Learning with Simulations in Medical Education
Validity and Design of Learning Settings in Particular Contexts

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Abstract: The aim of this symposium is to initiate the discussion on learning with simulations in the medical sector. Indeed, this domain represents a very complex and dynamic environment dealing with a great variety of knowledge (declarative, pragmatic, procedural, gestural, etc.) that can be learned under diverse pedagogical forms. The four presentations describe various forms of computer-based technology, which aim to enhance the teaching and learning capabilities of doctors mostly in the form of 3D visualisation, full-scale simulation and haptic technology. They focus on research conducted in the area of anaesthesia and surgery. These studies emphasize on the necessity to adapt the learning environment to the objective of the training (validity of the learning situations). If the presentations are specific to the medical domain, their methodological and theoretical approaches can be generalized and used in other learning situations.

Introduction

For several years, a lot of training settings have been designed and analysed in medical context. For example, modern simulation (3D, haptic, full scale, etc.) in medicine allows performing professional gestures in a quite realistic environment. However, these environments have limited capacity to efficiently support training because of the difficulty to provide learners with the relevant feedback in the relevant form (Issenberg et al., 1999). Indeed, the medical domain represents a very complex and dynamic environment which deals with a great variety of knowledge that can be learned under diverse pedagogical forms. So far, research activities from different perspectives acted independently to a large extent. One goal of this symposium is to bring together researchers from these different perspectives to explore potential synergies with respect to concepts, methods and technologies.

Highly specialised medical activity involves different aspects of knowledge: declarative, pragmatic, perceptual and gestural (sensorimotor). Declarative knowledge deals with explicit elements of knowledge, it is made for communication (encyclopaedic knowledge, like anatomy). Pragmatic knowledge allows the expert to use the declarative knowledge and apply it to a particular situation. It involves problem solving, reasoning, control and prediction. It is an experimental part of knowledge, and it is validated by empirical means. However it still remains a worded part of knowledge, which enables communication. This is not the case for the last type of knowledge: perceptual and gestural knowledge. It deals with dexterity, eye-hand coordination, spatial skills, and it is transmitted by a guided imitation. It cannot be easily worded, and relies on some pragmatic representation and validation frameworks. As declarative knowledge is well identified, and can be modelled by well-known computer representations, pragmatic and gestural knowledge are much more difficult to identify and represent.

Learning medicine implies the learning of each of these kinds of knowledge, their interactions and their use in practice. Different learning situations are involved in this process. Classical transmissive lectures, problem-based learning, laboratories, operating under supervision… different technologies can be introduced in these learning situations. The technical and epistemic characteristics of the environments influence the kind of learning they are relevant for. These learning situations are both integrated in the "operating under supervision" phase, or constitute an additional phase, aiming at reducing the gap between theory and practice. The related technologies constitute a very important and relevant category of the medical training. In this wide category we will distinguish different kind of simulators according to their technological characteristics and accuracy (Romero, Ventura, Gibaja, Hervás, & Romero, 2006):

- Screen-Based Simulators is the most classical, typically the user indicates the sequence of action using the proposed interface and the system shows the state result of this manipulation.

- Virtual Reality (VR) is a technology allowing a user to interact with computer-generated space and objects which are presented in a three-dimensional format (the most current) and sometimes with sensory information (sound, tactile, etc.). While its use is still not widespread, virtual reality is finding its way into the training of health care professionals. Use ranges from anatomy instruction, to surgery simulation (particularly in laparoscopy) are held to examine the latest research in utilizing virtual reality in the medical fields.
- Training Devices and Part-Task Trainers, of intermediate fidelity, allow users to acquire the skills for a specific task prior to patient contact.
- Realistic Simulators are realistic human simulator and they include an organ or a life-mannequin which simulates a real patient. Special sensors allowed detection of the face mask and tracheal tube. Several preprogrammed events, including patient bucking, cardiac arrest, changes in blood pressure etc., could be activated.

All these learning environments train or improve some knowledge. However, an important problem in the design of these learning settings in medicine is the lack of theoretical background of these projects. They mainly focus on the training of a technique to learn without taking into account some pedagogical aspects or cognitive components of the task. Because of the lack of theoretical background, most of these training settings have a problem of validity: they do not train the skill that they have to (content validity) or they do not represent the task that they want to train (construct validity, Gallagher, Ritter, & Satava, 2003). This important problem of validity can explain why a lot of these (expensive) training settings are not used by residents or are inefficient in the learning of medical specialities. In fact, first, medical students or residents do not have a lot of time for training, thus, this training has to be as efficient and relevant as possible, and secondly, the financial budget involved in these training settings is high and has to be used in an appropriate and necessary way. In this context, it is thus essential to study the appropriateness and the validity of these training settings in order to improve their benefits for the learning of medical procedures.

This symposium aims to study the validity of some training settings, to ask questions on the design of these learning situations, to present limits of some settings and to suggest some changes that have been made in order to improve the relevance of the training setting. If this symposium is specific to the medical context, the discussion on learning and validity and the theoretical approach of the papers go beyond a specific domain and can be applied to other domains (work situations or learning settings, e.g. aviation). The four presentations describe various forms of technology, which aim to enhance the teaching and learning capabilities of physicians mostly in the form of 3D visualisation, simulation and haptic technology. They focus on research conducted in the areas of anaesthesia and surgery. The first presentation focuses on the use of inanimate models in the training of surgical gestures. The findings suggest that the training environment has not to be necessary very sophisticated and realistic in order to reach some learning objectives. The second presentation describes the steps for the designing of a haptic simulator for spinal anaesthesia. It emphasizes the need to consider not only the accurate recreation of the real world but also all the features of a learning system. In the same way, the third presentation describes the design of a screen-based and web-based simulator in orthopaedic surgery. Finally, the fourth presentation studies how observation can enhance learning with a full-scale simulator. For that, it analyzes the effects of a collaboration script in simulation-based courses. The findings suggest that collaboration scripts can help turning passive learning situations during observation phases into more active and focussed ones.

Beyond the focus on medical context, all presentations have some important common characteristics: they use new technology in order to enhance learning, they place the pedagogical and cognitive aspects at the centre of their approach and they are mainly multidisciplinary (the research teams involve physicians, psychologists, pedagogues, engineers and computer scientists).

The objective of this symposium is to discuss with the audience in a participative way about some challenges of the learning in this domain which is directly related to the introduction of new technology and computer factors. It aims to present some of medical educational paradigms in relation to the kinds of knowledge (declarative, pragmatic, procedural, gestural, etc.), pedagogical learning forms (operating under supervision, problem solving based learning, collaborative, etc.) and technological devices (full-scale simulator, screen-based simulator). If the presented researches are specific to the medical domain, their methodological and theoretical approaches can be generalized and used in other learning situations.

Validity of bench models in learning minimal invasive surgery

Learning in surgery is a very long process, including a lot of different types of knowledge and competencies (anatomical identification, diagnosis activity, psychomotor skills). All these knowledge types are principally learned in operating room, despite of the limits inherent to this mode of training (risk for the patient, resources in time, personal). Moreover, with the introduction of some new surgical technologies, the training becomes more difficult and has to be organised in another way. The main innovation over the past decade is the minimal invasive surgery, which has revolutionized general surgery, laying new obstacles for surgeons attempting to acquire laparoscopic skills. This surgical technique is performed with the help of a camera and long instruments introduced through small incisions into the body. Laparoscopic surgery brings a lot of advantages, particularly for the patient (very small incisions, smaller risks of infections, higher accuracy due to the magnification by the camera, fast recovery). For all these reasons, minimally invasive techniques are now ubiquitous and indispensable in the management of surgical disease. However, despite the clinical benefices, significant challenges have been noted: the view of the surgical site is indirect and restricted, the surgeon has to observe and manipulate tissues and organs through very small incisions with long and rigid instruments, the tactile perception is lost, the feedback of the action is principally visual with a 2D image and finally, the degree of freedom for the instruments movements (DOF) is restricted at 4. All these drawbacks are responsible for the long learning curve observed in the training of the residents (Blavier, Gaudissart, Cadière & Nyssen, 2007a, 2006; Sidhu et al., 2004; Forbes, DeRose, Kribs, & Harris, 2004). A new robotic system has been designed in order to suppress main drawbacks of classical laparoscopy: it allows to regain 3D visualization of the operative field (perceptive advantage) and the DOF lost in classical laparoscopy (dexterity advantage).

In this context of new technology introduction, we evaluated the validity and the role of bench model (inanimate trainers) on the training of medical students and residents in these two techniques (classical and robotic laparoscopy, cf. Blavier, Gaudissart, Cadière & Nyssen, 2007b). To separately evaluate the effect of instruments dexterity and of depth perception according to the task, 60 medical students without any surgical experience were divided in 3 groups: one using the robotic system in 3D, another using robotic system in 2D, and the third using traditional laparoscopic technique (2D view). After a phase of familiarisation (pick and place) with the technique of their condition, subjects performed four specific fine motor tasks of increasing complexity (checkerboard, rings route, circle pattern cutting and suture and knot). We measured the speed, the accuracy and their subjective impressions about their performance (satisfaction, self-confidence and difficulty). Data showed that the training with these two techniques differently improved the performance and gesture accuracy of participants. Classical laparoscopy that is performed with a 2D view and low dexterity, required more practice than robotic system that is more intuitive in the view mode and gestures. Indeed, 2D view is less natural and requires more controlled cognitive processes and thus a specific training in order to act in a 2D world (as shown in cognitive psychology, cf. Marotta, Kruyer, & Goodale, 1998). Because of this difference between the two techniques, all tasks were not appropriate for the two techniques according to the learner's expertise: some tasks were too easy with one technique (e.g. pick and place in classical laparoscopy) and very difficult with the other while it was the contrary for another task (e.g. suture and knot were very difficult in classical laparoscopy and not with the robotic system). Performances in rings route task were the only one to be significantly correlated to the other tasks: indeed, rings route resumed a lot of useful and usual fine movements required in minimal invasive surgery and reproduced some components of the complexity of the suture gesture (except the knot). Moreover, scores on this task were highly correlated with the subjective evaluation of satisfaction, self-confidence and difficulty. Therefore, this task seemed to be a very efficient and accurate way to evaluate minimal invasive systems or to improve and train surgical performances. Furthermore, we showed that training with one technique did not lead to the mastery of the other technique: the transfer of skills from a technique to the other was very difficult. In conclusion, the training with both techniques out of operating room has to be differentiated and more intensive in classical laparoscopy (Blavier et al., 2007a,b).

Concerning the bench models, this study showed that using bench models allows us to understand better the nature of the cognitive and motor processes involved in the execution and in the control of laparoscopic gestures. This allows us to improve the quality of the training devices. Moreover, if bench models improve surgical performance out of operating room, several studies have shown that the skills acquired on bench models are transposable in operating room (Hamilton et al., 2002). Contrary to animals or cadavers, the principal advantages of bench models are their low cost, the possibility to repeat several times a same task at any time and thus to evaluate a training or to assess a performance (Stone & McCloy, 2004; Gallagher, Ritter, & Satava, 2003). Finally, studies using bench models show a benefit of the training in the improvement of the performance but also in the feelings of mastery, familiarity, satisfaction, self-confidence and facility, which are essential factors of well-being, motivation, accurate performance and new technology acceptance in operating room (Issenberg et al., 1999; Hamilton et al., 2002). By all these characteristics, most of studies encourage the use of bench models in training of surgical skills in parallel to traditional learning in operating room, but the type and the difficulty of the task have to be designed according the level of subject's expertise and adapted to the technique to train.

Designing a simulated haptic learning environment for spinal anaesthesia

One of the strengths of simulator-assisted learning is the application of knowledge in a hands-on approach without patient risk or time constraints. In the medical profession simulation technology is gaining widespread acceptance because of its ability to demonstrate multiple patient problems, the reproducibility of content, safety of the environment, and the ease of simulating critical events (Issenberg et al., 1999). The simulator offers the ability to provide hand-on learning in a risk-free, realistic environment, including constructive feedback and error correction that is crucial in the development of expertise in medical practice (Ericsson, Krampe, & Tesche-Rmer, 1993).

Clearly there are promising potential applications for simulation-assisted learning in the field of medical procedural skills. However, to date, much of the research has taken place in a fragmented manner directed primarily at modifying simulation technology and "parachuting" it into a variety of medical work or training environments. Many simulators have been developed focusing on the technical aspects, such as reproducing the physical and sensory environment and hereafter evaluated in educational settings, e.g. for anaesthetic procedures (Gorman, Krummel, Webster, Smith, & Hutchens, 2000; Dang, Annaswamy, & Srinivasan, 2001; Wilson, Pallotta, Reynolds, & Owen, H., 2003; Magill, Anderson, Anderson, Hess, & Pratt, 2004; Färber, Heller, & Handels, 2007).

It is of course important that the value of a simulator as an educational method must be explored and its usefulness over existing methods identified, before widespread implementation of new technology, as argued by Morgan, Cleave-Hogg, McIlroy and Devitt (2002). However, designing simulation tools for training also imply designing educational activities and educational context. Thus, pedagogical issues should be incorporated into the design process from the very beginning. Designing a simulation-based training system need to address technical, clinical and pedagogical considerations. As argued by Shaffer et al. (2001) the design process need to consider not only the accurate recreation of the interactions among anatomy, pathology and therapeutic actions, but also features of a learning system, such as functionality that allow rehearsal and practice, instructor review and testing capabilities. Only a full simulation system, including a high-fidelity simulation engine, a well developed simulation curriculum, and a robust set of interactions with other physicians, can develop the most subtle and important parts of a physician's skills (ibid).

Similar considerations were applied to our project of design and development of a simulator for "spinal anaesthesia" that involved researchers from the University Hospital and our University centre of design. Simulating the components of this procedure, adding learning features and making the simulation usable for a medical training is multidisciplinary research collaboration. The research team represents medical clinicians, medical educators, psychologists, engineers and computer scientists. All researchers were involved in all the phases of the research process although to a different degree. The case studies were designed and conducted by the medical experts with methodological support from educational psychologists. The engineers and computer scientists designed and redesigned the haptic devise in close collaboration with the medical doctors and educational psychologists. The testing and interpretation of the results was conducted with all parties involved.

The lack of design approaches in the area of simulation-assisted medical learning was incentive to the proposed approach, which we named the Design-Based Medical Training (DBMT). If improvements in simulator-assisted training are to proceed effectively, we propose to apply the following basic design principles:

1. Learning outputs, including core competencies, should be defined and be integral to the development and implementation of the learning systems.
2. A multidisciplinary approach should be applied to the design and evaluation of technology (virtual reality, simulation and web-based learning) and through an iterative process to its applications.
3. Applications of such systems should include, not just training, but selection for specialty training, credentialing (and re-credentialing) and competency-based assessment of medical doctors. Advanced forms of these applications can result in adaptive and personalised training programmes.
4. The role of human-human and human-machine interaction should be factored into the development of training programmes at the design stage.

The training in "spinal anaesthesia" was selected to serve as a pilot for developing an improved system of learning using an integrated approach. The DBMT approach was adopted with the aim to develop a simulated-assisted learning environment for training of the psychomotor and cognitive skills involved in "spinal anaesthesia", including a training program/curriculum.

Perform this technique the anesthetist needs to place a needle in the thin layer of fluid that surrounds the spinal cord. As there are no visual clues, the doctors need to 'feel' the resistive forces as the needle passes through the different layers (skin, subcutaneous tissue and ligaments). Verbal explanation of these sensations to trainees is obviously very difficult. Recognition and identification of the different sensations can only be learned by experience - although having a mental representation of the anatomy and the procedure also seems to be important.

In order to define core competencies, we carried out a pilot study in a large teaching hospital over a period of one year. It applied both qualitative and quantitative data such as questionnaires and focus group discussions, and involved in total 66 participants (consultants, trainees, nurses and patients). The results from the study were essential in order to identify so-called "user requirements" for the design of the system. For the first prototype of the simulator we focused on recreating the feel of going though the different layers of tissue, which was argued to be one of the most important indications of correct needle insertion, and also the most difficult aspect of the process to explain to trainees. The specification of the authentic 'feel' was carried out with a number of consultants and trainees based on a haptic devise that were designed for this purpose (the ‘landscape’ model with force feedback). The results were applied to the design of the haptic devise which consists of: i. the different sensations for surface resistance, for example needle tip on skin; ii. pop-sensation, when the needle breaks through and proceeds to the underlying layer; iii. viscosity, the sensation of going through tissue.

The simulator applied a PHANTOM haptic device from SensAble Technologies Inc. The interface consisted of a model of a spine and included educational components such as audio and visual feedback The ‘requirement’ to be able to visualize the procedure was created using 2D and 3D animations. While performing the procedure it is possible to simultaneously view the needle insertion in a small window on the interface. It is also possible to rotate the image of the (transparent) back to view where the needle had been placed.

The ability to visualize the process goes beyond what is possible in real settings. This feature makes the simulator powerful for training purposes. Viewing the same image of the spinal cord from multiple perspectives, and having the ability to reflect and discuss various options before a second attempt makes the learning process easier and possibly faster. To learn by exploring, by making mistakes and by responding to feedback in a safe environment are valuable features of effective learning processes.

An initial assessment of the haptic devise was carried out with a number of consultants and trainees with a very positive result. However, a more methodical assessment is needed to identify which aspects of the simulated procedure are required for successful training, such as e.g. in what way visualization support building a mental model of the procedure, the relationship between the haptic sensation and the visualization, and the introduction of problem-based learning situations. The validation of its teaching and learning efficacy will be conducted in the near future in a number of hospital settings applying a Competence-based Knowledge Space Theory (Heller, Steiner, Hockemeyer, & Albert, 2006). Following this a curriculum will be developed which includes training on the final prototype of the hactic learning environment.

Learning by Problem solving: a case study of screen-based and web-based simulations design

Percutaneous techniques in orthopaedic surgery have been developed during these last 15 years, enhancing the safety of patients while reducing morbidity and duration of recovering. These techniques imply that the control of surgeons’ actions is entirely made by X-rays taken during the operation. There is no more open surgical area. This shift in means of control, from direct 3D visualisation to indirect 2D visualisation, evidently modifies the way the techniques can be taught and learned. In French University Hospitals surgical techniques are taught during real interventions, by observation and increasing responsibilities given to the resident by the expert surgeon. This pedagogical set up, which was sufficient when direct visualisation was possible, presents some limits for the learning of percutaneous techniques.

Our work aims to design a computer based learning environment to accompany and foster the learning process in percutaneous orthopaedic surgery. The design process implies a pluridisciplinarity of researchers: psychologists, educationalists, computer scientists and surgeons. In a first step the approach consists on a crossed analysis of the prescribed technique, based on academic articles and courses, and the real activity of surgeons during the operations, based on videos and post verbalisations of operations. Results show evidence of discrepancies between prescription and reality, even some contradictions and violations. The second step of our design process focuses on the elicitation of pieces of knowledge used by surgeons in action to operate. This long term analysis of expertise has conducted to the formalisation of about a hundred of knowledge elements, together with the definition of their domain of validity (Vadcard & Luengo, 2005). One key aspect of the design process of the project is that the results of these psycho-cognitive analyses have been expressed in a sufficiently formalised way to allow their computer implementation. The network of problems (defined by their didactic variables such as: kind of lesion, quality of the bone, age of patient…), actions performed (insert a pin, take an X-ray…), controls of actions (the elicited elements of knowledge), and systems of representation (X-ray, speech, vision, proprioception…) is the key element of a dynamic learning environment which can diagnose learners’ knowledge and calculate appropriate feedback to be given.

The learning environment architecture relies on the communication of different components. A screen-based simulator for the placement of screws in case of pelvis diseases allows learners to act, and produces traces of these actions that are communicated to the diagnosis component. This one, thanks to the traces of actions and the previously described network, calculates hypothesis concerning the learner’s used knowledge during the problem-solving session. These hypotheses are communicated to a didactic decision making component, which calculates the best fitted feedback to be given to the learner, according to the actions performed (Luengo, Mufti-Alchawafa, Vadcard, & Vu Minh, 2007). At the present state of development of the project, possible feedbacks are the proposition of another problem to solve (the choice of the problem is calculated thanks to the didactic variables), a precise part of an online course to consult, a clinical case to consult (clinical cases can play the role of counter-examples or reinforcement). Evidence is already validated of learning added-value of the use of the single simulator component. Further validations are ongoing, dealing with two aspects of the work: the pedagogical added-value of the whole environment, and the validity of the design process.

Learning with full-scale simulations: Effects of a collaboration script for observers

Simulation-based learning can play a significant role for learning about the real world: simulations provide learners with rich and dynamic situations in which knowledge is supposed to be acquired that can hardly be obtained in the context of traditional lectures (see Swaak, van Joolingen, & de Jong, 1998). Most patient simulator trainings in medical education do not solely aim at fostering domain-specific (medical factual) knowledge of the learners, but also more domain-general knowledge, like heuristics to cope with situations of medical crisis for instance. The key points of Crisis Resource Management (CRM) are examples for such heuristics and include principles like "know the environment", "call for help early" or "communicate effectively" (Howard, Gaba, Fish, Yang, & Sarnquist, 1992; Rall & Gaba, 2005). Ultimately, it takes more than just medical factual knowledge to be successful as a health professional: effective communication and adequate strategies to prevent and handle critical incidents are essential aspects when performing in medical crisis situations.

Active participation is considered a major advantage of simulation-based training courses likewise. However, only few persons can usually act concurrently in the simulator hands-on while the remaining group observes the running scenario live or via video. Most of the individual learners' time in simulator courses is actually spent watching others perform. While learning through observation can be beneficial under certain circumstances (see Rummel & Spada, 2005), the observational phases found in many simulator courses tend to be hardly structured, leaving the observing participants in an unfocussed and passive state.

In our research, we have explored how collaboration scripts can be used to instructionally support students in these observational phases. In short, collaboration scripts are instructions that distribute roles and activities among learners and can also include content-specific support for task completion (Kollar, Fischer, & Hesse, 2006). There has been good empirical support from many domains on the positive effects of collaboration scripts, for example the individual acquisition of knowledge (see King, 2007), the acquisition of domain general knowledge (Stegmann, Weinberger, & Fischer, 2007) or the improvement of interaction between learners (Weinberger, Ertl, Fischer, & Mandl, 2005).

In a field study, effects of a collaboration script for observational phases in a full-scale simulator course with video-assisted debriefing in anaesthesia were investigated with 35 medical students from the University hospital of Tuebingen. The empirical study had a control group design and aimed to investigate the effects of a collaboration script in simulation-based courses with video-assisted debriefing on the individual learning process, the collaborative learning process and the individual learning outcome with respect to applying the CRM heuristics in crisis situations. The collaboration script was represented on a sheet of paper and designed to support the individual learning processes by drawing the attention of the students to specific CRM key points during the observational phases. Moreover, the script introduced a collaboration phase where student dyads were asked to reciprocally suggest examples of appropriate as well as inappropriate or missing applications of CRM from the respective session observed. A control group attended the regular simulator course.

Even though the whole intervention was rather short, results showed the expected positive effects of the script on individual and collaborative learning processes: scripted students showed an increased focus on CRM heuristics ($t(13.00) = -4.13$, $p < .001$, $d = 1.56$) and improved information exchange on CRM ($t(12.00) = -5.62$, $p < .001$, $d = 2.21$) as compared to the control group. They were also more active during the observational phases with regards to elicitation ($t(16) = -2.47$, $p < .05$, $d = 1.45$), externalization ($t(15.96) = -2.67$, $p < .05$, $d = 1.14$) and consensus building ($t(15.81) = -4.63$, $p < .001$, $d = 1.94$). Regarding individual learning outcomes, subjective and objective measures diverged strongly, resulting in a complex pattern with no clear advantage of the script condition: interestingly enough, the self assessment data revealed that students in the control group actually perceived a significantly higher improvement of CRM skills throughout the course than the scripted students ($t(31) = 2.36$, $p < .05$, $d = .88$). The groups did not show any significant differences in a CRM skills test at the end of the course.

Findings suggest that collaboration scripts can help turning passive learning situations during observation phases into more active and focussed ones. The individual and collaborative learning processes could be fostered, but the script failed to show the expected positive effect on the learning outcome, leading us to the assumption that either the intervention was too short or that the validity of the CRM skills test was insufficient. With regards to the divergence found between the perceived improvement of CRM skills and the low scores in the CRM skills test, one could speculate the danger of developing illusion of competency (Stark, Gruber, Renkl, & Mandl, 1998) was eventually reduced by the collaboration script. Further research including both longer periods of script intervention and a more fine-grained analysis of processes and outcomes is needed.

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