Interprofessional Critical Care Training: Interactive Virtual Learning Environments and Simulations

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***Abstract*-Interprofessional critical care training (ICCT) is an important activity that helps develop and formalize an understanding of the roles, expertise, and unique contributions attributed to members of multi-disciplinary teams in critical situations. Such training is of particular importance for teams that operate under tight time constraints in highly stressful conditions, such as that found in medicine. Here we describe our first steps towards developing a virtual learning environment (simulation) specifically aimed at ICCT for pediatric critical care teams. Our virtual learning environment employs a tabletop computing platform with novel image-based sensing technologies to enable collaboration and interaction amongst a group of trainees while promoting a learner-centric approach where the simulation is tailored specifically to the needs of each trainee.**

Keywords—learner-centered instruction; virtual simulation; strategy-based learning; tabletop computer;

I. Introduction

Critical care responders are health professionals (HPs) who are called to attend to critically ill, and rapidly deteriorating patients in acute care settings. These individuals bring a variety of skills (e.g., medical, nursing, and anesthesia) that must be integrated flawlessly for an optimal patient outcome. Although each health care professional is required to be proficient and skilled within their own domain, the opportunity to practice these skills in collaboration with members of other disciplines is scarce. Interprofessional education (IPE) is a pedagogical approach that enables health care practitioners to develop a clear understanding and appreciation of the roles, expertise, and unique contributions of other disciplines to successful patient care. IPE can assist in the development of the skills necessary to interact and interpret the language of other disciplines involved in patient care ultimately leading to positive patient outcomes. With IPE, trainees are able to develop a better understanding of the other professions in the team with respect to their role, expertise, and contributions, thus reducing any preconceived biases that may result from a knowledge deficit regarding other disciplines. However, despite the importance of IPE, it is currently a relatively minor component of health care education and training. The little interprofessional learning that does exist in current medical education and training is typically not a part of "mainstream" clinical learning and is thus rarely included in the assessment process [1].

Clinical training is typically based around supervised experiential learning and the use of simulated clinical situations. According to Halamek et al. [2], simulation involves immersion of the trainee in a realistic situation (scenario) created within a physical or virtual space (simulator) that replicates the real environment. In the context of health professions education (HPE), simulation can be defined as an education technique that allows interactive and immersive activity by recreating all or part of a clinical experience without exposing patients to associated risks [3]. It can include devices, technologies, computer programs and virtual spaces, scenarios, standardized patients, and a host of other methods of imitating real-world systems [4].

Although simulation-based training strives for a *learner-centric* approach whereby information is provided to the learner on a per-need basis, current simulation technologies do not meet this goal. There are at least two main reasons for this failure. The first relates to the simulator itself. More specifically, current simulators (often referred to as models) have a limited number of learning objectives that they can deliver. For example, a synthetic bench-top simulator, such as a representation of an arm, may be well suited for teaching the clinical technical skills of intra-venous (IV) catheter placement, but the same simulator is not well suited for teaching the underpinning anatomy. The second is related to the learner. Simulation is often used to train teams of health professionals not only to develop clinical skills within their own domain, but also to understand the skills required by other members of the team, and to help develop team-based skills. Since multi-professional teams consist of members with various backgrounds and skills, knowledge and attitude (SKA) levels, learning styles and needs, the same-for-all mode of information delivery is not necessarily appropriate for optimal learning for all of the team members.

Recently, smart tabletop touch-screen computers (also known as surface computers, tabletop computers, or smart tables), where users position themselves around a horizontal computer screen in a manner similar to sitting around a "traditional" table, have been introduced. These devices promote collaboration amongst the users providing the opportunity for the development of innovative, engaging, interactive, and highly collaborative pedagogic applications. This technology can, for example, provide the opportunity for novice learners to access additional information that is specifically tailored to them when they need it.

Several efforts have examined the use of interactive tabletop computers for medical education. von Zadow et al. [5] developed SimMed, a system that enables medical students to collaboratively diagnose and treat a virtual patient using a tabletop computing platform. Results of a user study with student participants indicate that the system provides a high level of immersion, cooperation, and engagement. Lundström et al. [6] employ a tabletop computer for medical visualization with the goal of keeping the visualization similar to a real physical situation while maintaining a low learning threshold. A user study conducted with five orthopedic surgeons demonstrated the appropriateness of the system for orthopedic surgery planning. The Anatomage Table from Anatomage Inc. [7] is an interactive tabletop computer designed specifically for human anatomy training. It resembles a typical operating table or hospital bed and with virtual patient models developed from real patient scans or cadavers allow the table to display "true human gross anatomy in real life size" [7]. Finally, although not specific to medical education, Ioannou et al. [8] investigated the use of an educational tabletop application designed specifically to allow collaboration amongst young learners while facilitating the learning about the various plants in Cyprus. A study with 28 third-grade student participants demonstrated a large amount of collaboration amongst the students while they completed their learning task and also revealed that the student participants were very positive about the experience. That being said, results also indicated that several student participants dominated the activity despite the equal access on the tabletop surface amongst all of the participants.

Given the importance of IPE in addition to the benefits of virtual simulation, we have begun development of a strategy-based, learner-centric virtual learning environment (VLE) to facilitate IPE in the critical care setting. Our approach is unique as it employs a multi-user interactive tabletop computer in conjunction with novel image-based sensing and positioning technologies to facilitate a virtual simulator that promotes embedding many learning objectives into a single simulation modality and tailor the learning experience to the needs of each of the learners involved (i.e., a learner-centric approach). Furthermore, to allow for robust and accurate touch-sensing positioning on the surface with multiple users/participants as may be required within the scope of a virtual medical simulation, our approach incorporates a multi-user/multi-interaction interface.

II. Simulation Protocols and Training

A. An Example of a Simulation Protocol

Patient history: Johnny is a seven year old, male patient admitted to an emergency room in a tertiary children's hospital. Upon admission, his parents report that he has been complaining of dizziness and nausea. While at the emergency room, Johnny loses consciousness and stops breathing.

Simulation Protocol: In this scenario, a computerized mannequin, known as *human patient simulator* (HPS) [9] plays the role of Johnny. The emergency nurse calls "code blue" and the critical care team (CCT) is mobilized. The CCTs are fundamental components of most hospital patient safety infrastructure designed to assist with critically unstable patients. The CCTs are multi-professional teams consisting of nurses, respiratory therapists and physicians. The team is expected to respond according to a strict protocol that dictates actions, sequences, timing and coordination with other team members. The HPS-Johnny is capable of providing the team with vital signs, such as breathing, oxygen saturation, heart rate, just the way a real patient would. His chest rises as he breathes and he can communicate with the team using voice. The simulation event is similar to role-playing exercise, where the instructor plays the role of the patient. She can adjust the vital signs, rhythms etc. and talk to the team. She implements an adaptable scenario script developed based on real clinical experiences [10].

B. Mapping to Learning Objectives and User Needs

Many learning objectives, many simulators: The HPS-Johnny responds to the actions of the team by being controlled by the instructor who follows an algorithm where pre-defined characteristics of the patient improve or deteriorate based on the actions of the individuals and the team. Although the instructor, via Johnny, is capable of providing information related to the script, if the learners need to acquire information outside of the scenario, such as related anatomy or physiology underpinning the procedures, the learning environment could not provide this information. A different simulator would need to be used at some later time, which will not only disrupt the learning, but which will also add cost to the training. Therefore one of the major problems with current simulation technologies is that they are very specialized, and deliver a very narrow band of learning objectives. Since clinical practice is a complex activity, the simulation needs to be able to deliver multiple learning objectives when the learners need them.

Many learners, many needs: Each learner in the team may have a different set of needs, as their base line SKAs may be different. These differences are expected, as they are a direct result of prior training as well as the variable scope of practice of the specific health professions. Given the heterogeneity of base line SKAs, each learner requires different information at different times, known as just-in-time (JIT) learning [11]. JIT provides a learning solution when it is actually needed, rather than on a deferred basis. Collectively, taking into account learner-centered needs, delivered at the time when they are needed, can be accomplished by utilizing instructional scaffolding [12]. Instructional scaffolding is defined as a learning process designed to promote a deeper learning, as it is the support given during the learning process, which is tailored to the needs of the learner with the intention of helping them to achieve specific learning objectives [12]. Current simulation technologies do not take into account learner-centric, JIT driven instructional scaffolding.

III. TABLETOP COMPUTING PLATFORM

Tabletop computers provide the opportunity for the development of innovative, engaging, interactive, and highly collaborative pedagogic applications, lending themselves nicely to interprofessional training of health professionals. The VLE is being developed for a tabletop computing platform and to this end, expanding and building upon our prior work and successes of an existing joint Canada-Japan-Colombia research collaboration that is investigating tabletop computers, particularly with respect to auditory interaction and spatial sound generation for tabletop computer platforms (see [13,14]). We are currently examining image-based sensing and positioning technologies (e.g., *cluster pattern interface* (CLUSPI) [15,16,17]) to allow for virtual simulators that promote embedding many learning objectives into a single simulation modality and tailor the learning experience to the needs of each of the learners involved while promoting IPE amongst a team of health professionals and thus improve patient care.

We are also examining the application of stereoscopic 3D (S3D) for multiple users situated around the tabletop display. This presents some interesting technical challenges that must be solved, including the ability to present individualized views to each of the users (ideally greater than two) which will require some form of user tracking and incorporating a display with a large refresh rate as it may involve multiplexing of the rendering using shutter glasses and rendering the scene for each individual separately. More specifically, allowing the display refresh to be multiplexed across each of the users (this will of course require an *N-fold* increase in rendering of the scene; e.g., ideally 480 Hz with four users).

A. Smart-Table: System Overview

Tabletop computer: Given the international nature of the collaboration, the system being developed is intended to operate on a range of different tabletop computers currently in place at the partner institutions. For example, the system in place at York University (Toronto, Canada) is based on the *active desktop* [18], while the system in place at the University of Ontario Institute of Technology (Oshawa, Canada) is custom designed and constructed "in-house". This system employs an Ultra Short Throw (low noise) LCD projector mounted on one of the interior walls of the table and a webcam on the floor of the interior to monitor touch-interaction. A similarly designed system is in place at the Shizuoka University (Hamamatsu, Japan). Common to all of these technologies is the ability to run a standard software infrastructure and the support of multi-user/multi-touch interactions [18].

Audio System: Each of the tabletop computers is designed to be supported by a spatialized sound infrastructure. Sound is delivered via four loudspeakers in a diamond configuration (whereby a loudspeaker is placed at each of the sides of smart table), facing the table computer surface. A sub-woofer is used to provide low-frequency effects and is placed to the side of the surface computer. Spatial sound is generated using a bi-linear amplitude panning method that independent of each of the user's (listener's) physical position; the sounds are simulated as coming from their position on the table, and if the user were to move farther away from the desk, the volume would naturally get quieter in relation to their distance away from the table [14].

Video System: Users interact with the virtual world and characters through the multi-touch smart table surface. In this model, a flat tabletop surface is employed to interact with an essentially three-dimensional virtual world.

B. Cluster Pattern Interface (CLUSPI) Technology

Although the tabletop computer provides multi-user/multi-touch interaction, it is desirable to provide tangible objects in some training scenarios that support their own localization technology. One promising option here is the use of CLUSPI technology [15,16,17]. CLUSPI technology employs a special digital pattern, practically invisible for the naked human eye when printed, which carries absolute positional information. The CLUSPI pattern is read by a digital camera such as that available in a cell phone or tablet computer, and is used as an interaction device for implementing various point-and-click functionalities. Using CLUSPI, the entire tabletop surface and tangibles associated with the training scenario can be covered with a touch-sensitive CLUSPI "code carpet" to allow for pin-point touch accuracy on the surface. With the use of CLUSPI technology, depending on the user's role in the simulation (e.g., whether they are taking on the role of a nurse, doctor, anesthesiologist, etc.) specific information may be presented to them and the level of detail contained within this information can vary depending on whether they are novice or advanced trainees. CLUSPI codes can be incorporated into interaction devices provided to the users within the simulation (e.g., medical devices and tools) to provide further personalization. Through camera-based methods, the tools can be accurately followed/tracked to determine whether they are being used properly. Depending on their use, specific information can be provided to the user to let them know that they are using the tool correctly or not, and provide additional correction information if used incorrectly. Finally, CLUSPI codes can be used to permit simple interactions with the simulation environment. For example, a back-and-forth motion of a CLUSPI-coded interaction device can be used to peel away a layer of skin from the virtual patient to expose the underlying muscular structure.

IV. SMART TABLETOP TOUCH-SCREEN COMPUTERS FOR JIT INSTRUCTIONAL SCAFFOLDING

A. Many Learning Objectives, Single Simulator

A tabletop computer-based simulation offers the possibility of using a single simulator to deliver a multitude of learning objectives. The educator, who runs the simulation scenario algorithm, may overlay images and information on top of the simulated patient (e.g., the human patient simulator-Johnny) in order to ensure that the team of learners understands key concepts related to the procedures performed. This offers the possibility of embedding learning objectives that are not possible when using the current physical and virtual simulation technologies.

Considering the example scenario described in Section II, one could suppose that the team of learners may require greater information about the anatomy of a certain body structure, which is critical to the execution of the clinical procedure. Similarly, the team may need to understand the pharmacokinetics of a drug that is administered to the patient (i.e., the mechanisms of absorption and distribution of an administered drug and the effects and routes of excretion of the metabolites of the drug [19] in order to expect certain physiological reactions). In both cases specific user actions can be detected and the simulator can provide information as needed (e.g., the layers of skin, or muscle tissue can be "stripped" and the anatomy in question exposed). In a similar manner, a diagram representing pharmacokinetics of the specific drug can be displayed providing the learners with accurate information. Thus, the team of learners learns how to interact with the patient, and develops basic knowledge of the underpinning anatomy and mechanism of any administered drugs.

B. *Many Learners, Many Needs*

Current simulation technologies do not take into account learner-centric instructional scaffolding. Such scaffolding needs to address the individual needs of each learner in the team and deliver when these needs arise. Specific supplementary information may be embedded in the textures of the simulated tissues. Each learner may use their own hand held device instrumented with a camera, and by reading the code embedded in the surface of the simulated tissue they will be directed to this supplementary information. This information will be available to the learner only as needed. Furthermore, this information can be encoded to meet a specific scope of practice of each of the health professionals by pointing the device in a specific configuration in relation to the surface of the table (i.e., the simulator). This approach ensures achievement of a homogenous level of SKAs across the learners, without disrupting the learning process of other team learners.

V. Overview of the VLE

The VLE is based on scenarios with specific learning objectives, feedback, and predictors of attainment of the learning outcomes related to critically ill patients (see Section II). In this context, a health professional in a critical care ward may be expected to respond according to a strict protocol that dictates actions, sequences, timing, and coordination with other team members. In each scenario, the critically ill child patient (virtual avatar) will require the immediate attention of a critical care rapid response team consisting of a number of health care professionals including nurses, doctors, and respiratory therapists. The patient avatar, controlled by an expert in critical care, will respond to the actions of the trainees based on the *deteriorating patient scenario* (DPS) script. In the DPS script, the patient deteriorates following previously scripted path if the team performs sub-optimally. Alternatively, if the team performs optimally, the patient becomes more stable. For example, the patient may start to have labored breathing. In this case, one of the nurses may respond by providing the patient with oxygen from an oxygen mask at which point the patient's breathing stabilizes and the oxygen saturation starts to increase to normal levels as indicated on the monitor. However, an inappropriate response on behalf of the nurse (or other health care professional) could result in the patient's condition deteriorating further. The patient can have several clinical concerns that will increase in complexity and severity if not responded to appropriately. The goal of the trainees is to stabilize the patient through the collaboration of response team members. Virtual decision support systems can be made available to enhance information seeking behaviors of the team members. This is analogous to the current gold standard in physical simulation using computerized mannequins and portable digital assistant devices.

VI. Conclusions

Simulation in health professions education (HPE) is a well-established pedagogical practice [20]. Although the pedagogical models supporting the use of simulations as a teaching tool is evolving, the technology to support these models is growing at a slower rate. This is especially pronounced in interprofessional education (IPE) settings where learners from different professions, with different backgrounds, different scopes of practice, and different base line knowledge, skills and attitudes must learn together. In this paper, we have identified two important problems in how simulation is predominantly used in HPE. The first relates to the simulator itself, where the simulators have a limited number of learning objectives that they can deliver. The second is related to the learner. Simulation is often used to train teams of health professionals. Since multi-professional teams consist of members with various backgrounds, skills, knowledge and attitude (SKA) levels, learning styles and needs, the same-for-all simulation experience and mode of information delivery may not be appropriate for optimal learning. That is, both of the outlined problems relate to the notion that health care practice is complex, and thus multiple learning objectives need to be addressed concurrently when teaching the skills involved. Conventionally employed simulation technologies, are not in a position to tackle such multiple learning objectives to many different learners. Furthermore, teams of learners are heterogeneous in relation to the skills, knowledge and attitude of each learner.

Our ongoing work involving a combination of a smart tabletop touch-screen computer and a vision-based, virtual learning environment may provide a technological solution to the above pedagogical problems. The solution is rooted in the principles of instructional scaffolding to address learners' needs, both as individuals and as a team, when they arise. More specifically, our approach utilized a single simulator to deliver a number of individualized learning objectives, supplementary learning information, and offers the possibility of invoking learning that is not possible when using the current physical and virtual simulation technologies. This approach also ensures achievement of a homogenous level of SKAs across heterogeneous groups of learners, without disrupting the learning process of other team learners.

In summary, the proposed approach is rooted in principles of individualized scaffolding and the optimal challenge framework [21]. We are currently in the process of developing and testing the technology to support this approach. Our future steps will follow a research framework recently outlined by Haji et al. [22] where this technology will be iteratively subjected to empirical testing of its feasibility and acceptability, effectiveness, and broad implementation in the health professions education system.

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