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DESIGNING A SIMULATION-SUPPORTED ADAPTIVE ASSESSMENT SYSTEM FOR SPINAL ANAESTHESIA

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ABSTRACT
This paper describes the development of a technology architecture that not only supports the technical performance assessment of a medical simulator but also facilitates a validated competence based assessment system in one selected anaesthetic procedure i.e. spinal anaesthesia. Based on extensive mapping of the competencies required for the performance of this procedure, a system architecture is proposed utilising a specifically designed anaesthetic simulator, a learning management system and back-end assessment logic. The overall system is designed to assess the agreed spinal anaesthetic competencies i.e. *patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism* and *system-based practice,* as defined by the Accreditation Council for Graduate Medical Education.

KEY WORDS
Advanced Technology in Education, Architecture of Innovative Software, Medical Simulation, Virtual Reality, and Web-Based Assessment.

1. Introduction

Advances in computer technology, such as 3D visualisations and haptic feedback, have realised the potential of simulating advanced medical procedures for training and assessment purposes [1]. However, much discussion has been generated within the medical community regarding the integration of these simulators as valid assessment tools into existing medical curricula [2-5].

To date, successfully "integrated" simulators focusing on technical performances have been mainly in the area of surgery, where assessing technical performance has been defined [6-7]. The complexity of surgical procedures makes simulators invaluable tools for assessing the technical performance of a surgeon [8].

However, technical performance is only one of the many competencies required by a proficient practitioner. According to the Accreditation Council for Graduate Medical Education (ACGME) [www.acgme.org], the competencies a practitioner should hold are patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism and system-based practice. For example patient care involves sub- competencies such as competently performing technical procedures and performing an accurate investigation of a patient's history. Interpersonal and communication skills involve creating and sustaining patient relationships as well as being a leader or a member of a group of health care professionals, etc.

We strongly believe that until simulation developments seriously meet the educational requirements of competence-based medical training, the potential of simulator-supported training is likely to remain largely unrecognised by the overall medical community and the statutory medical training bodies.

An initial step in this direction was initiated by the Anaesthetic Department in Cork University Hospital, Ireland in collaboration with the Interaction Design Centre, University of Limerick, Ireland. The feasibility of designing novel learning technology to assist the training of hospital doctors in performing spinal anaesthesia was investigated. The project, termed Design-Based Medical Training (DBMT), involved identifying key determinants of learning and teaching spinal anaesthesia [9] and the design of a medical simulator.

Following this research, an EU funded project called Competence Assessment for Spinal Anaesthesia (MedCAP) [www.medcap.eu] has been initiated, involving five partners (Cork University Hospital, Ireland, University of Graz, Austria, University of Pécs, Hungary, Interaction Design Centre, Ireland and MedicVision Ltd., Australia). The overall aim of this project is to develop an assessment procedure utilising the competencies stated by the ACGME. The project focuses on the procedure of spinal anaesthesia for its research. It seeks to identify and investigate methods for assessing all ACGME-competencies involved in the procedure of spinal anaesthesia and incorporate these into a computer-supported assessment procedure by utilising simulation technology.

The main focus of this paper is to describe a possible technology architecture required for such an assessment procedure.

2. Background

2.1 The procedure of spinal anaesthesia

Spinal anaesthesia involves injecting a local anaesthetic solution into the fluid surrounding the spinal cord (cerebrospinal fluid - CSF) by inserting a long needle into the space between the bones (vertebrae) of the lower back. The anaesthetist relies heavily on the haptic cues experienced through the needle for identifying the correct injection point. When the solution is injected it blocks impulses along nerves supplying the lower half of the body. The temporary block of sensation and movement allows the patient to remain awake and pain free while surgery is performed in this region.

2.2 Surrounding aspects of spinal anaesthesia

The administration of spinal anaesthesia commences with a detailed history, examination and review of relevant investigations by the anaesthetist. Correct patient selection is imperative as spinal anaesthesia is specifically contraindicated in some circumstances, such as in patients who have bleeding tendencies. It is the responsibility of the anaesthetist to communicate the nature, risks and benefits of spinal anaesthesia to the patient and to respond to any concerns the patient may express.

Before any injection of local anaesthetic solution can begin the patient is attached to monitoring devices so that the ECG, blood pressure and oxygen levels are displayed at all times. The patient is then positioned to obtain maximal curvature of the lower back (lumbar region). Good positioning maximises the chance of success at inserting the needle. Palpating the hipbones and the midline orientates the anaesthetist as to the correct spaces between the back bones (vertebrae) for needle insertion.

The anaesthetist then “scrubs up” (i.e. the lower back is cleaned with antiseptic and draped) and performs the procedure in a sterile fashion. After injecting some local anaesthetic to the skin and superficial tissues, the spinal needle is inserted in the midline and directed slightly towards the head in order to navigate a clear path between the bones. The anaesthetist secures the needle with one hand and attaches a syringe with correct amount of local anaesthetic with the other.

A high level of vigilance is required at this stage particularly to the occurrence of low blood pressure which should be treated promptly. Before surgery commences the level of the block should be tested to ensure it is adequate and that the patient will not experience pain.

From this description, it is evident that a proficient anaesthetist is required to hold a wide range of competencies for the administration of spinal anaesthesia in addition to the technical performance.

2.3 Mapping of competencies

To develop the basis of a potential assessment procedure for spinal anaesthesia, an extensive mapping of the competencies involved has been performed as part of the work programme of the project. These were mapped during a number of workshops in Cork University Hospital, Ireland, involving both trainers and trainees. The participants were asked to map out what they perceived were the relevant competencies using the notation stated by the ACGME. For each of the 6 ACGME general competencies, an extensive competence structure was created using a large subset of competencies (skills and knowledge) including their interrelationships, required for the administration of spinal anaesthesia. This structure is currently being validated by anaesthetists at Pécs University Hospital.

3. Simulator assessment of technical performance and skills

A simulator for spinal anaesthesia, initially designed as a learning tool, had previously been developed by two of the members of the MedCAP consortium, the Interaction Design Centre, University of Limerick and Cork University Hospital [10].

The simulator facilitates the technical aspect of spinal anaesthesia i.e. the insertion of the spinal needle. It also rotates the anatomy which allows the user to ‘see’ the anatomical projection of the spinal needle. It uses a force feedback system, i.e. a haptic device to reproduce and represent the sensations of needle insertion and a stereoscopic screen to provide 3D visualisations.

3.1 Technical aspects

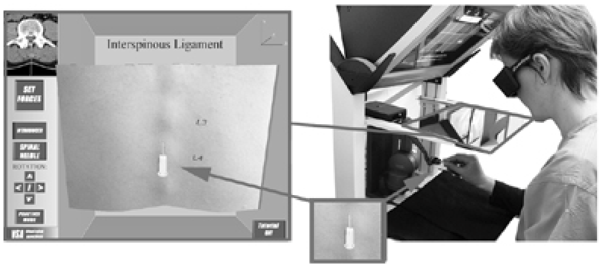
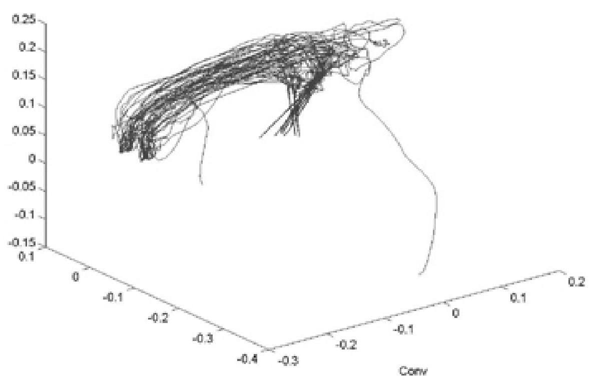


Figure 1. The virtual back is displayed in the Immersive workbench, creating an intuitive workspace for the simulator. The movement of the haptic device corresponds to the needle in the virtual environment.

Haptic technology refers to mechanical devices that generate computer controlled force or vibration stimuli and are mainly used to allow users to perceive objects by the sense of touch in virtual environments [11]. The simulator system utilises a Phantom Desktop [www.sensable.com], which can be programmed to reproduce the sensations of needle insertion. To create a more intuitive and realistic interface, an actual spinal needle is attached to the apex of the device, allowing the user to go through the motion of insertion, penetration of the skin and experience the sensation of the various tissue layers as the needle passes through, thus providing a realistic sensation of using a real spinal needle. The view for the user is a 3D model of the lower part of a human back (Fig. 1).

3.2 Assessment of performance

The MedCAP project will see the spinal anaesthesia simulator being expanded to record data in the virtual training environment, allowing automatic assessment of a subset of competences (technical performance) related to the overall competency patient care.



Graph 1. The graph illustrates recorded movements of the haptic device during the simulated procedure. The left part of the graph corresponds to the tapping of buttons within the interface, which are used to switch between the different needles required for the procedure of spinal anaesthesia. To the right, repeated attempts of needle insertion can be seen.

The haptic device used in the simulator offers excellent opportunities for capturing a range of data as the simulated spinal anaesthetic procedure is being performed. By measuring position, angle, and velocity of the haptic device, the system is able to detect how the anaesthetist performance relates to the virtual anatomy. The raw data from the device can be translated into meaningful information for assessing competencies related to the technical performance. In Graph 1 the trajectory of the needle is plotted and shows how position can be tracked to acquire information of different needle insertion paths.

For example, a sub-competency associated with patient care was identified during the workshop discussions as the ability of knowing when to redirect the needle if bone is encountered. A novice generally repeatedly attempts the same path, before redirecting the needle. By tracking the device, the system can monitor needle behaviour and through assessment logic determine if the assessed person holds the relevant competency of sufficient needle re-direction or not.

3.3 Assessment data handling

As the simulation of the medical procedure is a demanding process, the handling of data is divided into two processes. The assessment of a particular sub-competency is done in real-time by the simulator. Algorithms for assessing different competencies are incorporated into the simulator system which records all aspects of the performance of the simulated procedure of spinal anaesthesia. After the assessment is completed, the overall data is sent to a back-end assessment module, which calculates the relation of all competencies detected by the simulator, derived from the competence mapping.

4. Expanding the assessment procedure

The simulator is so far limited to assess competencies related to patient care only. To cover a wider range of competencies, this research proposes to utilise a Learning Management Systems (LMS) for creating a system for systematically acquiring additional data from the assessed anaesthetist.

LMS are commonly used to provide a remote interface between teacher and student for managing courses, to distribute and access learning material and to provide and receive feedback. There exists a range of available LMS, for example open-source based, such as Moodle [www.moodle.org] and commercially available, such as Blackboard [www.blackboard.com].

4.1 LMS functionalities for spinal anaesthesia

By incorporating an existing, open source LMS to the simulation-supported assessment procedure, a platform for handling student information, presenting learning material, displaying questions for assessment and providing feedback is provided.

The anaesthetist starts by logging-in to the system and thus has access to a wide variety of learning materials through the Spinal Anaesthesia Learning Management System (SA-LMS), before any assessment is performed. The anaesthetist is also briefed on the specific competencies (learning objectives) required of a proficient practitioner. The anaesthetist can then undergo an assessment using predefined problems within the SA-LMS interface.

The SA-LMS offers the flexibility for updating the learning and assessment material. Different hospitals might have different ways of performing spinal anaesthesia, standards might change and new practices might be introduced to the medical procedure.

Besides being an integral part of an assessment procedure, the SA-LMS creates a potentially valuable resource of learning material, easily accessed by an anaesthetist through a standard computer with Internet connection.

4.3 Case-based assessment

For facilitating efficient assessment of competencies, the SA-LMS will be modified to present questions in a case-based assessment format, based on real-life clinical scenarios. These scenarios developed by the Anaesthetic Department, Cork University Hospital and validated by Pécs University Hospital, incorporate a range of question formats, such as multiple choice and true or false. Pictures and video clips are used in the questions to allow anaesthetists to make choices depending on visual information, derived from a real clinical setting. The responses to the questions within a specific case are linked with certain, pre-defined competencies.

The case-based assessment procedure will allow the SA-LMS to gather data for assessing a subset of competencies related to patient care, medical knowledge and professionalism that are not covered by the simulator.

4.4 Portfolio

The SA-LMS offers the possibility of incorporating an electronic portfolio for record keeping of performances in the real, clinical setting. A paper-based portfolio is generally required by the anaesthetist, however the electronic format allows flexibility and easy maintenance of the stored records. The incorporation of a portfolio will enable the anaesthetist to systematically reflect on his or her current practice and facilitate the retention and maintenance of the practitioner's skill set. The portfolio offers the opportunity to assess a subset of competencies related to practice-based learning and improvement.

5. Assessment engine and logic

The simulator and learning management system facilitates the collection of data covering a range of competencies associated with the procedure of spinal anaesthesia. However, none of these provide sufficient assessment on their own. A back-end assessment logic has to be applied for processing the acquired data from the simulator and the SA-LMS.

An external module will be assigned to perform a mathematical analysis of the performance on the simulator and the responses from the cases in the SA-LMS. The module is based on the Competence based Knowledge Space Theory (CbKST) [12-13] which will allow the system to map out what competencies an anaesthetist possesses and what he or she still needs to learn. This information will be accessible both for the anaesthetist and educator/trainer through the SA-LMS.

The reasons why CBKST was chosen and why traditional assessment procedures are insufficient in this context have previously been discussed [14].

5.1 CbKST

The *Competence based Knowledge Space Theory* is a cognitive framework extending the originally behavioural *Knowledge Space Theory* [15-16], in which a knowledge domain is represented by a set of problems and surmise relationships (prerequisite relationships) among them. The set of problems and their inherent relations form the structure of the knowledge space. The advancement of CbKST is to separate observable performance (e.g., correct or incorrect answer to a test item) and its underlying skills or competencies [12, 17]. By comprehensive analysis of a knowledge domain, the interrelationship among the competencies can be identified and structured. In such a competence structure, the mastery of some skills surmises the possession of some others, which is essential for the adaptive assessment logic.

5.2 Competence mapping of an anaesthetist

Based on the outlined competencies of spinal anaesthesia, test problems to be used within the different cases are developed. The relationships between the skills needed for spinal anaesthesia and the test problems are mapped by skill and problem functions. Given a test problem, a certain skill or some skills are necessary for solving it. Conversely, given a certain skill state, one or more problems can be solved by it. Note that in a knowledge domain, the number of skills is finite while the number of feasible problems that can be solved by those skills may be infinite.

By mapping the skills with test problems of a domain, the knowledge structure with a set of problems is associated with the skill/competence structure. With the established structures, the adaptive assessment procedure does not have to test all the items in the problem set. Instead, based on surmise relations among the problems, the assessment will be much more efficient.

The assessment system will soon capture the anaesthetist's current knowledge state, represented by the set of problems he or she can solve, which accordingly denotes his competence state (i.e., the skills and knowledge he possesses or lacks) established by the skill and problem functions.

6. The computer-supported assessment procedure

The complete system will consist of the simulator system, the SA-LMS and the assessment engine (Fig. 2). The anaesthetist will be interfaced with the assessment procedure (as well as learning material) through the SA-LMS where the case-based assessment format will create a natural link between the SA-LMS and the simulator.

The simulator is linked to different case scenarios. At certain stages of the assessment the anaesthetist will switch interfaces from the SA-LMS to the simulator and perform spinal anaesthesia on a patient corresponding to what is outlined in the specific case (i.e. anatomy, force feedback sensations etc.). However, the anaesthetist is given the choice to practice the procedural skills on the spinal anaesthesia simulator before assessment.

The data retrieved from the SA-LMS and the simulator system is sent to the back-end assessment logic for analysis to create an overall map of an individual's competence state. Data of the outlined competencies as analysed by the assessment logic will then be sent back to the SA-LMS and presented to the anaesthetist and supervisor. Along with the mapping of the anaesthetist's competencies, the system will provide additional feedback in terms of suggested reading materials and skills that needs to be practiced further on the simulator.

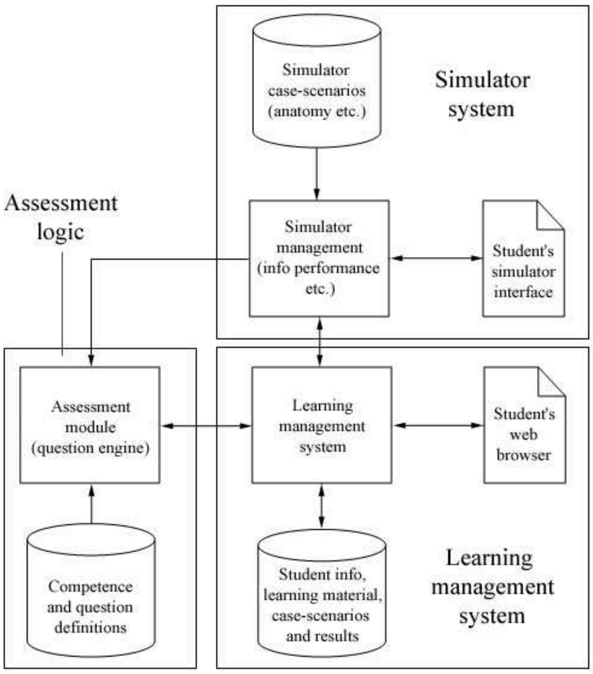


Figure 2. Description of the assessment system architecture and the relationship between the three different modules: *simulator system, LMS* and *assessment logic*.

7. Discussion

The simulator does not simulate all aspects associated with the technical performance (the subset of patient care) of spinal anaesthesia. For example palpation of the patient, i.e. the process of determining the correct needle insertion point is currently not possible to assess in the existing simulator. Aspects of the skill set associated with spinal anaesthesia currently not capable of being technically assessed by the simulator will instead be assessed through questions incorporated in the SA-LMS. However, since the simulator is under constant development with a view to increase its capability to include additional features for assessment by the simulator.

Due to time limitations and the complexity of assessing all ACGME- competencies within one system, this project has been forced initially to limit itself to implement and investigate competencies that can be assessed by the simulator on a case-based format (even if all competencies were mapped in the initial stages of the project). For example, to assess competencies associated with Interpersonal and Communication skills, the computer-supported assessment procedure will have to be expanded to incorporate other suitable methods, e.g. Objective Structured Clinical Examination [18].

The long-term aim is to provide a computer-supported assessment procedure for all competencies outlined by the ACGME. This will draw from other work, such as [19], who suggests a range of methods for supporting each of the ACGME defined competencies.

8. Conclusion

The suggested system architecture, if successful, for a competence-based assessment procedure in the case of spinal anaesthesia could potentially be applied to other medical procedures that utilises simulation technology. This would greatly aid the medical certifying training bodies in their search for a reliable and validated assessment training tools.

The assessment procedure for spinal anaesthesia will be tested for construct validity and reliability, i.e. to investigate if the results from the simulation-supported assessment procedure correlate with the actual competencies an anaesthetist is observed to possess in a real, clinical setting. If the outcome from this study is successful as anticipated, it is intended to disseminate the assessment procedure to European medical training bodies, who have already expressed an interest in the results to date.

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References

[1] R. M. Satava, Surgical Education and Surgical Simulation, *World Journal of Surgery*, *25*, 2001, 1484-1489.

[2] S. Dawson, Procedural Simulation: A Primer, *Radiology*, *241(1)*, 2006, 17-25.

[3] R. Reznick & H. MacRae, Teaching surgical skills - Changes in the wind, *New England Journal of Medicine, 355(25)*, 2006, 2664-2669.

[4] A. G. Gallagher, E.M. Ritter, H. Champion, G. Higgins, M.P. Fried, G. Moses, C.D. Smith & R. M. Satava, Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. *Ann Surgery, 241*, 2005, 364-372.

[5] H. Champion & A. Gallagher, Surgical simulation – a "good idea whose time has come", *British Journal of Surgery*, *90*, 2003, 767 – 768.

[6] N. E. Seymour, A. G. Gallagher, S. A. Roman, M. K. O'Brien, V. K. Bansal, D. K. Andersen & R. M. Satava, Virtual reality training improves operating room performance: results of a randomized, double-blinded study, *Ann Surgery*, *236*, 2002 458-463

[7] T. P. Grantcharov, V.B. Kristiansen, J. Bendix, L. Bardram, J. Rosenberg & P. Funch-Jensen, Randomized clinical trial of virtual reality simulation for laparoscopic skills training, *British Journal of Surgery, 91*, 2004, 146–150.

[8] S. Dawson & J. Kaufman, The Imperative for Medical Simulation, *Proceedings of the IEEE*, *86(3)*, 1998, 479-483.

[9] Z. Kulcsár, A. Aboulafia, T. Hall & G. Shorten. Determinants of learning to perform spinal anaesthesia – a qualitative study. *European Journal of Anaesthesiology,* 2008, In press

[10] E. Lövquist, Z. Kulcsár, M. Fernström, A. Aboulafia & G. Shorten. The Design of a Haptic Simulator for Teaching and Assessing Spinal Anaesthesia. *Proceedings of the 5th Intuition Conference*, Turin, Italy, 2008, In press.

[11] M. Srinivasan & C. Basdogan, Haptics in virtual environments: Taxonomy, research status, and challenges, *Computer Graphics. 21(4)*, 1997, 393-404.

[12] D. Albert & J. Lukas Eds., *Knowledge Spaces: Theories, Empirical Research, and Applications*, (Mahwah, NJ: Lawrence Erlbaum, 1999).

[13] J. Heller, C. Steiner, C. Hockemeyer, D. Albert. Competence-based Knowledge Structures for Personalised Learning. International Journal on E-Learning, *5(1)*, 2006, 75-88.

[14] D. Zhang, D. Albert, C. Hockemeyer, D. Breen, Z. Kulcsar, G. Shorten, A. Aboulafia & E. Lövquist. Developing Competence Assessment Procedure for Spinal Anaesthesia. *Proceedings of the 21th IEEE International Symposium on Computer-Based Medical Systems,* Jyväskylä, Finland, 2008, In press.

[15] J.-P. Doignon & J.-C. Falmagne, Spaces for the assessment of knowledge, *Int J Man Mach Stud*, *23*, 1985, 175-96.

[16] J.-P. Doignon and J.-C. Falmagne, *Knowledge Space*. (Berlin: Springer, 1999).

[17] K. Korossy, Modeling knowledge as competence and performance, in *Knowledge Spaces: Theories, Empirical Research Applications*, D. Albert and J. Lukas, Eds., (Mahwah, NJ: Lawrence Erlbaum Associates, 1999, pp. 103-32).

[18] R. M. Harden, M. Stevenson, W. W. Downie, & G. M. Wilson, Assessment of clinical competence using objective structured examination, *Br Med J*, *1(5955)*, 1975, 447–451.

[19] J. Tetzlaff, Assessment of Competency in Anesthesiology, *Anesthesiology, 106,* 2007, 812-825.