

A surgical Virtual Learning Environment

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Abstract

A computer based Virtual Learning Environment is proposed for training and evaluating novice surgeons. Although this Virtual Learning Environment is thought to be useful in other learning situations as well, especially where knowledge of different complex procedures and the ability to correctly assess a complex situation is critical, in this project we specifically focus on vascular surgery.

This environment will be developed as part of the DIME project (Distributed Interactive Medical Exploratory). We are building this Virtual Learning Environment using a new navigational metaphor, which affords modeling the learning process, rather than focusing solely on modeling the operating room.

This 'navigational metaphor' can be thought of as an semi-three-dimensional interface to a database containing multimedia fragments and expert annotations of the knowledge domain under study.

Need for Virtual Learning Environments in surgical training

Two educational practices are recognized in conventional surgical training:

One is the conventional surgical teaching method: a close daily working relation is established between the experienced surgeon and the relatively unskilled trainee [1] (fig. 1). In a setting where more trainees must learn more in less time, this places an unrealistically high burden on both the trainee and the experienced surgeon. It's also a rather cost-intensive teaching method [2].



Figure 1: traditional surgical training

The other is related to the way new operating techniques find their way to clinical use: surgeons hear of new techniques at conferences, through demonstrations in centers of excellence or through the literature, and decide to implement these techniques in their own practices. This often leads to a period of trial-and-error before the new operating technique is well established, which

is not beneficial for the patients. The lack of sufficient training opportunities and formal skills assessment in this scenario is problematic.

These educational practices are not sufficient in a time when surgery is becoming increasingly complex. For one thing, more pathologies are becoming candidates for surgical treatment and more specific surgical techniques for each of these pathologies are being developed. The techniques themselves are becoming more complex, due to the continuous creation of more sophisticated equipment and the patient's higher expectation of the outcome of the procedure (loss of function is hardly acceptable anymore). The increasing age of patients electable for surgery adds further complexity to surgical procedures.

Because of the factors mentioned above, the 'turnover' of surgical techniques is getting higher. As a result, the learning curve to master these techniques is getting steeper and longer, and in addition a need for 'life long learning' emerges [3].

Several approaches to surgical training are taken to overcome these disadvantages, most notably are the use of animal models, the use of cadaver models and the use of computer-related technology. This last approach seems to be the most promising candidate for future surgical curricula, both cost and flexibility of this approach comparing favorably in comparison to the others.

Drawbacks of Virtual Learning Environments so far

A lot of different hardware/ software configurations are presented in the literature under the heading of virtual learning environments (VLE's), ranging from interactive software applications [4, 5, 6], haptic workbenches [7], laparoscopic simulators and electronic manikins [8, 9, 10, 11], to telesurgery approaches [12].

What these approaches have in common is that the focus is basically on making them as realistic as possible, which continues to be a challenge, for instance in the areas of haptic feedback and visual effects as realistic bleeding, cutting, etc. This has led to a predominantly technical approach to VLE construction. Realizing that many VLE's are approaching a state of maturity and are being used as training and assessment tools in surgical curricula, work is starting on evaluating the effectiveness, ergonomics, and usability of these environments [13], which is badly needed, since many basic questions regarding the transfer of skills and/or knowledge learned in a VLE to surgical practice are largely unanswered.

One important characteristic of the hard- and software that are used to build these VLE's, is that they afford the implementation of more advanced learning paradigms than the instructional approach that is demonstrated by most of them. More on learning paradigms follows in the next few paragraphs.

Instruction versus construction

When learning relatively non complex skills, where there is basically one way to achieve the desired outcome (e.g. tying one's shoes), a traditional method of instruction may be a good way to achieve this goal. In many real world domains however it is impossible to reach one's goals in such a structured, one-dimensional way, simply because the factors influencing the outcome are many, influencing each other in complex non-linear ways, and stemming from a host of different conceptual backgrounds. In surgery for instance, factors as diverse as patient's age, anatomical variability, patient's medical history, physiology of involved anatomical structures, etc. are factors whose features and interactions must be part of the practitioner's knowledge. Moreover, the practitioner must integrate this knowledge in his daily practice of performing surgery. This in turn

refines, and adds to, the practitioner's knowledge. The result of this combination of knowledge and practice can be called experience, and is needed to complete even the simplest of surgical procedures. Traditional instructional approaches fail to take into account both the unpredictability of the application of knowledge, and the differences in previous knowledge and learning styles of different learners, so a different approach is needed.

The traditional approach to optimize learning through 'just-in-time' information and feedback can be summarized as instruction. As the trainee has a larger repertoire of prior knowledge and skills, this 'cybernetic' approach has the disadvantage of not enough stimulating the meta-cognition and the potential to learn-to-learn by the trainee [14, 15]. The complement and to a certain extent the alternative for instruction is learning by construction. Constructivism is the awareness that learners undergo a highly personal process, due to their cognitive style, various ways of mental imagination and differences in prior knowledge as well. Under this paradigm, trainees in surgery need the opportunity to acquire a model like the rules underlying the trade-off in artery intervention, in an unthreatening situation with a larger bandwidth for experimentation and reflection, before the actual practice with real patients take place. The connotation of constructivism is that the learner actually builds his/her conceptual knowledge upon prior analogue knowledge.

Guidelines derived from constructivist learning paradigms

Leaning towards a constructivist view of education, cognitive flexibility theory [16] gives some useful guidelines when designing computer-based systems for learning in such a complex knowledge domain. Using a metaphor derived from Wittgenstein of criss-crossing a conceptual landscape in order to learn about the whole terrain, he uses the possibilities of hypertext to implement a system that deepens a learner's understanding of the classic movie 'Citizen Kane'. While not being true constructivist, knowledge is still presented as an invariable outcome somewhat disconnected from the actual learners and their preexisting knowledge, it nevertheless gives many useful hints as to how to present complex information in such a way as to become more easily comprehended by the learner.

An important feature that is implemented in the VLE presented here, derived from this theory, is to afford and stimulate learners to study the same material from a variety of conceptual angles.

The 'cognitive apprenticeship model' [17] is another illustration of the shift from guidance to self-control; it claims that effective teachers involve students in learning by problem confrontation even before fully understanding them. Essentially you may say that learning is in fact the recreation of earlier cultural processes and evidences. Though this is an expensive phenomenon, it has the power of revalidation, as learners will also check the presented expertise against their own experiences. Also the regeneration facilitates the knowledge activeness during life; simply storing and remembering transmitted ideas is less adequate to pop-up in new problem settings. One way to implement this is by presenting multiple cases, which can be studied with or without expert annotations.

'Case-based reasoning' is an approach that assumes that people refer to experience of past cases to serve as guidelines when a new, similar case arises. To present learners with a variety of cases taken from the field under study is an important guideline derived from this approach [18].

The way in which these guidelines are implemented is subject of much of the following paragraphs, which detail the design and possible uses of the presented VLE.

Design

It is recognized that several factors will influence the building up of experience once sufficient preliminary medical domain knowledge is gathered by a learner; three of those factors are singled out to function as dimensions in a cube-like interface (fig.2) that allows the learner to navigate in prior surgical interventions

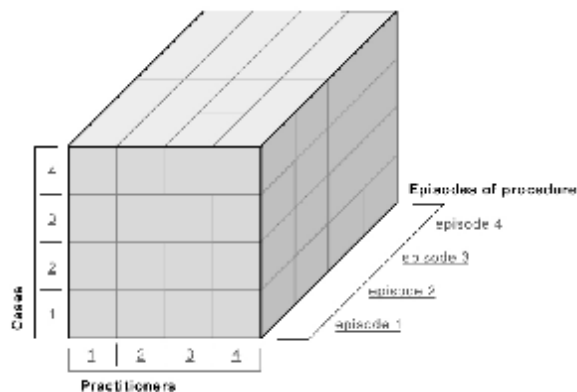


Figure 2: interface to database

The first dimension (called Cases) is the set of indexed patients who vary from showing standard features of a given pathology to patients who show additional variations and complications of such a pathology. These complications will often radically alter the actions needed to be taken in the medical procedure under study.

The second dimension (called Practitioners) will implement the opinions of different domain experts with respect to the cases & episodes that make up the other two dimensions of the interface. It will allow learners to get a feel for what is critical to a given procedure in a given case, and what is not. For instance: noticing that all experts opt for one particular stentgraft in a given AAA repair procedure, but vary highly in the way they stitch up the patient ending the procedure, will make it clear to the learner that the former is a highly critical factor, while the latter allows for a broader range of possible solutions. This specific feature of the presented knowledge-based system even surpasses traditional one-on-one teaching in this respect. Another affordance of this dimension could be the inclusion of recorded procedures by freshmen demonstrating the many (or most common) thinkable flaws. At each of the suboptimal interventions the supervising surgeon should mark the reason for labeling the flaw as being suboptimal and activate links that show the proper interventions that should have been made.

The third dimension (called Episodes) captures the subsequent stages in the medical procedure under study. Two criteria for ordering them can be taken: The chronology of sub actions from early to later, versus the ordering from easy to complex. Analytical and experimental validation still needs to be performed in order to make a sensible choice here. In any case following the strict order of this dimension allows the learner to follow the prior interventions in it's chronological order.

A cell of this cube (a cubette) always consists of a scene taken from the procedure of a specific case with a specific expert, what this expert has done in that scene, and the annotations of the expert to that scene. These annotations can consist of written notes, video material, interactive 3D reconstructions, animations, photographs and graphics. The learner will have the possibility to make annotations as well, that later can be used to evaluate the learners progress and will help clarify difficulties in understanding.

Navigation

Since navigating the cube is almost identical to interrogating its content, in the following exposé navigational strategies are used as guidelines to the cube's functionality.

Point-clicking once & pressing 'enter' on any cubette brings the corresponding episode on screen.

Point-clicking once on one cubette and shift-clicking once on another cubette selects both cubettes. When up to four cubettes are selected, pressing 'enter' opens all episodes in a split view.

When more than four cubettes are selected, pressing 'enter' brings annotated thumb-nails on screen (each thumbnail corresponding to the selected episode). Up to four thumbnails can be selected and activated in the same way one would select cubettes, to bring the corresponding episodes on screen.

Double-clicking a cubette selects the cubettes that lie in a row behind that cubette, in a plane orthogonal to the side from which the clicked cubette was advanced. Pressing 'enter' brings this row on screen as a field of annotated thumbs. Clicking any link (in the figures: {1, 2, 3, 4} horizontal, {1, 2, 3, 4} vertical or episode {1, 2, 3, 4}) preselects the corresponding plane of cubettes (fig. 3).

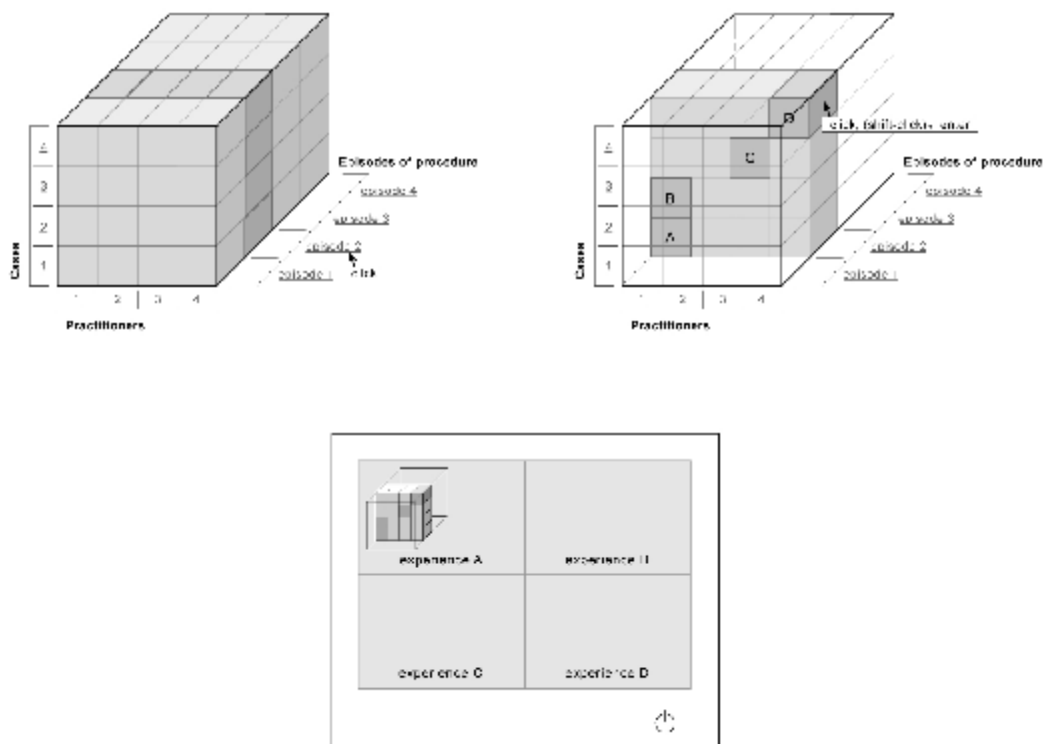


Figure 3: selection of cubettes

So, depending on the plane from which the cube is advanced, a complete procedure from one practitioner for a specific case can be assessed, all practitioners for one case and episode can be selected (fig. 4), allowing assessment of the surgical strategies of different practitioners for an episode in a specific case; or all cases for one practitioner and one episode can be selected, allowing assessment of the surgical strategies of one practitioner in the same episode on different cases.

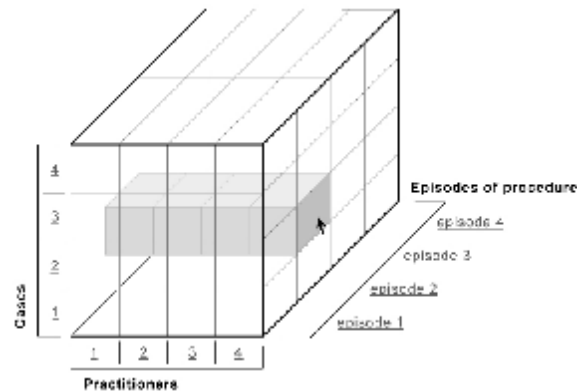


Figure 4: preselection of all practitioners for one case and episode

Hyperlinks are used to guide the learner to relevant other cells, depending on the choices made in the current cell, but can also be used to show paths other learners have taken.

This framework can be of use in other VLE's as well; especially those which prepare learners for work in environments where knowledge of different complex procedures and the ability to correctly assess a complex situation is critical. In any Virtual Environment, a learner can explore critical, life-threatening situations, without the real-life consequences of making a wrong decision.

In fact, any database containing at least three parameters can be navigated as outlined here, though not every database might benefit from it. Besides databases containing (multimedia) material optimized for learning, probably databases relating to actual three-dimensional information (e.g. databases containing geological information) can successfully be studied within this framework.

Possible user scenarios

The same knowledge embedded in the proposed learning system could be integrated in different ontologies: it is thinkable that surgical trainees, as well as nurses in training or anaesthesiological trainees are faced with the same patients and procedures, yet described from a different experts-domain perspective.

A multi-user scenario, based on cubes that are identical in cases and procedures, yet different in the way this knowledge is annotated, is thinkable as well. An indication for the importance of this social aspect comes (i.e.) from Montgomery et al. [19], who describes ten years of research into building and evaluating VR hardware in medicine, and who comes to the conclusion that the implementation of teleroboting techniques in the operating room is largely hindered if it doesn't allow for a natural communication between the surgeon and his team, despite the hardware's superior amplification of a surgeon's skills.

A scenario in which learners state their goals before starting to explore the VLE, and then are logged in their behavior in the VLE would open other interesting areas of investigation. Based on the log data generated by this VLE, the supervisor and learner can evaluate his/her progress and set out an appropriate personal learning path, and the coach can extract general trends in learning of his/her trainees, as well as differences in learning styles of individual trainees.

Not only can this system be used to let learners explore a knowledge field, and trace their behavior, when given an assignment to treat a specific case, without the help of expert annotation, this VLE can be an assessment tool as well.

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