FEATURE ARTICLE

Integration of Advanced Technologies to Enhance Problem-Based Learning Over Distance: Project TOUCH

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Distance education delivery has increased dramatically in recent years as a result of the rapid advancement of communication technology. The National Computational Science Alliance's Access Grid represents a significant advancement in communication technology with potential for distance medical education. The purpose of this study is to provide an overview of the TOUCH project (Telehealth Outreach for Unified Community Health; http://hsc.unm.edu/touch) with special emphasis on the process of problem-based learning case development for distribution over the Access Grid. The objective of the TOUCH project is to use emerging Internet-based technology to overcome geographic barriers for delivery of tutorial sessions to medical students pursuing rotations at remote sites. The TOUCH project also is aimed at developing a patient simulation engine and an immersive virtual reality environment to achieve a realistic health care scenario enhancing the learning experience. A traumatic head injury case is developed and distributed over the Access Grid as a demonstration of the TOUCH system. Project TOUCH serves as an example of a computer-based learning system for developing and implementing problem-based learning cases within the medical curriculum, but this system should be easily applied to other educational environments and disciplines involving functional and clinical anatomy. Future phases will explore PC versions of the TOUCH cases for increased distribution. *Anat Rec (Part B: New Anat) 270B:16–22, 2003.* © 2003 Wiley-Liss, Inc.

KEY WORDS: medical education; anatomy; patient simulation; problem-based learning; PBL; Access Grid; traumatic head injury; TOUCH

INTRODUCTION

Medical knowledge and skills essential for optimal health care delivery are dynamically changing. With the rapid advancement of knowledge in basic medical sciences and the resultant impact on clinical therapy development, the volume of information and complexity of corresponding theoretical constructs have placed tremendous pressure on medical professionals to achieve more in less time. Medical professionals must devote more time in their education, re-education, and training to keep pace with these advances and to continue to hone their skills. Simultaneously, they must maintain patient contact and care while applying the latest knowledge to achieve optimal corrective therapy. In an attempt to effectively shorten the interval between the period of education and the application of high quality health care, dramatic advances have occurred in information technology, particularly innovations in high-performance computing and communication, visualization, and virtual reality environments. The benefits from these efforts include lower costs for education and training, increased effectiveness of the health system to provide well-trained and qualified professionals, and the delivery of health care education

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and training to rural areas that would otherwise not receive it.

Project TOUCH, an acronym for Telehealth Outreach for Unified Community Health (http://hsc.unm.edu/touch), represents a multiyear collaboration between the Schools of Medicine at the University of Hawai'i and the University of New Mexico. A multidisciplinary, interinstitutional group from these two institutions has formed to address common concerns in medical education. The project was conceived in response to two major challenges in healthcare education faced in Hawai'i and New Mexico. Both states are presented with large distances between their university health centers. A critical issue arises in the third year of the curriculum when students pursue rotations in remote locations, but only one medical school exists in each state (Figure 1). Thus, students become separated by large distances but must retain contact with the respective problem-based learning (PBL) tutorial groups. A second common issue concerns the commonalities in the curricula. Both schools converted to PBL systems many years ago (Kaufman et al., 1989; Anderson, 1991). With new developments in technologies, it now should be possible to establish computer-based PBL cases, thus providing students with a more realistic experience, particularly if a virtual patient could be developed incorporating learning issues relevant to the case.

The purpose of this study is to describe how Project TOUCH is addressing these common issues. The intention of the TOUCH system is to provide a learning environment for students to understand the relevance of important basic science concepts within a realistic, interactive environment and in a time-effective manner. In particular, the immersive environment provides an outstanding opportunity to involve the student in the study of basic medical science concepts that relate to a variety of clinical problems. Anatomy, as a primary basic medical science, is particularly amenable to this delivery system due to its visual relevancy. The TOUCH system exploits this fact in its demonstration case that involves functional neurology and neuroanatomical learning issues.

PARTNERSHIPS

University of Hawai'i and University of New Mexico have much in common. Both serve to educate a multicultural population, including native peoples. Cultures in the states include robust non-Western belief systems and attitudes toward health care. Both states have large areas of medically underserved populations, which face geographic barriers to access: ocean in the case of Hawai'i, and desert in the case of New Mexico. The two states have similar curricula in their medical schools, i.e., they both use PBL as their primary curricular delivery tool. Both universities are committed to training students in rural settings, with continuing efforts to attract and retain providers in these locations. There are several programs under way in both states to train local ethnic minorities in health care professions. These similarities have facilitated the establishment of common objectives for the dissemination of medical education and training of medical personnel.

The TOUCH project was conceived in response to two major challenges in healthcare education faced in Hawai'i and New Mexico.

Many partnerships have been formed during this collaboration. All organizations have made significant contributions to the project as a whole, bringing together a multidisciplinary, interinstitutional group, including educators, basic scientists, practicing clinicians, computer scientists, evaluation experts, librarians, and a medical illustrator. However, each one has particularly unique strengths. The University of New Mexico School of Medicine brings organizational structure and computer expertise to the project. The University of Hawai'i School of Medicine contributes curricular expertise and content development. Maui Community College and Northern Navajo Medical Center are two rural sites used to test the distance-learning pieces of the project. The High Performance Computing Centers in Albuquerque and Maui provide the necessary information technology personnel and systems to facilitate communication among PBL participants and between sites by means of the National Computational Science Alliance's Access Grid (http://archive.ncsa.uiuc.edu/alliance/access-dc/). Through these common goals and partnerships, TOUCH began as a feasibility study, but now it is evolving into a proof of concept study, with plans for broad implementation.

TOUCH DEMONSTRATION CASE: TRAUMATIC HEAD INJURY

As an initial demonstration of the TOUCH system, a PBL case was developed and implemented with the objective of: (1) establishing interactive, instantaneous, and effective information technology communication to remote sites using the Access Grid; (2) developing an interactive patient simulation engine and virtual reality environment that could be manipulated by students at multiple sites; and (3) developing and deploying a PBL case across the system to sites in both states to assess student learning within this environment. Thus, the long-term goal aims to provide distance education while enhancing the quality of participation, eventually to create a PBL development and implementation package for broad application in health care training.

In the current setting, PBL focuses on small group interaction and experiential, case-based learning. The clinical problem is the vehicle for learning. It is peer-taught, and tutor-mediated. A specific case scenario is developed to serve as a demonstration of the technology and to assess learning using this system. The case involves traumatic head injury with resulting neurological effects stemming from an epidural hematoma. The objective of the case is to provide the tutorial group with an appropriate clinical experience for exploration of underlying basic medical science mechanisms.

This project uses emerging Access Grid (AG) technology, developed by

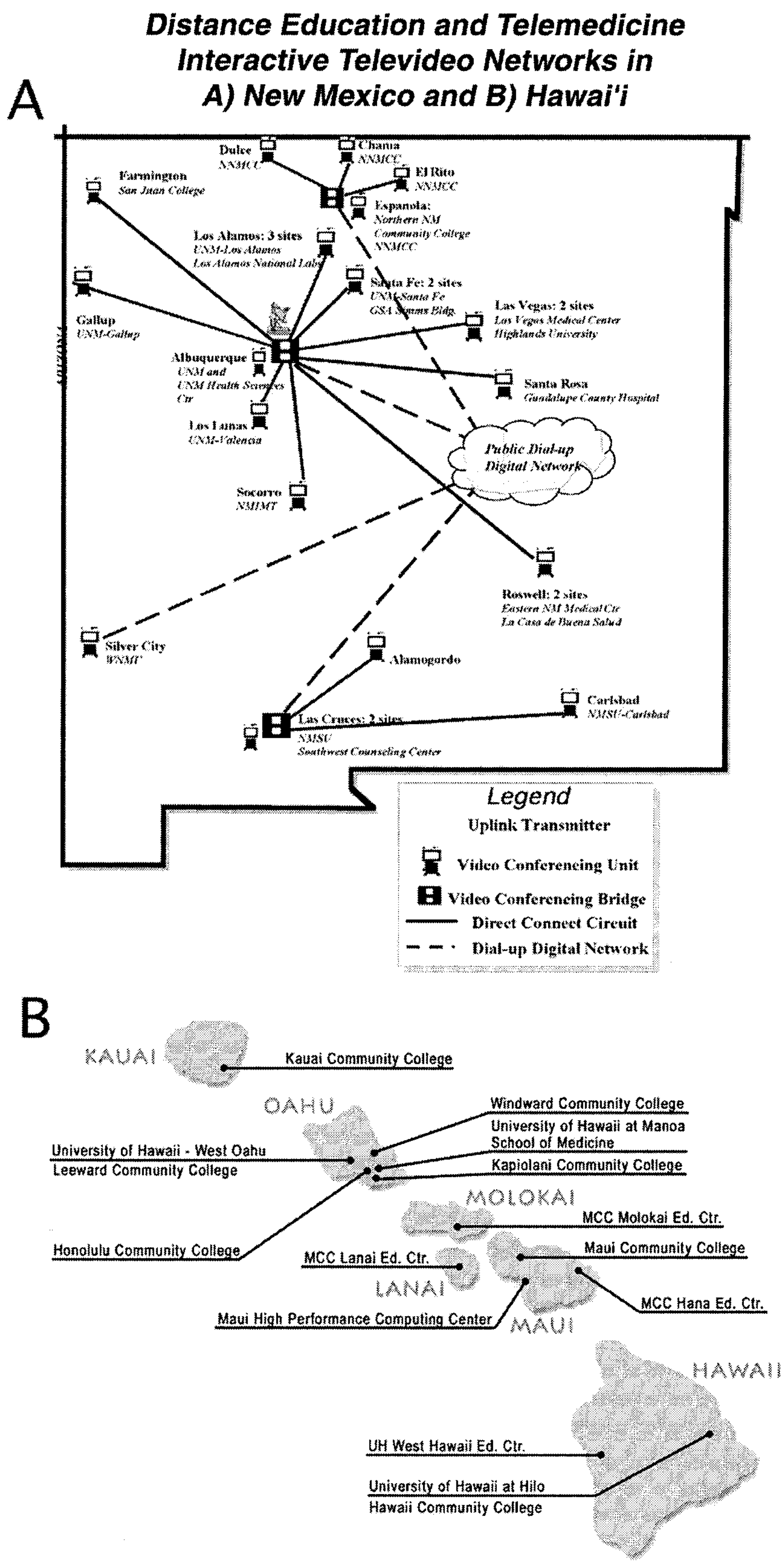

Figure 1. Both Hawai'i and New Mexico share large distances between their main health centers in Honolulu and Albuquerque, respectively, and remote sites where students undertake clinical rotations. As a result, a mechanism must be developed to enable communication and facilitate problem-based learning interaction.

the National Computational Science Alliance (NCSA) as the advanced system for group-to-group interaction by using Internet2. It uses TCP/IP-based video conferencing using broadband multicasting for simultaneous interactions with multiple applications at multiple sites. It is designed particularly to facilitate multimedia, multipoint, real-time participatory group interaction and support a variety of applications (Caudell et al., 2003). Grid/Studio components include multimedia displays, and interactive environments with interfaces to visualization environments (Figure 2).

To enhance the interactive experience, a patient simulator was developed. The addition of an interactive patient simulation engine brings a new dimension to PBL, in which the students can dynamically determine the direction of the case scenario. The simulator has three components: (1) a real-time artificial intelligence (AI) simulation engine, (2) a three-dimensional (3D) virtual reality (VR) environment, and (3) a system for human-patient interaction. The AI system reasons with case-specific clinical knowledge in the form of rules, extracted from a team medical experts using knowledge engineering methods. The AI engine is coupled to the virtual environment that contains a representation of the virtual patient manifesting the signs and symptoms consistent with an actual clinical case. This scenario provides a unique environment for experiential learning. The rate of the simulation is controllable by the users, allowing the session to be stopped, slowed down, or sped-up according to the learning needs of the students. The students may interact with the virtual patient during the case through a set of intuitive interaction metaphors, including hand-held tools. Thus, it is hypothesized that realism will be heightened by the 3D immersive virtual reality technology.

The VR immersive environment in which the students work is called Flatland, which facilitates participant interaction with various data sets and computer-generated images (Caudell et al., 2003). The name "Flatland" was taken from the title of a short novel by Edwin Abbott published in 1884. In his book, Abbott described interac-

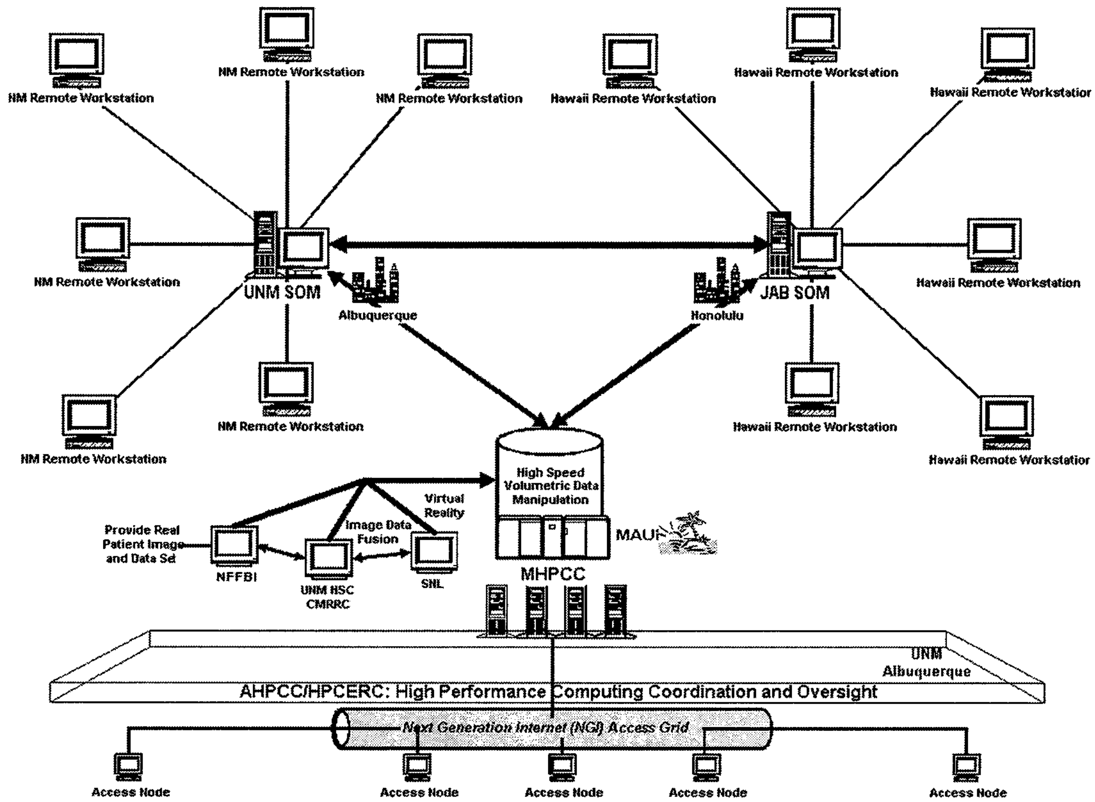

Figure 2. Access Grid communication between the University of New Mexico School of Medicine (UNMSOM) and the John A. Burns School of Medicine (JABSOM) enables direct communication between these two primary sites and remotely located students at individual nodes.

tions among geometric personalities who live in a two-dimensional planar "flatland" but who discover the existence of higher dimensions and experience the uncertainties, but also the wonder, of their new geometric world. The Flatland platform constructs arbitrarily complex graphical and aural representations of data and systems for interaction by the user. Flatland is written in C/C++ and uses standard OpenGL graphics language extensions to produce all graphics and operates on a wide range of computer platforms, including Linux systems. The Flatland environment has been extended to allow remote controlled viewing within the virtual environment from AG nodes and with a high degree of remote user interaction. This strategy allows remote users to independently view and interact with the immersed medical student during a patient simulation session. It also facilitates construction of, and interaction with, arbitrarily complex graphical and aural representations of data and simulations. Flatland is used to create and animate the graphical environment within which the students view and manipulate three-dimensional data sets, as well as interact with the virtual patient simulator.

The combination of the AI system controls and Flatland facilitates interaction with the simulation during the evolution of the case. These systems control all patient parameters and observable events, thus determining how the diagnostic direction is modified by the actions of the immersed student. The AI rules for this system were initially developed by generating a patient-response grid (Supplementary Table S1, available online at the journal home page www.interscience.wiley.com/jpages/0003-276X+/). This response grid outlines the disease path with points of user interaction and possible responses. The disease path is then incorporated into the AI simulation using standard knowledge engineering practices (Caudell et al., 2003). The rate (time) of the simulation is controllable by the users, according to the learning needs of the students. Thus, a new dimension in PBL, in which the students can dynamically determine the direction of the case scenario, is provided. It is expected that the realism of a 3D immersive environment will enhance the learning experience, but this enhancement remains to be tested.

The initial case concerns a traumatic head injury. A set of instructional objectives was established by a group of clinical and basic medical science knowledge experts. Subsequently, a storyboard was developed to establish a visual script for the case. The storyboard consisted of a set of keyframes capturing the essence of an educational concept (Figure 3). After revisions and final consensus by the group, a timeline was developed for the evolution of the patient's response to the traumatic head injury (Supplementary Table S1). This timeline was incorporated into the AI paradigm, facilitating the virtual patient's response to an action exerted by the student within the Flatland environment. The timeline continued with one possible endpoint being the patient's death if not appropriately treated by the immersed student. In addition to graphics provided in the AI simulator, additional multimedia learning tools were developed, including Quicktime ani-

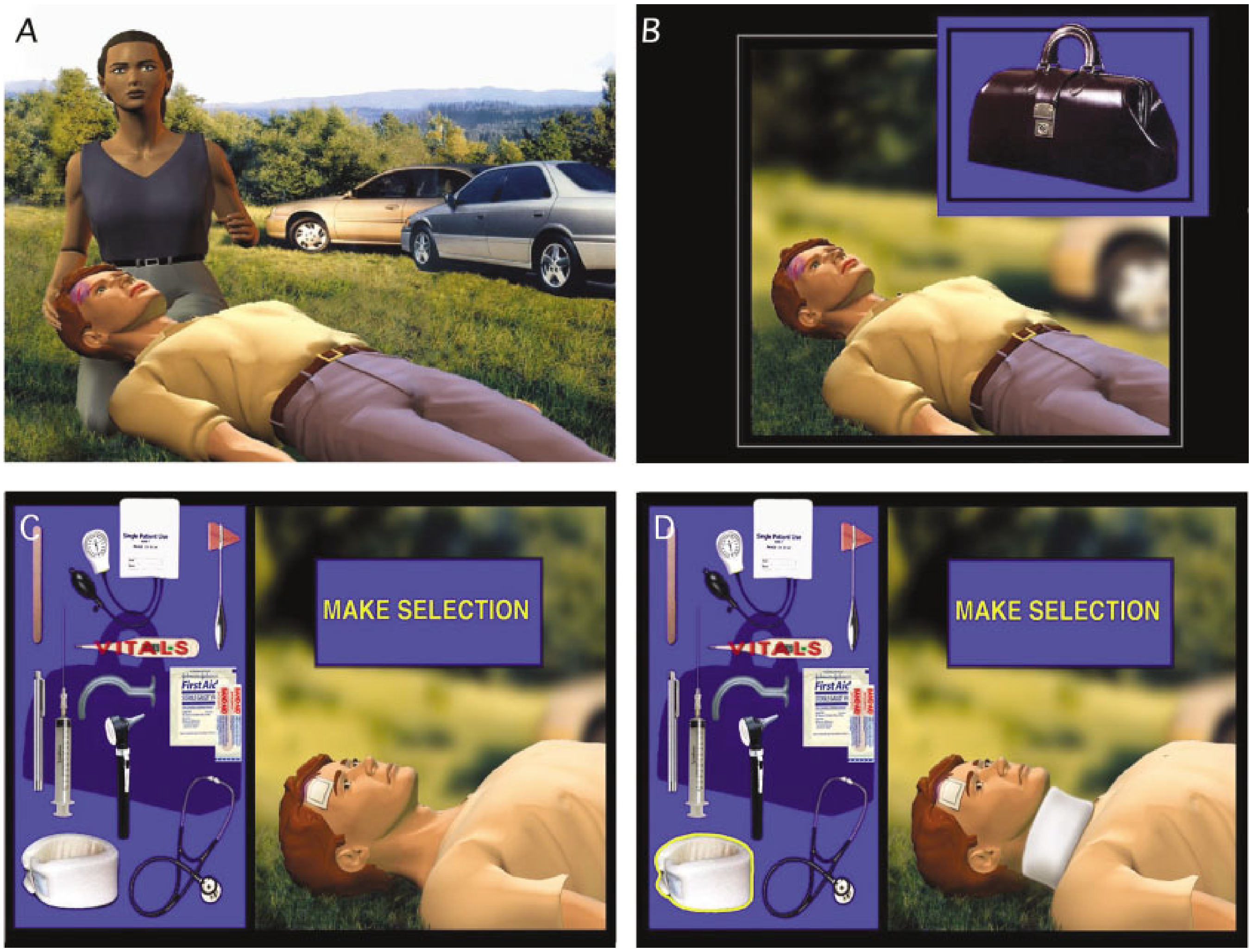

Figure 3. Selected key frames taken from the traumatic head injury storyboard. **A:** Mr. and Mrs. Toma immediately after the accident and at which time the patient history is communicated. **B:** Once the student immerses into Flatland, a set of tools is provided and the group must decide how treatment should proceed. **C:** Various options are presented. For example, after a bandage is applied and the bleeding stopped, the neck brace is selected next and applied to Mr. Toma for stabilization (**D**).

mations of epidural and subdural hematomas so that students could explore additional learning issues as they proceeded through the case (Lozanoff et al., 2003).

The case is initiated with the introduction of Mr. Henry Toma, a 35-year-old Caucasian male who is a victim in an automobile accident (Figure 3). Mr. and Mrs. Toma are on their way to the airport to return to their home in Lihue, Hawai'i after a visit with relatives in Albuquerque. Mrs. Toma is very upset and indicates that they may have been traveling too fast when they collided with another car. Mr. Toma apparently hit the right side of his head on the right roof support of the vehicle. Mrs. Toma says that her husband had been wearing his lap seatbelt, but had put the shoulder restraint behind him. She mentions that he never wears the shoulder strap because he says it is uncomfortable for him. Mr. Toma has been unconscious for roughly 10 min, but he is regaining consciousness. His ABCs (airway, breathing, and circulation) are normal, but he begins complaining of a headache and he appears anxious as he revives. He complains because he must return to Hawai'i by tomorrow for work, and he feels fine, and he simply wants to go home. Mrs. Toma indicates that the patient has no known drug allergies, takes no medication, and has no significant past medical or surgical history. His last meal was 4 hours ago. The students are expected to proceed through the tutorial process, determining facts, identifying patient problems, generating hypotheses and information to be determined, and finally establishing learning issues. In particular, the group should determine the portions of the physical exam most important and why.

The immersed student is then presented with Mr. Toma while others in the group look on and the simulation proceeds (Figure 4). Mr. Toma has a decreased level of consciousness and is supine. The primary survey indicates that Mr. Toma's airway is patent and he is moving air on his own at present. He has good pulses in all extremities. The immersed student conducts a secondary survey, and data indicate that the pulse is 60 bpm, respirations are 22, temperature is 37°C, and blood pressure is 140/100 mm Hg. The student should notice a contusion

Figure 4. Examples of problem-based learning case implementation over the Access Grid. **A:** An immersed student (lower right) inserts an oral airway as students look on in New Mexico, while students at various remote sites, including Hawai'i, observe through the Access Grid. **B:** The immersed student views the tympanic membrane with blood collecting inferiorly. (Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.)

with ecchymosis on the right side of his forehead and a scalp laceration. The immersed student should also test the gag reflex and perform a HEENT exam, noting blood behind the right tympanic eardrum. After checking the chest (trachea is midline; lungs clear to percussion and auscultation in all fields), cardiovascular system (regular rate and normal S1, S2; no murmurs, gallops, or rubs), abdomen (soft, nontender with normoactive bowel sounds), extremities (no deformities; no cyanosis or edema), the immersed student performs a neurological exam. At this point, it should be observed that Mr. Toma opens his eyes spontaneously, his right pupil is larger than the left, and it reacts sluggishly to light. He also withdraws all extremities in response to pain. A Glasgow Coma Scale score should be determined to be 9.

The AI simulator is programmed so that, after a specified time, Mr. Toma becomes cyanotic (changes hue as the visual indicator) and the immersed student must react accordingly by inserting an oral airway to stabilize. If this is not performed expeditiously, Mr. Toma expires. Thus, a sense of urgency is introduced into the case, providing realism to the learning experience. The attending student is removed from the immersive environment and the case continues with Mr. Toma being transported to the local emergency department, placed on a cardiac monitor and intravenous access is secured. The student re-examines him, but the patient is now unconscious. Blood pressure is 200/140 mm Hg, respirations are agonal and assisted with a bag-valve mask. The right pupil is fixed and dilated. The left pupil is sluggishly reactive to light.

As a result of the simulation, the students should have successfully navigated the case, generating numerous learning issues related to functional neurology and the neurological exam.

He now withdraws only his right extremity to pain and he appears to have developed left hemiparesis. The patient must be endotracheally intubated and then taken for an emergency computed tomogram of the head, confirming a right-sided epidural hematoma. There is radiographic evidence of uncal herniation that correlates to the clinical presentation. After surgical evacuation of the hematoma and a prolonged recuperation, Mr. Toma is discharged for further outpatient rehabilitation. He is to follow-up with his neurologist in Honolulu to discuss his risk of seizures.

As a result of the simulation, the students should have successfully navigated the case, generating numerous learning issues related to functional neurology and the neurological exam. These learning issues are then pursued during an intersession after which the group reconvenes and discusses them. The virtual setting and distributed learning structure will be compared with a standard nondistributed written case scenario and on-site tutorial format following the development of assessment tools (Table 1). Specifically, the evaluation component of the demonstration case will examine four groups of students: one that uses the traditional paper case; one that uses the paper case and AG; one that uses the AG to interact with the case presentation using virtual reality and patient simulation, with graphical 3D data sets for learning; and one that uses all of these technologic tools, but in a local environment, not over the AG. From this evaluation, differences in educational value and potential impediments or advantages to education should become evident.

DISCUSSION

The system being developed offers an outstanding opportunity to provide a

TABLE 1. PBL components and their formats in traditional and TOUCH tutorial groups*

PBL Component	Traditional Format	TOUCH Format
Case scenario	Paper-based	Graphical, immersive virtual reality patient simulator
Data sets	Paper-based books	Graphical, 3D, animations
Communication	Face-to-face with whiteboard	Face-to-face and remote, with shared electronic whiteboard

*PBL, problem-based learning; TOUCH, Telehealth Outreach for Unified Community Health

realistic experience within a student-centered learning paradigm. It will be particularly applicable for anatomically based clinical correlations given the visual nature of the experience (Lozanoff et al., 2003). Currently, haptic technologies are being explored as an additional enhancement for the virtual experience. Project TOUCH should serve as an example of computer-based learning system for future case development beyond the traumatic head injury presented here. If successful, future case development will involve multiple systems for delivery during all years of the medical curriculum. Potentially, the hardware and case development method could be applied to other medical training programs and possibly to other scientific disciplines. Future phases will also explore PC versions of the system for increased distribution.

Currently, the fully immersive virtual reality experience is limited to one person at a time. This adds a new dimension to the standard PBL group, because the immersed student fulfills the role of the attending physician who must, on one hand, entertain suggestions from the group, but also treat the virtual patient directly. Just as the other duties within the PBL group are rotated from week to week, e.g., scribe, reader, time keeper, learning issues recorder, the role of attending student–physician would also change ensuring that each student is subjected to the decision implementation experience. However, current work is being directed at the development of avatars, thus facilitating immersion of multiple students so that the virtual experience could be expanded to a group setting. Additional case scenarios will be developed, along with additional supplemental multimedia presentations to enhance these group-learning experiences.

A primary effort will be expended evaluating the system for its effects on the educational process. Presently, evaluation will be achieved by establishing PBL groups who will participate in this head trauma case. Case presentation will be performed over various modalities (Table 1). Evaluation will be performed through standard PBL questionnaires assessing the knowledge content of each student, comparing the learning issues generated by each group, and student assessment of the multimedia resource materials. In addition, tutors will provide evaluations covering substantive behaviors and group processing behaviors. If evidence indicates a clearly superior learning outcome, then the current system under development may indeed become a standard for medical education.

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