interactivity is achieved through a Phantom® Omni™ device, illustrated in Figure 6. The Omni™ is our choice due to its force-feedback qualities. It has a compact footprint making it easily portable. It is also backed up by an open source API (Application Programming Interface).

Figure 6: Students using the HaptEK16 hydraulics module

The HaptEK16 hydraulics module is being deployed using the following key technologies: Python scripting language, the X3D (Extensible 3D) standard (web3d.org) and the SenseGraphics' H3D API (www.sensegraphics.com).

We designed and executed a pilot study to collect feedback from students and teachers in order to assess the project's impact on learning. The study was conducted at the Richmond Hill High School (RHHS) in southeast Georgia. The background material used for developing the project was provided by the Science department at the RHHS. We began the assessment process by interviewing three teachers in charge of 9th and 12th grade classes. 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.

The software and haptic interfaces were delivered and installed during the spring semester. The students were selected from the 11th and 12th grade, Earth Science classes. All students involved in the study received the traditional classroom lecture on Pascal's principle and a group of the students received additional instruction using the hydraulics module from HaptEK16. In what follows, the students who *did not* receive the HaptEK16 instruction will be called "Group A" (33 students) and those students who received the HaptEK16 instruction will be called "Group B" (23 students).

Group B students were monitored during the HaptEK16 activities, and information was collected for learning efficiency evaluation. Students were asked to make predictions, then describe what they observe while performing the activity, and finally compare predictions to their observations. All the comments and user reactions were recorded for later analysis. The student evaluations, comments and assessments were all designed to examine various aspects of the study such as ease of use, effectiveness and level of satisfaction

After completion of the HaptEK16 activities, Group B participants were asked to fill out an evaluation questionnaire (see *Appendix I*). These questionnaires and the interviews were used to gather student perceptions about their learning experience.

After the students in Group B had the opportunity to evaluate the HaptEK16 simulator, they were given the same assessment test (see *Appendix II*) as Group A. Questions for the assessment were designed by the RHHS science teachers.

On the first day of the study, all 56 students received the classroom instruction. On the following day, two computer workstations with the Phantom™ haptic devices and the HaptEK16 simulator were installed in the school library. The students in Group B were brought in small groups throughout the day and interacted with the three activities from the HaptEK16 program. Following the use of HaptEK16, these students were interviewed and asked to complete the survey. On the third day of the study, all 56 students took an identical test on their knowledge of Pascal's principle and hydraulics.

5 Results and Analysis

We assumed that both groups of students entered the study with similar knowledge regarding Pascal's principle, although no pretest was administrated since the topic had not been discussed in any previous science courses at the Richmond Hill High School. To objectively assess if learning occurred and to avoid experimenter's bias, the test scores of group B and group A were compared to determine if they were significantly different. Each question (i.e. 1 to 5) is accompanied by the percentage of students from each group that answered that question correctly, as illustrated in Figure 7.

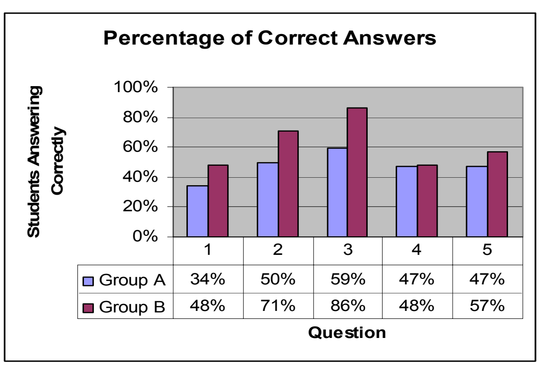

Figure 7: Percentage of Correct Answers

The analysis of the influence of haptic feedback on students' test scores indicates that students who received complementary instruction using the HaptEK16 simulator had a better understanding of the hydraulics concept.

We developed an additional questionnaire to investigate the usability of the HaptEK16 module and its capability to convey a clear explanation of the concepts. In this subjective assessment, students were asked to rank the software activities from "high" to "mid" and "low," as illustrated in Table 1. Activity 1 (Simulating Pressure) was ranked the least effective by 70% of the students, and Activity 3 (Simulating Hydraulic Car Lifting) was ranked the most effective by 50% of the students.

TABLE 1: Summary of Answers to Evaluation Questionnaire

	Effectiveness (subjective evaluation)		
	High	Mid	Low
Activity 1	20%	10%	70%
Activity 2	30%	60%	10%
Activity 3	50%	30%	20%

In an effort to quantify the usability we asked the students in Group B to rate on a scale from 1 to 5 the ease of use of the HaptEK16 simulator. As shown in Figure 8, around 96% of the students rated the haptic technology as easy to use (4) and very easy to use (5) and 78% rated the technology as effective (4) and very effective (5) in helping them to learn the hydraulics concepts. This offers very encouraging feedback as it proves that the haptic technology could be easily accepted by students in the educational environment.

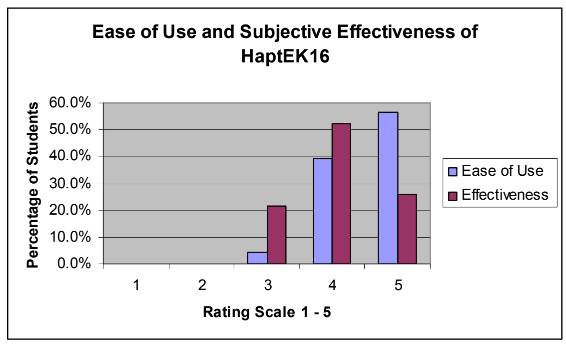

Figure 8: Ease of Use and Subjective Effectiveness

Post interviews and observations indicated that students had many positive comments about the activities.

6 Conclusions and Future Direction

In this paper we briefly reviewed multimodal virtual environments with haptic feedback and their use in education. We have also summarized the HaptEK16 E-learning system, particularly the hydraulics module and its potential use as an addition to existing and future systems.

Involving students in the learning process has been a challenge for educators for many years. According to the statistics on Georgia High School Graduation Tests (GHSGT), 41% of all students in 2004-2005 failed the science portion of the test [12]

The haptic simulator facilitates student understanding of the difficult concepts and has the potential to augment traditional laboratory instruction with an interactive multimodal interface offering enhanced motivation, retention and intellectual stimulation. With the decrease in haptics hardware costs (e.g. Falcon™ Novint) such setups may be deployed on a large scale in school laboratories in the very near future.

The haptics-augmented activities allow students to interact and feel the effects of pressure based on their choices. Through a preliminary assessment we showed that seeing and "feeling" the effect of pressure will lead to a more effective learning. We are encouraged by the positive results, and we are in the process of expanding the assessment with additional studies. We plan to seek a broader implementation of this educational tool at other states via collaboration with various universities and school systems. Moreover, we plan to use the results of this project to explore more potential applications of this system in vocational schools to reeducate the workforce and continually reacquire them with new skills.

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APPENDIX I: EVALUATION QUESTIONNAIRE

1. Check one:
   Student: Freshmen ☐ Sophomore ☐ Jr ☐ Sr ☐
   OR Teacher ☐

2. On a scale from 1 to 5 (1 being very difficult, 5 very easy) rate the ease of use of HaptEK16

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3. Please rank the activities on a scale from (1-High effectiveness to 3- Low effectiveness).

   Activity 1 (Simulating Pressure) ☐

   Activity 2 (Hydraulic Machines) ☐

   Activity 3 (Hydraulic Car Lift) ☐

4. On a scale from 1 to 5 (1 - not effective, 5 - very effective) rate how helpful the software was in your learning of the Hydraulics principles.

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

5. Additional comments.

6. Please suggest improvements.

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 II: SAMPLE STUDENT ASSESSMENT

1. According to Pascal's Principle, the pressure _______ throughout a fluid.

   a. Can change
   b. Remains constant
   c. Increases as depth decreases
   d. Decreases as depth increases

2. How is pressure determined? (P- pressure, F-force, A-area)
   a. P/A
   b. F * A
   c. F/A
   d. P * F

3. In a hydraulic lift, if the force on side A one with an area of $.25m^2$ is 50N, what will happen to the force exerted at side B with an area of $1m^2$?
   a. Stays the same
   b. Increases then decreases
   c. Decreases
   d. Increases

4. The amount of force is _______ in a hydraulic lift.
   a. Multiplied
   b. Added
   c. Subtracted
   d. Divided

5. Which of the following represents Pascal's Principle?
   a. $F_1/A_1 = P_1$
   b. $F_1/A_2 = F_2/A_1$
   c. $F_1/A_1 = F_2/A_2$
   d. $P_1 = F_1/F_2$