SCETF: Serious Game Surgical Cognitive Education and Training Framework

Brent Cowan*, Hamed Sabri*, Bill Kapralos*, Sayra Cristancho† Fuad Moussa‡, and Adam Dubrowski§
*Faculty of Business and Information Technology, and Health Education Technology Research Unit,
University of Ontario Institute of Technology. Oshawa, Canada.
†Department of Surgery and Centre for Education Research & Innovation,
Schulich School of Medicine and Dentistry, University of Western Ontario. London, Canada.
‡Division of Cardiac & Vascular Surgery, Schulich Heart Centre, Sunnybrook Health Sciences Centre. Toronto, Canada.
§The Hospital for Sick Children Learning Institute. Toronto, Canada.
Department of Pediatrics, Faculty of Medicine, and The Wilson Centre, University of Toronto. Toronto, Canada.
Email: bill.kapralos@uoit.ca

***Abstract*—Surgical proficiency requires command of both technical and cognitive skills. Although at times overlooked, cognitive skills training allows residents to practise detecting errors ultimately leading to a reduction of errors. Virtual simulations and serious games offer a viable alternative to practice in an actual operating room where traditionally both technical and cognitive skills acquisition takes places. They provide residents the opportunity to train until they reach a specific competency level in a safe, cost effective, fun, and engaging manner allowing them to make more effective use of their limited training time in the operating room. Here we introduce a serious game *surgical cognitive education and training framework* (SCETF) that is currently being developed specifically for cognitive surgical skills training. Domain-specific surgical "modules" can then be built on top of the existing framework, utilizing common simulation elements/assets. The SCETF is being developed as a research tool where various simulation parameters such as levels of audio and visual fidelity, can be easily adjusted allowing for the controlled testing of such factors on knowledge transfer and retention.**

I. INTRODUCTION

Competent surgical performance requires mastery of not only technical skills but cognitive skills (judgement) as well (i.e., the capability of responding and adapting to the wide range of contextual variations that may require adjustments to the standard approach) [1], [2] and similar to technical skills development, cognitive judgement takes practise to develop [3]. It has been suggested that cognitive skills training could accelerate the understanding and planning of a particular procedure, lead to a reduction in the training time required to become proficient with the procedure, may provide greater meaning to the actions being practised, and creates more effective learning while making more efficient use of resources [2], [3]. Training of surgical residents has traditionally followed the master-apprenticeship model whereby the resident (trainee) acquires the skills (technical and cognitive), required surgical techniques, and knowledge in the operating room. However, such an approach leads to increased resource consumption (e.g., monetary, faculty time, and time in the operating room) and has generally become more costly [4]. This has lead to decreased training time in the operating room and hence less operative exposure, teaching, and feedback. As a result, traditional educational methods in surgery have come under increasing scrutiny [5]. It is evident that given the increasing time constraints, trainees are under great pressure to acquire complex surgical cognitive and technical skills. Therefore, efforts must be made to optimize operative room exposure by devising training opportunities using artificial settings before exposure to patients.

Simulations, both physical and virtual, offer a viable alternative to practice in an actual operating room, offering residents the opportunity to train until they reach a specific competency level. One of the prevailing arguments for using simulation in the learning process of trainees is their ability to engage the trainee in the active accumulation of knowledge by doing. To date, simulation in the surgical domain has been primarily developed and studied as an educational tool for the development of foundational skills (i.e., basic technical skills and appropriate use of instrumentation). The rising popularity of video games has seen a recent push towards the application of video game-based technologies to teaching and learning. A serious game can be defined as an interactive computer application, with or without a significant hardware component, that i) has a challenging goal, ii) is fun to play and/or engaging, iii) incorporates some concept of scoring, and iv) imparts to the user a skill, knowledge, or attitude that can be applied to the real world [6]. Serious games "leverage the power of computer games to captivate and engage players/learners for a specific purpose such as to develop new knowledge or skills" [7] and with respect to students, strong engagement has been associated with academic achievement [8]. In addition to promoting learning via interaction and engagement, serious games allow users to experience situations that are difficult (even impossible) to achieve in reality due to factors such as cost, time, and safety concerns [9].

Despite the benefits of serious games, there are open, fundamental issues related to immersion and knowledge transfer and more specifically, how levels of realism and multi-modal cue interaction can affect immersion, knowledge transfer, and retention that must be addressed before they are adopted on a larger scale. Tashiro and Dunlap [10] developed a typology

978-1-4577-0257-0/11/$26.00©2011 IEEE

of serious games for healthcare education and explored the strengths and limitations of serious games for improving clinical judgment. They identified seven areas that require research and improvements for the effective development of serious games: i) disposition to engage in learning, ii) impact of realism/fidelity on learning, iii) threshold for learning, iv) process of cognitive development during knowledge gain, v) stability of knowledge gain (retention), vi) capacity for knowledge transfer to related problems, and viii) disposition toward sensible action within clinical settings.

Serious games provide the opportunity to optimize trainee time in the operating room before exposure to patients. Given the strain on resources associated with the current master-apprenticeship surgical training model, and the importance of cognitive skills training, we have recently begun the investigating the application of serious games for cognitive surgical skills training (see [11] for a serious game we developed for total knee arthroplasty that focuses on the steps and tools required at each step of the procedure). Building on our previous work, here we provide preliminary details of a multi-modal, *serious game surgical cognitive education and training framework* (SCETF) that is currently being developed. Domain-specific surgical "modules" can then be built on top of the existing framework, utilizing common simulation elements/assets and ultimately reducing development costs. The SCETF focus is on the cognitive components of a surgical procedure and more specifically, the steps comprising a particular surgical procedure, the contextual cues that trigger decision-making, the tools/equipment required at each step/stage of the procedure, error detection, forward planning and decision making. By clearly understanding the steps of a procedure and the surgical decision making that goes along with each step (i.e., the cognitive skills), trainees are able to focus solely on the technical aspect of the procedure (i.e, the actual execution) in higher fidelity models or in the operating room thus making more efficient use of the limited available resources. The SCETF is also being developed as a research tool where various simulation parameters (e.g., levels of audio/visual fidelity) can be easily adjusted allowing for the controlled testing of such factors on learning and this will ultimately lead to a better understanding on fidelity and knowledge transfer.

A module for the off-pump coronary artery bypass (OPCAB) grafting cardiac surgical procedure is being developed for the specific testing of the cognitive aspects of the SCETF. The OPCAB procedure itself is complex and technically challenging and therefore, it has been suggested that "appropriate training" be provided before operating on patients [12]. In addition to its use as a training tool, the OPCAB module will also serve as a test-bed to allow for the methodical investigation of the effect that varying audio/visual simulation fidelity and the interaction of audio/visual cues have on knowledge/skills/behaviours (KSB) transfer and retention. Furthermore, it will be used to measure the feasibility/usefulness of using serious games as a tool for assessing/screening cognitive skills (e.g., situation awareness) in surgical decision making.

II. SCETF DETAILS

The SCETF consists of graphical and spatial sound rendering engines in addition to other components that are common (generic) to all serious games including a "scenario" editor (currently being developed) that allows users of the module (educators/instructors) to create and/or modify/edit specific scenarios using a graphical-based user interface. The scenario editor that allows a scenario to be easily developed by "clicking and dragging" various interface components.

Trainees take on the role of the surgeon, viewing the environment through their avatar in a first-person perspective and such only their hand is visible (see Figure 1). Several other non-player characters (NPCs) also appear in the scene including the patient (lying on a bed), assistants, and nurses. Future work will see the addition of networking capabilities to allow these NPCs to be controlled by other users and provide an entire surgical team the opportunity to practise remotely. The trainee can move and rotate the "camera" using the mouse in a first-person manner thus allowing them to move within the scene. A cursor appears on the screen and the trainee can use this cursor to point at specific objects and locations in the scene.

The task of the trainee is to complete the surgical procedure following the appropriate steps and choosing the correct tools for each step. Along the way, complications can arise which will require some action from the trainee. These complications will appear in the form of visual or auditory cues adapted according to predefined features of the simulated surgical scenario. The surgical scenarios are currently being designed as part of a concurrent observational study in the operating room. One of the co-authors in this paper has developed a diagrammatic tool to map the motor and cognitive aspects of surgical procedures (known as the "MCMD"; see [13]). This tool has been used to create the mapping for the OPCAB procedure [14] and the appropriate contextual cues for various types of challenges related to this surgery are currently being identified through further intraoperative observations, which will be incorporated in our proposed SCETF. We expect that the final version of the OPCAB module will allow trainees to practice some aspects of decision making that might enhance their confidence in dealing with intraoperative challenging situations that may have consequences on patient outcome.

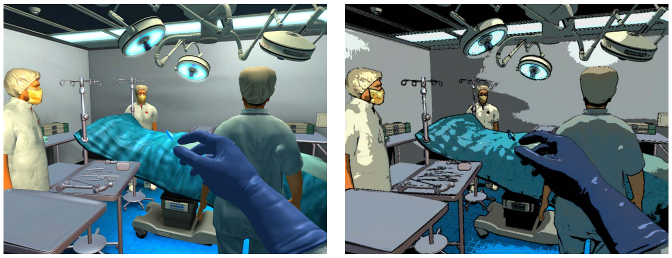
A. Graphics Rendering

The 3D graphics rendering engine was developed completely "in-house" and is based on the C++ programming language and the OpenGL 3D graphics API. Real-time rendering is accomplished using the graphics processing unit (GPU) via the OpenGL shading language (GLSL) [15]. Although each of the modules that will be built upon the SCETF will require their specific assets (models of the appropriate tools, etc.), we have also developed a number of "common" assets/models such as an operating room with surgical lights, bed, nurses, etc. Both low- and high-polygon count versions of these "common" models have been developed. The low polygon count models were developed using the Autodesk

Fig. 1. Example of the outer glow effect that is used to indicate interaction with the corresponding object is possible.

(a) Original (no filter).

(b) Blur filter.



(c) Color saturation filter.

(d) Cel-shader filter.

(e) Outline "filter".

(f) Gray-scale filter.

Fig. 2. Examples of the filtering effects that are available to alter visual fidelity. The degree of filtering for each of the effects is also adjustable via a scroll-bar via the graphical user interface and all effects are implemented with the GPU.

Maya 3D and 3Ds Max modeling and rendering software and the Pixologic Z-Brush "digital sculpting" tool. NVIDIA Mental Ray was used for "baking" and simulating the light, Headus UVLayout was used to apply UV mapping to all the models, and Xnormal was used for "baking" all the model normal maps. Finally, the SCETF utilizes GPU-based effects such as "outer glow" (used to indicate a "selectable object"), "reflection mapping", "bloom filtering" (to provide more realistic lighting effects particularly when considering objects in front of a light source), and various effects to generate realistic metal effects given the widespread use of metal (stainless steel) in an operating room. An example of the outer glow effect is provided in Figure 1. In this example, the outer glow surrounds the outline of the operating room nurse after the end-user (taking on the role of the surgeon in a first-person perspective) moves the cursor over the nurse to indicate that they are able to interact with the nurse. Interaction is initiated by clicking the left mouse button.

B. Sound Rendering

SCETF supports spatial sound rendering including reverberation and occlusion/diffraction modeling using novel GPU-based methods that approximate such effects at interactive rates [16], [17]. The system also supports head-related transfer functions (HRTFs) and HRTF filtering is accomplished using GPU-based convolution ensuring interactive frame-rates [18]. Spatial sound by default is not activated; it is an option that can be chosen during start-up. By default, sounds are non-spatialized and output in a traditional stereo format. Although each module will have its corresponding sounds (e.g., background sound, sound effects, and dialogue), the user is also provided the opportunity to provide their own sounds during start-up (e.g., the user can provide their own background sound or can choose to have no sound output at all).

C. Adjusting Levels of Realism and Multi-Cue Interaction

As previously described, the SCETF is being developed as a research tool to enable the investigate the effect of audio and visual fidelity on knowledge transfer and retention. Our current focus is on audio and visual fidelity, and the interaction of audio and visual cues particularly if they are incongruent, and mis-matched (i.e., high quality audio and poor quality visuals and vice-versa). With respect to audio fidelity currently, the following options are supported: i) spatial sound vs. non-spatial sound, ii) no audio (background sound and/or all sound effects can be turned off), iii) adjustable quantization levels, iv) addition of white noise to background sounds and/or sound effects, and v) adjustment of loudness and dynamic range. Such effects (and their corresponding settings) are chosen during start-up and cannot be adjusted dynamically. Graphical fidelity ranges from high to low quality, defined with respect to polygon count, and resolution (both texture resolution and overall resolution). These effects cannot be adjusted dynamically but rather, their settings must be specified during an initialization phase at start-up. The SCETF also provides for the dynamic adjustment (using a "slider control") of graphical fidelity through various graphical filtering effects implemented using the GPU. Such effects include: i) blurring, ii) color saturation, iii) Cel-shading (to provide a "cartoon", non-photorealistic effect, iv) edge outline enhancement, and v) gray-scale. An example of these effects is provided in Figure 2 where the results of applying each of these filters (individually) to the original scene of Figure 2(a) are shown in Figures 2(b)-(f) respectively.

III. SUMMARY AND FUTURE WORK

Serious games provide a viable alternative to training in the operating room allowing trainees (residents) to develop their cognitive and technical skills in a safe, fun, engaging, and cost effective manner. To become a competent surgeon, in addition to technical skills, one must master cognitive judgement as well and such cognitive skills requires practise to develop. Here we presented a serious game surgical procedure education and training framework (SCETF) whose focus is on cognitive surgical skills development. Domain-specific surgical modules are built on top of the SCETF allowing it to be utilized for a variety of surgical procedures and scenarios while taking advantage of common simulation elements/assets. Development of the SCETF is ongoing and our current focus is on the development of the OPCAB module. Upon completion of the module, usability testing will be conducted with cardiac surgery residents to test effectiveness. The OPCAB module will also serve as our "research test-bed" where we will be able to modify both audio and visual fidelity and investigate the resulting effect on knowledge transfer and retention.

ACKNOWLEDGMENTS

The financial support of the *Natural Sciences and Engineering Research Council of Canada* (NSERC) in the form of Post-Graduate Scholarship (PGS B) to Brent Cowan and individual Discovery grants to B. Kapralos and A. Dubrowski is gratefully acknowledged.

REFERENCES

[1] Van Merrienboer and J. Jeroen, *Training Complex Cognitive Skills: A Four-Component Instructional Design Model for Technical Training*. Englewood Cliffs, NY. USA: Educational Technology, 1997.

[2] J. A. Kohls-Gatzoulis, G. Regehr, and C. Hutchison, "Teaching cognitive skills improves learning in surgical skills courses: a blinded, prospective, randomized study," *Canadian Journal of Surgery*, vol. 47, no. 4, pp. 277–283, 2004.

[3] K. A. Ericsson, R. Krampe, and C. Tesch-Romer, "The role of deliberate practice in the acquisition of expert performance," *Psychological Review*, vol. 100, no. 3, pp. 363–406, 1993.

[4] R. K. Reznick, "Teaching and testing technical skills," *American Journal of Surgery*, vol. 165, no. 3, pp. 358–361, 1993.

[5] P. J. Gorman, A. H. Meier, C. Rawn, and T. M. Krummel, "The future of medical education is no longer blood and guts, it is bits and bytes," *The American Journal of Surgery*, vol. 180, no. 5, pp. 353–356, 2000.

[6] B. Bergeron, *Developing serious games*. Hingham, MA. USA: Thomson Delmar Learning, 2006.

[7] K. Corti, "Game-based learning; a serious business application," PIXELearning, Coventry, UK, 2006.

[8] V. Shute, M. Ventura, M. Bauer, and D. Zapata-Rivera, "Melding the power of serious games and embedded assessment to monitor and foster learning," in *Serious Games. Mechanisms and Effects*, U. Ritterfeld, M. Cody, and P. Vorderer, Eds. New York, NY. USA: Routledge Publishers, 2009, pp. 97–122.

[9] K. Squire and H. Jenkins, "Harnessing the power of games in education," *Insight*, vol. 3, no. 1, pp. 5–33, 2003.

[10] J. Tashiro and D. Dunlap, "The impact of realism on learning engagement in educational games," in *Proceedings of ACM Future Play 2007*, Toronto, Ontario, Canada, 2007, pp. 113–120.

[11] B. Cowan, H. Sabri, B. Kapralos, M. Porte, D. Backstein, S. Cristancho, and A. Dubrowski, "A serious game for total knee arthroplasty procedure education and training," *Journal of Cybertherapy and Rehabilitation*, vol. 3, no. 3, pp. 285–298, 2010.

[12] J. I. Fann, A. D. Caffarelli, G. Georgette, S. K. Howard, D. M. Gaba, P. Youngblood, R. S. Mitchell, and T. A. Burdon, "Improvement in coronary anastomosis with cardiac surgery simulation," *The Journal of Thoracic and Cardiovascular Surgery*, vol. 136, no. 6, pp. 1486–1491, 2008.

[13] S. M. Cristancho, A. J. Hodgson, G. Pachev, A. Nagy, N. Panton, and K. Qayumi, "Assessing cognitive & motor performance in minimally invasive surgery (mis) for training & tool design," *Studies in Health and Technology Informatics*, vol. 119, pp. 108–113, 2006.

[14] S. M. Cristancho, F. Moussa, and A. Dubrowski, "Simulation-augmented training program for off-pump coronary artery bypass surgery: Developing and validating performance assessments," *Surgery*, 2011 (in press).

[15] R. Rost, *OpenGL Shading Language*, 2nd ed. Boston, MA. USA: Addison-Wesley Professional, 2006.

[16] B. Cowan and B. Kapralos, "A GPU-based method to approximate acoustical reflectivity," *Journal of Graphics, GPU, and Game Tools*, 2011 (to appear).

[17] ——, "GPU-based real-time acoustical occlusion modeling," *Virtual Reality*, vol. 14, no. 3, pp. 183–196, 2010.

[18] ——, "Spatial sound for video games and virtual environments utilizing real-time GPU-based convolution," in *Proceedings of ACM Future Play 2008*, Toronto, Ontario, Canada, 2008, pp. 166–172.