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Use of Haptics to Augment Presence in an Experiential HCI Environment

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ABSTRACT

This document proposes a study on the use of haptic devices in an educational setting. Devices that employ "haptics" provide a touch-based/force feedback system of interaction with virtual environments. The proposed study will focus on the use of a haptic device to augment the sense of presence that a student perceives while dissecting a virtual frog in a high school Biology classroom. Experiential learning coupled with the notion of "presence" will provide the theoretical foundation for this endeavor in an attempt to create a bridge from John Dewey's philosophy of experiential education to the current emphasis on interactive interfacing within the realm of Human Computer Interaction (HCI) research.

KEYWORDS
Haptic Feedback, Dissection, high school, Biology, Human Computer Interaction, Presence, Experiential Education

“All genuine education comes through experience.” – John Dewey, 1938
“Technology is becoming an inseparable aspect of experience.” – Thecla Schiphorst, 2007

Introduction

Haptic, from the Greek αφή (*Haphe*), means “pertaining to the sense of touch” (Miriam-Webster’s Online dictionary), and haptic technology refers to technology that interfaces with the user via applied tactile and/or force feedback, i.e. vibrations and/or motions. This mechanical stimulation is used to create a sense of touching a virtual object. Haptic devices are typically classified into Tactile Feedback devices and/or Force Feedback devices (Laycock & Day, 2003). Tactile feedback denotes the devices ability to interact with a user at a sensory level, and often encompasses being able to actually feel a virtual surface. Additionally, force feedback is when the device applies literal forces on the user. Common usage of the term Haptic Feedback encompasses these two ideas, and for the following proposed study, the use of the word haptic(s) will denote haptic feedback. Through their ability to allow interaction with virtual objects, haptics have begun to play a critical role in many fields of study.

Several examples of successful use of haptics have been demonstrated in the areas of the arts, design, entertainment, and medicine (Laycock & Day, 2003); however, the field of education has been as yet untapped. (Please note: success is being defined in these instances as the ability of the haptic device to improve the immersive experience by augmenting the sense of presence for the user.) The main barriers for haptic usage historically have been computing power and the high price of haptic devices, which have limited/prevented the application of haptics in fields that are traditionally economically bounded such as education. However, in recent years the prices of haptic devices have come down to a degree where they are no longer cost prohibitive. For example, Novint Technologies has produced a mass-market haptic device called the *Falcon* that runs approximately 239 US dollars. This is considerably better than the tens of thousands of dollars that the models that preceded the *Falcon* have cost. Thus, it is now a financially viable option within the field of public education. However, would using haptics in a classroom actually increase engagement and comprehension? In short, our proposed study centers around the hypothesis that:

> *A haptic-based model of virtual dissection will be found to have significant results with regards to engagement and comprehension than a non-haptic based model, i.e. virtual or literal.*

In order to test this hypothesis, we propose a study utilizing haptics during a virtual dissection of a frog in a high school biology classroom. The use of virtual frogs for dissection is becoming more commonplace in classrooms (www.usnews.com, 2007; www.thisislondon.co.uk, 2007); however, currently these programs do not have a tactile dimension to them. The only forms of interaction that are currently utilized are graphically based. This study seeks to add to the literature on educational technology with the goal of finding new ways to utilize cutting edge technology to increase engagement and comprehension within the classroom environment.

Rationale

There are a number of reasons why school systems choose virtual dissection over traditional modes of dissection, and adding a haptic interface has the possibility of strengthening the argument for virtual dissection even further. The reasons are:

It is inexpensive. The cost of haptic devices is now within the $200 to $300 range. Furthermore, virtual dissection software has already significantly lowered the costs associated with acquiring, storing, handling and disposing of animals for dissection. The cost of virtual dissection not only gets cheaper as it is used by a greater number of students, it also represents a one-time cost for schools rather than a line on each year’s annual science budget. It is also a solution that requires very little of school systems in the way of storage space and upkeep.

It allows for a flexible educational environment. In a virtual environment, students cannot only experience the dissection process once; they can repeat the process again and again, learning the results of dissections done in several different ways. This iterative process allows for greater retention and allows for students to learn from their mistakes. Additionally, virtual models allow students to easily compare the differences between healthy or diseased, pregnant and non-pregnant, and/or developing or fully-grown specimens.

It is morally sound. Debates have raged in the media for the last several years on the use of real animal dissection and whether it is humane (e.g. www.eschoolnews.com, 2000; www.newyorktimes.com, 2006). In an age where increasing numbers of parents and students are opposed to killing animals unnecessarily, virtual dissection offers the educational experience of dissection without moral qualms.

It is engaging. There is a growing body of evidence (Mount & Cavet, 1995; Fällman et al., 1999) that suggests that involving multiple senses in the educational process can improve learning outcomes. Virtual worlds coupled with haptics have the possibility to tap into these senses, combining to create powerful emotional and intellectual effects on students.

It is easy to implement. Because the cost and size of the haptic are modest, and because such devices do not require additional training for the staff, the “adoption cost” of a switch to haptic enabled virtual dissection would be minimal, allowing for easy implementation in an environment that may be hesitant to change.

It is sanitary. The spread of germs and other contagions is a critical issue within school systems. The introduction of dead animals, no matter how well preserved, could at the very minimum create distress over germs being introduced into the classroom. Though proper measures should be followed when cleaning up the environment and oneself, there is no guarantee that it will be perfectly sanitary. With haptics the usefulness of touch can once again be realized, but within a more sanitary environment.

It is relevant. With each successive generation, students are becoming more acclimated to the digital landscape. These “digital natives” have spent most of their lives utilizing technology not only to play, but also to learn (Prensky, 2006, p. 9).

Alternate Perspectives

Despite the advantages listed above, the haptic model of virtual dissection would not appeal to everyone, and certainly a strong argument can be made for the direct involvement of students with the physical world in the way that traditional dissection affords (www.nytimes.com, 2006). For example, a sensible argument could be made for the value of future doctors having experience with real specimens before they enter their profession. However, unlike the medical field, the field of education, especially at the k-12 level has many unique issues to deal with including financial considerations and overall parental and student concerns.

Theoretical Framework

Jacob et al. (1993) notes that in the field of human computer interaction (HCI) research, underlying theory has not been well established. Since this time there have been advancements on this front (e.g. Antle, 2007), though many aspects of our technology often appear to still suffer from the “hey its cool” approach to design and development, e.g. the persistent changing of cell phone interfaces, many of which serve no innovative purpose. The field of education may be able to rectify this issue by providing a theoretical underpinning to connect the technology to a non-consumer driven conceptual purpose. Experiential Learning Theory first expressed by John Dewey in the early 1900s may interestingly enough provide this foundation for the 21st century development of Experiential Human Computer Interaction Theory (EHCI).

Dewey (1997[1938]) sites the principle of interaction as fundamental to experiential education. Experiential education is “a process through which a learner constructs knowledge, skill and values from direct experience” (Association for Experiential Education, 1991, p.1, qtd. in Ives, B., & Obenchain, K., 2006). A potential framework for the use of haptic devices in a classroom setting can be found in Bialeschki’s (2007) work. The original framework, which is focused on *research* in experiential education, encompasses the concepts: Relevance, Relationships, and Real (authentic), which are transferable to the *practice* of experiential education and HCI research. The conjunction of these three tenets with the conception of ‘presence”, i.e. a “state of consciousness” or a “sense of being in the virtual world” (Slater & Wilbur, 1997, as cited in Van Schaik et al., 2004, p. 541), in virtual reality research creates a theoretical framework that supports the implementation of haptics in a classroom. This is increasingly relevant in a time when teachers run the risk of alienating their students via traditional means of education that do not utilize technology to tap into the students lived world beyond the school.

Prior to discussing the framework further, it must be noted that though our study will not be immersive in the sense that the subject will be fully enveloped by the VE, the notion of presence is still very applicable to our theory. Hecht and Reiner (2007) contend that the possibility exist that one can also be “present” in a non-immersive VE as well, especially when a haptic device is utilized. Dewey (1997[1938]) argued that the environment in which a student interacts can either be real or imaginary, the true educative experience comes from the ability of this environment to interact with the student's "needs, desires, purposes, and capacities to create the experience which is had" (p. 44).

Relevance

Bialeschki (2007) points to the rapid growth of technology as an aspect that must be considered under the arch of relevancy. Students enter school in the 21st century with many years of prior knowledge of computers and a predisposition to the engagement this technology offers. Data from 2003 indicate that 43 percent of three- and four-year old students used computers at school, 80 percent of five- to nine-year-olds, and 90 percent of 10- to 14-year-olds (U.S. Department of Education's National Center for Education Statistics NCES, 2006). Furthermore 72 percent of 10- to 14-year-olds also uses computers at home. This data indicated a sharp increase from 1997. Moreover, according to Walsh, D. et al. in 2005 87% of 8- to 17-year old children played video games at home. One conclusion to be drawn is that computers and other interactive technology are relevant to students at every age and must be incorporated into the curriculum more fully.

Relationships

Relationships are also important in establishing a true experiential learning environment (Bialeschki, 2007; Dewey, 1997[1938]). Though the word relationship is often connected with human-to-human social interaction, research has shown that interaction with technology has many social dimensions as well (Brown, 2006). In order to produce a sense of presence in a virtual environment (VE) the cultivation of a *relationship* with the VE is critical (Hecht & Reiner, 2007). In 1938, Dewey advocated the need for interactions with both humans and objects to improve the quality of education, now we are able to produce these interactions on a virtual level. VE researchers claim that this sense of presence is critical in facilitating the perception of interaction in a virtual world. Furthermore, Antle (2007) argues, “meaning is created in the interaction” (p. 195), and the ability to interact with a physical object has been found to be critical in childhood cognitive development. Healy (1998) supports this claim arguing that tangible, physically based forms of child computer interaction, i.e. the ability to touch, feel, and manipulate, enable children to build sensory awareness of relationships in the world. An important aspect of making these HCIs “real” Jacob et al. (1993) notes, “is linking the three-dimensional input to the three-dimensional output in a faithful and convincing way” (p. 73). An experiential computer environment will establish a relationship with users where they may gain multiple perspectives via direct sensory stimulus that will aid in a deeper insight into the information they may be exploring (Jain, 2003). This is the key, moving information querying to information exploring, and adding a tactile based dimension to this is critical in the sense that it will allow for users to experience the information in a more “natural” way (Jain, 2003, p. 50).

Real (authentic)

According to Schiphorst (2007), there is a real value in designing experiential technology. Furthermore, he contends that there is not just a value in designing technology for experience, but “as experience” (p. 7). This need for the experience to be real or authentic is also critical to experiential learning (Bialeschki, 2007; Dewey, 1997[1938]); however, this need to be real has been a difficult hurdle in VE research (Brown, 2006). Utilizing haptics could improve the immersive experience of the user by adding the ability to not just perceive objects, i.e. visually and/or auditorially as in current VE, but through tactile perception as well enabling the user to virtually feel what he or she may be touching or experiencing in the VE (Laycock & Day, 2003). This has been found to augment the feeling of “presence” in VE (Van Schaik, et al., 2004).

For example, basic haptic technology has been an influence on a generation of gamers.

For decades, the sense of reality was mostly generated by graphics and sound, but with the advent of the rumble pack and most recently the Nintendo Wii, the sense of touch was added to the paradigm. The success of such features in the entertainment/gaming industry indicates a strong need for the experience to appear as real as possible (Laycock, & Day, 2003). It is critical that schools learn to take advantage of this technology, because students are already engaged with it beyond the classroom walls and thus prior-knowledge/familiarity has already been established (Walsh, D. et al., 2005, Prensky, 2006, & U.S. Department of Education's National Center for Education Statistics NCES, 2006). The use of haptics with educational based computer programs can potentially close the gap that currently exists between the experiences students have outside of school and the ones they have within with regards to technology. Research has demonstrated that students are academically more engaged and often more academically successful when school experiences are more applicable to their "real world" beyond the classroom (e.g. Dewey, 1997[1938]; Brown, 2006; Ives & Obenchain, 2006). Furthermore, Brown (2006) notes that the utilization of technology, especially technology implementation based on a "demand-pull" approach to learning, i.e. learning through participation and interaction, is "Dewey for the digital age" (p. 23).

Bringing it all together

Jacob et al. (1993) argue that one of the main issues in HCI is "effectively communicating requests and results between the system and the user" (p. 69). They site improvement of the user interface as aiding in overcoming this current issue, as opposed to the system internal processes, that can complement and even augment "communication-relevant characteristics of humans" (p. 69). We make the claim that haptics can do just this by directly interfacing with the user at a tactile level, which is one way that has been found to affect a person’s learning (Gardner, 1983). This claim is further bolstered by findings that suggest that direct manipulation interfaces have been found to be successful due to the way they draw on “analogies to existing human skills” as opposed to the typical method of relying on trained behaviors (Jacob et al., 1993, p. 70). Additionally, kinesthetic feedback has been found to remarkably add to perception of three-dimensional displays. Schubert et al. (2001) posit that VEs need to be as close to reality as possible for presence to occur, and we propose that haptic utilization has the potential to increase this sense of reality by enabling the user to virtually “feel” their environment thus increasing the sense of presence perceived in a VE. The act of presence is not an unconscious act, but a conscious one (Van Schaik et al., 2004), thus it is strengthened by the sense of touch that a haptic device can allow. Ultimately presence is based on experience.

Literature Review

The study of haptics saw a significant boost in research during the 1980s when the concept of robotics was being developed. As the research in robotics advanced, it was felt that there was a need for manipulation of objects by touch. Further research bifurcated in two directions: one in development of ‘robotic hands’ and the other in the direction of developing and creating devices that enabled the users to be able to get the feeling of touch while manipulating objects. Development in these areas led to the birth of another sub-specialization of computer science called ‘computer haptics' (Salisbury, et al., 2004).

Srinivasan and Basdogan (1997) describe computer haptics as a science that enables the display of simulated objects to humans in an interactive manner. Computer haptics uses a display technology through which objects can be touched and palpated. One of the major advantages in a user-haptic interaction is that the flow of information and energy is a two way process between the user and the device. Incorporating the haptic component into virtual environments (VE) facilitates the tactile sensation and imparts a more realistic, life-like experience to the user. The 'haptic' component not only imparts a sense of touch in VE, but it also enhances the user experience by offering a more realistic, life-like interaction with the system. Technological advancements in haptic devices have enabled the end user to feel a range of surface textures from fine to coarse in VE (Srinivasan & Basdogan, 1997).

Salisbury (1999) and Srinivasan and Basdogan (1997) stated that in the early 1990s, there was noteworthy progress in the potential to simulate haptic interactions with 3D virtual objects in real-time. The explosion of computers, digital and multimedia technology has given birth to several new areas like the virtual worlds of Second Life, or the open source format Croquet, whose growth has spurred the desire for researchers to apply haptic technology to these environments. Due to haptic devices becoming more cost effective, several exciting possibilities have opened up for the inclusion of haptics in VE. Technological advancements in haptics have unfolded its applications in a myriad of disciplines ranging from medicine to the military to video games (Stone, 1992; Srinivasan & Basdogan, 1997).

Pertinent to our study, medical literature reveals that haptic devices have been widely applied in surgery for developing surgical simulators to train surgeons in performing surgeries in virtual environments (Stone, 1992; Colwell, et al, 1998; Dawson, et al., 2000; Satava, 2001; Laycock & Day, 2003). Further examples of utilization of haptics in the medical field include:

- Chial, et al. (2002) created haptic virtual environments where force feedback was used to design scissors that could simulate the cutting of rat tissues. Initial results of this experiment had been encouraging and the users found cutting of natural and virtual tissues similar. Also, Greenish, et al. (2002) demonstrated that subjects could identify tissues with similar precision when performing a real or simulated cutting task on various parts of the animals. Further work needs to be done in this area but the initial results have been encouraging.

- Lieu, et al. (2003) discuss how haptic surgical simulators can be used successfully in medical courses, and the advantages of these systems in medical education. Among the many advantages they have enumerated are that these systems are very flexible to use and provide a uniform learning experience. They also state that despite initial costs, in the long run these systems can be very cost effective for educational institutions.

Most recently, the discipline of education has begun to use haptics as well; however, the applications are currently confined to the arena of higher education. For example, haptics have been widely used in undergraduate engineering curriculum and in undergraduate medicine.

Nevertheless, despite the use of haptics and their potential advantage in the aforementioned fields, not much work (if any) has been done in the area of biology at the k-12 level. However, as virtual dissection becomes more prevalent amongst k-12 biology programs, haptics may be seen as an advantage within these classrooms.

Potential Uses of Haptic Devices in K12 Education

Computer simulation has added a whole new dimension to science education. Today we are observing an increased departure from the traditional method of teaching to an adoption of computer assisted teaching methods. More specifically, recent research also shows that computer simulation is changing the traditional science classroom atmosphere (Akpan, 2002). Akpan and Andre (1999) note that, “simulation is the use of the computer to imitate dynamic systems of objects in a real or imagined world. Akpan (2002) posits that the key to a student’s success in science is to develop an intuitive understanding of the physical systems involved. In the traditional approach, the students frequently learn concepts in a linear fashion and often do not understand the mechanisms involved in the process or where theory merges with the practical application. Furthermore with regards to an application such as animal dissection, Akpan and Andre (1999) have observed that students showed an improved performance in learning frog anatomy when trained on a simulated version of frog dissection. Williams, et al. (2003) further emphasizes that computer based learning should aim at providing a better understanding of learning concepts and stimulate interest in the students. The incorporation of haptic devices in computer simulation environments could provide an excellent method for stimulating both engagement and comprehension in k-12 students that are not audio-visual learners (Grow, et al, 2006). Okamura, et al. (2002) have reported that research in psychology demonstrates that learning styles vary from student to student, and that students have diverse learning needs depending on their cognitive styles and abilities. Okamura, et al. also discuss that an interactive audio-visual environment, i.e. the traditional method of schooling, can prove to be inefficient and sometimes ineffective for those who learn best by using touch. By addressing this sense of touch, haptic interfaces provide a potential tool for helping students with cognitive development.

Augmenting Computer Simulated Dissections via Haptics

Kinzie, et al. (1993) compared organic dissection with an interactive computer based simulation program. The study revealed that the students preferred virtual dissections to the real dissections and they reported it to be a better learning experience. Additionally, in a pioneering study Robertson, et al. (1995) designed a web based dissection kit and a tutorial that enabled the students to conduct a virtual dissection on the web. A common gateway interface was used to develop this program. Cross and Cross (2001) conducted a study on four biology classes in which comparisons of real versus virtual frog dissections were made. Their results reflected that the students using a computer program did not score as well in the practical examinations as the students who had practiced on the organic frogs. The authors, however, concluded that it might be the result of the computer technology not being completely evolved enough to adequately replace the organic frog dissections. They also predicted that with technological advancement, better virtual dissections would be created that would enhance the students experiences. In 2003, Maloney conducted a study similar to Cross and Cross's 2001 study in which the viability of a virtual fetal pig dissection versus an actual dissection for female students enrolled in high school biology classes was tested. It was found that student scores on the virtual dissection group were significantly higher than the organic dissection group. The author also suggested that a virtual laboratory experience was a suitable replacement to an actual dissection. It may be reasonable to conclude, given the rate of technological advancement in both software and hardware, that the technology of virtual dissection had evolved in the two years between the Cross-and Cross and Maloney studies to demonstrate a change in the findings. It is important to note that all the systems described above lacked the incorporation of haptic force feedback.

Technology has advanced sufficiently so that currently it is now not only technologically feasible, but also economically feasible to enhance virtual dissection with a haptics mechanism, which could prove valuable in many ways. Studies in the medical literature suggest that haptically enabled force feedback provides the students with a life like experience while dissecting in VE (Fager & Von Wowern, 2004; Hart & Karthigasu, 2007). The literature also suggests that students have a better experience with dissection in a virtual environment (Maloney, 2003). Virtual dissection enables students to work with a clearly labeled model and provides flexibility to undo instances where they have gone astray. Also after dissection, many animal bodies are too mutilated and are difficult to learn from. Furthermore, real dissection has sparked much debate about cruelty to animals, plus it is expensive. A virtual dissection enhanced with a haptic device is much more cost effective. The conclusion that can be drawn from the literature ultimately suggests that haptics may be an advantage over both traditional and non-haptic based virtual dissection methods for biology students in the k-12 environment.

Methodology

The proposed study will utilize a case study methodology involving three groups of high school biology students at a single high school: students in the *first* group would perform the dissection of a real frog and follow the standard procedures for that school's biology curricula; students in the *second* group would receive the same lectures and readings as the first, but instead of doing a dissection of a real frog, they would perform a virtual dissection on a virtual frog object using a haptic device; the *third* group would be like the second, but students in this group would perform a virtual dissection without a haptic device. In the end the grades of students from each group would be compared, and all of the students would complete a survey on their experiences.

Participants

In order to devise a study that controls for the largest number of variables, we have chosen to limit the target population to the students following a single high school's biology curriculum. Because the target population will be relatively small, the implications of the study will necessarily be limited. However, we hope that the study will be relevant to a wide array of other educational contexts, including ones that are distant from our sample group both geographically and culturally. In order to maximize the applicability of the study, we have decided to focus only on a high school that displays a relatively diverse population in terms of gender, ethnicity and family financial status.

Groups will be chosen via stratified random sampling from the appropriate student population, with the first group performing the traditional dissection, the second performing haptically-enabled virtual dissection and the third virtual dissection without a haptic device. Each group will receive the same in-class preparation, including lectures, presentations and readings, and will be tested on the same material at the end of the process. Every attempt will be made to ensure standardization of the educational process with the sole exception of the mode of dissection.

Measurements

This study will employ a mixed methods approach consisting of both quantitative and qualitative measures to compare the student groups. The aim is to produce a study that considers both objective and subjective factors surrounding the students' educational experience, providing a model receptive to student perceptions and expectations, i.e. engagement, as well as student outcomes in the form of grades.

Quantitative measurements will take two forms. First, the grades of students on a post-dissection examination will be considered, comparing the results for members of all three groups. Second, all students will complete two surveys related to the dissection: one survey completed before the dissection unit, and one survey completed after it. The surveys will ask a standardized series of questions about their experiences, with questions measured by a Likert scale, with answers to the questions ranging from "strongly disagree" to "strongly agree" along a seven point scale. Some questions will be reverse scaled to ensure reliability in the measurement of the responses. The results of the answers from each group will then be compared with each other, as will the differences between the entry and exit surveys.

In addition to the quantitative measurements listed above, the surveys will also contain open-ended sections where students will be encouraged to speak freely about their experiences with the dissection, both positive and negative. Questions in this section will gauge both the student's own assessment of the dissection's educational results and a personal description of their subjective experiences and emotional states. Finally, in-person interviews with relevant faculty members and administrators will be performed in order to get a different perspective on the study and its results. By combining all of this data with the quantitative section, this study seeks to give a fuller picture of the educational value of haptic devices from a practical perspective. Faculty perspectives on the benefits and problems related to each dissection method will also be gathered using unstructured interviews.

Perspective Work

The final section of this study will involve the presentation of the data, focusing on educational outcomes in the form of exam grades for both groups, as well as student and faculty perceptions of virtual dissection with haptics compared to both the more traditional real method and the non-haptic virtual method. This section will focus on processing the data from each of the three groups, first comparing how the two virtual dissection models compare to the non-virtual model, and then comparing the influence of haptic devices on learning outcomes by comparing the two virtual groups. By triangulating the data in this way, we hope to gain a rich understanding of the impact of the haptic approach compared to other possibilities. This section will also outline some of the practical problems and benefits of implementing each method of dissection, and give recommendations for schools considering such options. Finally, the study will provide an outline of the principal findings and suggest areas for further inquiry. For instance, how does the choice of a specific haptic technology (such as the Novint Falcon as opposed to another device) affect learning outcomes?

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