Virtual reality for training medical skills

Piet Kommers and Jan-Maarten Luursema

University of Twente, Faculty of Behavioral Sciences,
Division of Educational Instrumentation, PO Box 217,
7500 AE Enschede, The Netherlands
Fax: +31 53 4894580 E-mail: kommers@edte.utwente.nl
E-mail: luursemajm@edte.utwente.nl
http://users.edte.utwente.nl/kommers/index.html

Steffan Rödel and Bob Geelkerken

Medical Spectrum Hospital, Enschede, The Netherlands
E-mail: s.g.j.rodel@planet.nl
E-mail: r.geelkerken@ziekenhuis-mst.nl

Eelco Kunst

Kunst en v Leerdam, Enschede, The Netherlands

Abstract: Virtual reality (VR) is becoming a serious candidate for a learning environment for complex skills like vascular interventions. The diagnostics, dimensioning and insertion of the endograft stent has been modelled as a decision-making process and now faces its implementation in a VR learning space. Beyond the topological and morphological aspects it is the orientation and navigation in earlier-performed successful interventions that offer the opportunity for a competence-based learning process before the candidate surgeon enters the clinical stage.

Keywords: virtual reality; medical training; vascular surgery; aortic aneurism; endoscopic interventions; conceptual orientation.


Biographical notes: Piet Kommers and Jan-Maarten Luursema are associated with the University of Twente and specialise in the application of Virtual Reality for Medical Training. Piet Kommers is Associate Professor and focuses his research on the cognitive effects of multimedia learning situations.

Jan Maarten Luursema builds upon his expertise as a Graphic Designer for medical research. His research thesis addresses on how stereoscopic 3D images promote visuo-spatial performance and higher-order learning that finally transfers to the actual medical task performance in the real patient.

Steffan Rödel and Bob Geelkerken are associated with the Spectrum Hospital in Enschede and intend to optimise vascular interventions like the placement of the abdominal aorta stent.
1 Introduction

The DIME project (Distributed Interactive Medical Exploratorium for three-dimensional (3D) Medical Images) aims at conceptualising, implementing and researching the effectiveness of a virtual reality (VR)-based pre-surgical planning and teaching environment. The DIME explorations aim at pre-surgical planning and teaching applications that will most likely result in better post-surgical results, lower healthcare costs and increased efficiency in the training of fellow surgeons. The project is a collaboration of a ‘computer science’ group from the University of Amsterdam (UvA) [1], a ‘medically oriented computer science’ group from the Leiden University Medical Center (LUMC) [2], a ‘cognition’ group from the University of Twente (UT) and medical specialists from LUMC and The Medical Spectrum Twente. A VR-based pre-surgical planning and teaching environment is proposed for novice surgeons. Although this environment is generic and can be put into practice in any medical specialisation where such 3D imaging techniques are in use, in this project we specifically focus on vascular surgery. This environment will be developed as part of the DIME project.

2 Surgical training in virtual reality

The surplus of surgical training skills as well as being oriented in medical disciplines like anatomy, histology, physiology, etc. is evident. The optimisation of its professional training elements requires the completion of the full repertoire of learning technology like the media spectrum and the full repertoire of new learning paradigms. The aim of this paper is to show the compatibility between the most advanced visualisation methods currently feasible for the average desktop work stations. The overall conception is that the clinical training will be gradually extended with VR learning systems in order to make the supervised real operations more effective and safe.

2.1 Relevance of virtual reality for medical training

- Surgical techniques have become increasingly complex, thus making the learning curve to master these techniques steeper and longer.
- More complex intervention techniques are being rapidly developed and introduced in the daily practice.
- The conventional surgical teaching method is a close daily working relation between the experienced teacher (trainer) and the unskilled pupil (trainee).
- In traditional teaching, the steep learning curve is encountered during interactions with real patients.
• The modern patient does not accept any mutilation attributed either to the disease or to the intervention.

• It is clear that perfect preoperative visualisation and planning and rehearsals of these interventions are essential.

• This means that while there is an increased demand for surgical training, experienced surgeons have increasingly less time and opportunity to cope with this demand. A dedicated medical virtual environment (VE) is badly needed to lift this burden off their shoulders.

• Also of importance is the possibility to allow trainees to explore critical situations and to let them experiment with an underlying model of the phenomena and processes in the human body, without the stress of having to deal with an actual patient.

• Virtual surgical tools should be available for life-long medical education and assessment of the surgical consultant.

• Based on the disappointing experiences with ‘Intelligent Tutoring Systems’ in the 1980s, we do not want to undertake the paradigm of ‘training dummy mannequins’ as it lacks the notions of ‘continuous learning’ and the ‘surgeon as active problem solver’.

2.2 The urgency for laparoscopic interventions

Nowadays many traditional surgeries are being replaced by laparoscopic interventions like the gall bladder extrusion via endoscopic procedures. Laparoscopic cholecystectomy is the preferred technique in many hospitals. However, the majority of the surgeons performing laparoscopic cholecystectomies are autodidactic. They had heard about the technique in congresses and visited clinical demonstrations in centres of excellence. Thereafter, they planned the first procedures in their own hospital. It is not surprising that the results are not as good as that reported in the literature in the early periods. The steep learning curve was moved on to the patients. Sufficient training and formal assessment of the surgical team before the introduction of the new technique into the hospital is not available. Moreover, more complex intervention techniques are being rapidly developed and introduced in the daily practice. An example of this is the endovascular exclusion of infrarenal aortic aneurysms with an endograft. Cuijper recently reported in his thesis that only after the endovascular experiences of 30 electively treated triple A patients that the complication ratio is sloping down to acceptable levels. In the Netherlands, only a few hospitals have such an experience. Also, the first ruptured aortic aneurysms are treated in the endovascular way with a very good outcome. However, this emergency procedure demands a large team having endovascular experience to be available during day and night. Gaining enough experience with this procedure is not possible in most of the hospitals in the Netherlands. Unfortunately, it is not possible to transport a patient with a ruptured triple A to a centre of excellence because of haemodynamical instability. In other words, the patients do not survive the delay of treatment due to transportation. The next generation of more complex endografts with the possibility of perirenal sealing is underway. The results of the first clinical experiments came from ‘down under’. It is
clear that a perfect preoperative visualisation and planning and a dummy operation of the whole procedure is essential.

2.3 The urgency for training in virtual reality

The conventional and current surgical teaching method, introduced more than a century ago, is a close daily working relation between the experienced teacher (a consultant surgeon) and the unskilled pupil (the surgical resident). Working weeks of 70–90 hours were accepted and after gaining theoretical and especially practical skills for six years under the direct supervision of the consultant, the resident becomes a surgeon. Nowadays, our society does not accept such long periods of formal learning and the working week is shortened to a maximum of 48 hours. This results in a 40% decline of directly supervised practical experience of residents in their first years of surgical training. Moreover, the government has asked the surgical society to offer the basic surgical training in only five years! On the other hand, the same government makes laws such as the BIG and the WGBO. The surgeons are obliged to be qualified (formally licensed) and to be skilled and properly trained to offer and execute an intervention to or on a patient. Due to the ‘Schengen convention’ there is a right of free establishment of the citizens of the European community in the participating countries. The formal training of residents and consultants in the European countries showed large diversities. Objective and proper methods for assessment and comparison of the outcome of the surgical training in the European countries are not available. It is clear that the conventional surgical teaching methods do not fulfil the demands of patients, the society, the government and the surgical profession. New training methods have to be developed. The development of VR surgical tools for theoretical and practical training and the assessment of the resident are urgently required. Moreover, virtual surgical tools should be available for life-long medical education and assessment of the surgical consultant in order to maintain a high level of expertise and skill in the profession. This project intends to contribute to the increasing need for practical training and objective assessment for the surgeon in training.

2.4 Goals of the DIME project

- To create a VR learning environment that allows surgical trainees to both practice their skills in the ‘Operating Room’ VE and enhance their understanding of the procedure under study by using the ‘Library’ VE or the peer-to-peer chat function.
- DIME aims at identifying the more ‘objective’ training elements that need to be conveyed before the constructive learning starts. This is the reason why the first stage groups teams with various expertises so that they can play a role in the definition of the anchoring points in the training of the future surgeon.
- Most of the VR projects have invested in the actual building of the models and have no didactic interface yet. The DIME project sees this need and aims at defining a generic instructional method that intermediates between a VR medical model and a novice who needs to understand and optimise its functioning.
- To specify and evaluate VR elements for the pre-clinical training phase of novices in artery surgery.
3 Expert system for risk-evaluation of endovascular stent-prosthesis placement

The VREST [3] group has undertaken the formalisation of dimensioning the stent-orthesis for the abdominal aorta aneurysm (AAA) patients. In order to obtain an uncomplicated passage and a lasting exclusion of an infrarenal AAA through endovascular placement of a stent-prosthesis, one has to take into account many unique anatomical properties of the aortic–iliac–femoral trajectory and many unique properties of the stent-prosthesis.

Figure 1 The stent orthesis for the AAA patients

Because of this large amount of relevant anatomical and stent-prosthetic variables it is not easy, even for the experienced clinician, to make the correct assessment. A validated stent-prosthesis expert system can offer support to the clinician in choosing between endovascular and transabdominal exclusion of the AAA. Such a system can also offer support in choosing the optimal type of stent-prosthesis, and in planning the procedure.

3.1 Goal

The goal of this study was the validation of a custom-developed stent-prosthesis expert system. The anatomical AAA criteria were measured in 202 patients from two endovascular centres. Every AAA was divided into various segments; suprarenal aorta, infrarenal aorta, aneurysm, aorta bifuration, right, left and common iliac arteries and right, left and common femoral arteries. For each segment, the following characteristics were recorded: length, thrombus, sclerosis, angulation and configuration. These 202 AAAs were then judged by five endovascular trained clinicians on anatomical fitness for placing the stent-prosthesis.
The chances for successful sealing were independently expressed in ‘complication rating’ for each AAA by five clinicians and the expert programme. The complication rating was divided into 0–59% (low to intermediate risk), 60–94% (intermediate to high risk), 95–98% (very high risk), 99% (practically impossible) and 100% (impossible) to obtain sealing. There was possibility to choose between all configurations of three commercially available stent-prostheses. A total of 3030 AAA assessments were given by the five clinicians. These were compared to the assessments of the expert system.

Table 1 Correspondence between the assessments of the clinicians and the expert system

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Agreement¹</th>
<th>False positive²</th>
<th>False negative³</th>
<th>Discussion⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon 1</td>
<td>73.4</td>
<td>0.0</td>
<td>1.7</td>
<td>24.9</td>
</tr>
<tr>
<td>Surgeon 2</td>
<td>75.5</td>
<td>0.7</td>
<td>2.5</td>
<td>21.3</td>
</tr>
<tr>
<td>Surgeon 3</td>
<td>73.7</td>
<td>0.0</td>
<td>1.8</td>
<td>24.7</td>
</tr>
<tr>
<td>Radiologic 1</td>
<td>70.6</td>
<td>0.5</td>
<td>4.2</td>
<td>24.8</td>
</tr>
<tr>
<td>Radiologic 2</td>
<td>64.8</td>
<td>0.0</td>
<td>8.1</td>
<td>27.1</td>
</tr>
<tr>
<td>Total</td>
<td>71.6</td>
<td>0.2</td>
<td>3.7</td>
<td>24.6</td>
</tr>
</tbody>
</table>

¹Same advice by clinician and expert system.
²Advice by clinician = no intervention; advice by expert system = intervention.
³Advice by clinician = intervention; advice by expert system = no intervention.
⁴Advice by clinician = high risk intervention; advice by expert system = no intervention.
3.2 Results and preliminary conclusion

There appeared to be a good correspondence between the assessments of the clinicians and the expert system as finally visualised in Figure 2. Specifically, the chances for an incorrect positive advice from the expert system are minimal (1:500 assessments). In case of a high complication rating, the expert system tends to advise negative on stent placement in more cases than the experienced clinician does.

Figure 3 Discrete modelling rational for the go–no go and the dimensioning of the stent artefact

The basic underlying rational for the go–no go and the dimensioning of the stent artefact has been certified in this way. The envisaged DIME project plans the support of the 3D aspects of the particular patient being treated. Both the experienced and the novice vascular surgeons will increase the effectiveness and task efficiency as the MRA images are transformed into 3D models that can be inspected for critical morphologies and to anticipate better the actual medical intervention.

4 VR for learning

4.1 The need for visual orientation

As computer-based visualisations like those in VR and modelling for design and idea generation become more common, the research interest may shift forward into a new and highly intriguing field. The question is how to promote a new type of visualisation that is based on human conceptual imagination rather than on the conventional perception of the 3D world around us. It is not an essentially new step since we extended our naturalistic
way of displaying what we saw into the more or less abstracted indication of what we take as crucial behind the meaning and impact of the issue; quantitative graphs, schematic displays of complex functioning and not to forget the topographical map itself. Maps may suggest that you see a landscape from a bird’s perspective. However, we soon perceive that without filtering and articulation there is no conveyance of thought and navigation. As visualisation techniques develop, we attempt to display conceptual entities rather than reminiscences to objects and physical space. Concept mapping is the more salient exemplar in this new line [4]. The paradigm is that any mental entity or process may appear in a spatial configuration of both concrete and abstract ideas. Further formalisms about how to control expressiveness and topology by pruning and zooming are matters of convention that should fit in the contract between a task, its user and the concrete representational device like a white board or a computer screen. Some tasks inherently aim at configurational awareness like planning, decision making, etc. Some tasks address the more intuitional stages of human thinking like learning, persuasion or worshipping. Concerning learning and teaching, the so-called instructional approach has almost become synonymous with effective cognitive growth. However, in the more recent years, we see that the cybernetic aspiration of the 1960s to the 1970s has mainly led to an over-organisation of study programmes and students complaining that the school is like a factory and at the same time like a hospital. The term ‘existential learning’ attempts to indicate its complement: the student being the main character, his longer-term development. We again start to accept that learning has a lot to do with mental and emotional growth in which information access plays only a subordinate role.

4.2 Learning in a virtual spatial reality

The tendency to allow trainees to explore critical situations and, in the case of medical students, to let them experiment with an underlying model of the phenomena and processes in the human body is not new [5,6]. There is a considerable amount of evidence that training by computerised models facilitates the learning process [7]. Also, we see a growing interest for offering fully 3D environments that allow a continuous fading between the full realistic reality like looking through glasses to the real patient on the one hand and on the other hand seeing the superimposed vectorised model of the same patient but with only the structure of the blood vessels (and, if available, the computed blood flow and the animated pressure on critical spots). In the pre-service training, novice surgeons may primarily explore the models at the vector side of the spectrum. As more experience builds up, the captured videos of the same patient may become involved. Finally, students may undertake real operations, supervised by a specialist. As this stage of the training is costly, it is quite desirable that an intense VR stage of the learning takes place. In this project we will establish the most effective instructional sequence in the VR-based training simulation.

4.3 Learning paradigms benefiting from VR

The traditional approach to optimise learning through ‘just-in-time’ information and feedback can be summarised as instruction. As the trainee has a larger repertoire of prior knowledge and skills, this ‘cybernetic’ approach has the disadvantage of not stimulating enough the meta-cognition and the potential to learn-to-learn by the trainee [8,9]. The complement and to a certain extent the alternative for instruction is learning by
Construction. Constructionism is the awareness that learners undergo a highly personal process, due to their cognitive style, and 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 takes place. The connotation of constructivism is that the learner actually builds his/her conceptual knowledge upon prior analogous knowledge. In the case of artery surgery, models from hydrodynamics, the principles in flow theory and many more play a crucial role. Besides these, there is a set of specific facts that play a role around blood vessels. During learning, the trainee attempts to reconcile earlier experiences with factual rules as formulated by experts in the field.

- If the factual data dominate the trainees’ intuition and imagination, we may expect that his/her performance later will be brittle and not flexible enough for the large variety of complex situations.

- If the trainee relies too heavily on similar domain knowledge and intuition, a discrepancy may arise with the ‘golden rules’ and the statistical lines based on experience among colleagues. Also, the more or less ‘standard’ operations may not become automated and the communication with colleagues about taking decisions may become troubled.

In the underlying project proposal, the first stage of ‘Medical Consultation’ aims at identifying the more ‘objective’ training elements that need to be conveyed before the constructionistic learning starts. This is the reason why the first stage groups teams with various expertises that plays a role for the definition of the anchoring points in the learning process of the future surgeon.

4.4 From an informational to a conceptual approach

Before further highlighting the need for conceptual rather than instructional representations, it is useful to stress that in pre-instructional learning theories the notion of meta-cognition has already played a dominant role. Ann Brown has systematically brought forward the dominance of cognitive development, intentional learning, transfer of learning, meta-cognition and self-regulation:

“… Learners came to be viewed as active constructors, rather than passive recipients of knowledge. Learners were imbued with powers of introspection, once verboten. One of the most interesting things about human learning is that we have knowledge and feeling about it, sometimes even control of it, meta-cognition if you will. … Those interested in older learners began to study the acquisition of disciplined bodies of knowledge characteristic of academic subject areas (e.g. mathematics, science, computer programming, social studies, and history). Higher order thinking returned as a subject of inquiry. Mind was rehabilitated.” (Ann Brown [10])
The ‘cognitive apprenticeship model’ [11] 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, one 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. The intriguing question is how we rely on pictorial, schematic and iconic images during this process of intellectual ‘reverse engineering’. Is there any prearranged repertoire of visual grammar or should we stimulate learners to reinvent one’s personal semiotics for conveying the learning process.

4.5 Concept mapping for navigation in a VR learning environment

The fast growing interest in multimodality, full 3D VR and the avoidance of anisotropy has partly supplanted the designer’s attention for the students’ conceptual states. One additional promising aspect is to prepare and structure the VR course for Educationalists on the web and bring an overview of ongoing research into the urgent question, how to orient students in conceptually complex domains using VR. The central theme is to give an overview of VR learning environments that enable learners to explore new physical spaces, but even more important: to let them experiment with new materials, complex processes like kinaesthetic, extruding, casting, etc. VR becomes a substantial and ubiquitous technology and subsequently penetrates applications for education, learning and training. In addition to multimedia, VR places the user in a 3D environment. The user feels that he/she is ‘in the middle of another environment’. Most of the VR systems allow the user to travel and navigate. It is more promising for learning purposes to let the user manipulate objects and experience the consequences. This paper introduces the potential impact of ‘immersion’ for learning environments, the current state of the art in VR, its drawbacks, the overall metaphor of virtuality and the most feasible application areas. The main section of the reporting is the research agenda for VR in the years to come. The recommendations involve VR and collaborative aspects (MOOs), its integration with video conferencing, drama and constructionism, temporal awareness and, finally, the integration into special curricular topics. The targeted goal of this paper is the gradual embedding of VR elements in current research and developmental practices. Especially, the rapid increase of WWW-based tele-learning can benefit from the VR prospects in the years to come, as VR programmes can now be accessed by the most common web browsers like Netscape and Explorer.

Different media have helped us to extend our perception, imagination and manipulation. VR is just an extra step on the long road bringing the imagination as close and realistic as possible to reality itself. After the first experiments in the 1950s with complex kinaesthetic devices like multiple cameras, senso-motoric devices and even smell generators, more elegant head-mounted devices were developed in the early 1990s. Both defence research and the computer games industry were the main stimulators of VR so far. It is hard to describe what VR is not: it encapsulates all previous media, even books, slides, pictures, audio, video and multimedia. The typical contribution of VR is its effect of ‘immersion’; the user feels as if she/he is in a different world. Both the sensations and the actions of the user should resemble humans as much as possible in a
normal physical environment; seeing, hearing, feeling, smelling, tasting, and also speaking, walking, jumping, swimming, gestures and facial expressions. The VR utopia means that the user does not perceive that a computer detects his or her behaviour, and also that he or she perceives the real world. The generation of proprioceptive and kinetic stimuli is only possible if the user is placed in a tilted room like the hydraulic-controlled cabins for flight simulators. The generation of taste and smell, and the realistic enervation of the human skin, as if one touches an object or another person, may be some of the most challenging and complex steps for VR to take in the future. Augmented reality occurs when the user faces the real world, and on top of that the VR environment superimposes a computer-generated message in order to assist the user to perform the right operations.

VR is a desired technology for those applications in which reality itself does not exist (yet), cannot be accessed or is too dangerous or expensive to be not done. As for many of the proponents of today’s VR, ‘Reality’ sounds as the only inevitable physical world; they would rather prefer ‘virtual environments’. This leaves behind the idea that there is mainly one real world. Because of its widespread usage, however, we will maintain the term VR. Computers are inherent tools to emulate situations and environments that are not there in reality. VR in its current shape informs the user that she/he is in a fictitious environment. The next generation of VR suggests that one can really walk around there, and can manipulate and experiment. This environment does not necessarily need the same properties as the real world. There can be different forces, gravity, magnetic fields, etc. Also, in contrast to the real solid objects, in VR the objects can be penetrated. The properties of a good VR are like those of a good teacher; it allows the student to explore the basic laws of a new domain; location, scale, density, interactivity, response, time and level of intensity can be varied. It is not necessary to explain what the VR user sees, hears, feels and finally smells. Also, textual descriptions are not optimal for this learning by intervention, as text (and also hypertext) is essentially not apt to describe complex spatial phenomena. In this sense, VR makes a substantial contribution to interactive learning environments; it combines the realism (like in a video recording) with the manipulative (fictitious) reality like in simulation programmes. We may expect that within 10 years, VR will be the default presentation mode of computer applications in general. Besides the visual/auditory and spatial aspects, VR can also provide support in the field of navigation through the concept of space. In this case, the dimensions no longer correspond to the Euclidean geometry; they can represent mental perspectives, rules and dependencies. Virtual space allows travelling through a 3D concept map. VR is a 3D simulation technique that becomes more important as:

- mistakes during the learning process becomes more dramatic
- reality itself cannot be accessed
- parts of an emulated reality have to be smudged.
There are at least four VR aspects of importance for the perception by the learner:

- **The mechanism of avatars.** They represent the user in a fictitious environment. Even the expert teacher should be represented in one way or another. In the scope of the DIME project, the avatar is integrated by making the demonstration of the many expert interventions available so that the learner can smoothly orient to the master solutions and gradually absorb the specific rules and conditions for the exceptional cases.

- **The mechanism of affordance.** This is the user’s ability to orient in a new world, based on distinguished features according to Norman (who refers back to J.J. Gibson, see [12]). Affordance is the relation between an object in the world, and the intentions, perceptions and capacities of a person. As an example he mentions that a door with a push button instead of a handle for pulling has the affordance to push the door.

- The man–machine interface gets an even more prominent position. Initially, the user interface was a kind of serving hatch between the user and the system. In the case of very interactive systems sometimes one speaks about user *intraface*; in this case the whole application establishes the manipulation space for the user. The user’s intuition then needs to be sufficient to instruct the user. The user should not need meta-communication in order to understand the programme’s potential.

- The confrontation between the learner and the new (physical) environment should be ‘immersive’; Rather than seeing a flat display, the user should feel himself in the VR. Especially if the task concerns complex 3D orientations like surgery and rescue expeditions in complex areas, then a VR exercise is quite useful before going into actual reality.

Concerning the relevance of VR for education and training, two aspects have to be taken into account:

- VR is a default component of the user interface in the future. The desktop metaphor was a revolutionary one, as it took the human’s physical (spatial) reality for the organisation of information in general. As long as it concerns 2D documents, this is a lucky choice. As soon as the user behaves in a 3D world, a more dynamic representation is needed. Also, the acoustic consequences of moving through space should fit; the sounds amplitude, reverberation and Doppler effects as one recedes or comes closer to the sound source, should resemble the reality.

- The second is that the ability to increase realism also implies the possibility to introduce a specific element of non-realism. One can confront the student with an alien world and make it stepwise more or less realistic. Basic nature laws can be explored, like mechanics, chemistry, electromagnetic fields, etc. Viewed from a constructionist perspective, VR has an important function in the realisation of understanding complex processes. The student is allowed to orient in several directions and subsequently find a way through the information space.

Educational VR systems seem to be a natural extension of computer-based simulations nowadays. The basic approach is to allow students to explore and discover the fundamental laws in a new environment and domain. For the initial confrontation with new tasks and for the stage of exercising, this approach seems logical and consequent.
The effectiveness of the training for the mastery of the final task in reality is a subject for further research. Based on similar developments in interactive video, multimedia and telematics, it is not desirable to wait and see until the development of technology is ‘over’. Educational and training research should keep pace with the newest VR systems and think along its new potential for learning. Can VR be an effective tool for education or training? The answer depends partly on one’s definition of VR and partly on one’s goal for the educational experience. It may not be worth the cost if the goal of the educational experience is simply to memorise facts. However, if the goal of the educational experience is to foster excitement about a subject, or to encourage learning through exploration, or to give students a taste of what it is like to be a research scientist, then VR may be worth the expense. It seems an interesting option to take the VR technology as a candidate metaphor for learning environments in general. That is why we introduce the more generic idea of ‘virtual learning environments’ later in the paper. Today it is a developing technology seen primarily in research laboratories, theme parks and trade shows. Tomorrow it may be as common as television. Lanier [13] states that VR is a medium whose only limiting factor is the imagination of the user.

4.6 Learning by exploration

Building upon previous and current research, the DIME project aims at further evolution into a training support system that orients novice surgeons to explore and learn the critical dimensions in the anticipation of blood vessel transplantation and the placement of a stent or a by-pass. The project covers the data delivery, medical, VR-interactive and instructional procedures. The transformation into a training support system needs two stages:

- **Medical consultation.** The collaborative use of VA by medical experts who discuss and deliberate about the interpretation of 3D visualisations of a patient’s artery system. The calculation of the pulsatile blood flow and the deduction into shear stresses on the vessel wall is an important but not satisfactory argument to decide upon medical intervention. This stage of the research aims at a multidisciplinary collaboration between actors from various medical disciplines, VR specialists, imagery experts and training designers.

- **Instructional design.** The design and implementation of a learning system that allows novices to prepare themselves for the supervised in vivo operations. The system should allow for both a tutorial situation, where the experienced surgeon explains and demonstrates the key functionality, and simulation mechanism. The trainee should also be allowed to make an in-depth tour through specimens of the cases. After this phase, a wrapping-up conversation with the expert and the trainee should take place, eventually leading to the stage of supervised interventions in real patients.

A large part of the testing is dedicated to the learning/teaching goal, as it is an articulation of the much wider potential that such a system has for research in general. A relevant side-effect of VR-supplied training situations is the fact that it allows a smooth transition between ‘being locally present in the training institute’ vs. ‘participating via telematic facilities at remote sites’. This aspect of ubiquity is of importance both for the trainee and the specialist/trainer as she/he does not necessarily need to monitor the student’s prior learning in his physical presence. Looking back to the logged students’ actions may
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enable the trainer to decide upon one’s qualifications before entering a real operating room.

4.7 Initial architecture of the proposed VR learning context

The surgical skills and its continuous sophistication; how should it benefit ideally from the virtual operating room? In this practice ‘space’ (at the right side of Figure 2), the cycle goes around diagnosis, preparation and execution of the intervention. But at unforeseen moments we expect that students consult a library of domain expertise. Based on the log data generated by this VE:

- the coach and trainee can evaluate his/her progress and set out an appropriate personal learning path
- the coach can extract general trends in learning of his/her trainees, as well as know the differences in learning styles of individual trainees.

Though overall this architecture looks adequate and robust, we decided not to adopt it, basically because of the suggested antagonism between the two. More adequate and fair seemed the model where the learning between the various approaches due to variations in patients and the subsequent surgeon experts and the various trainees was the central core of the learning.

Figure 4 The interplay between the students’ theory vs. skill-driven learning

![Diagram](image-url)
The alternative to the theory/practice model above was left behind and the key idea for the VR training space was called ‘Interconnected Expertise’. It aims at bringing the novice in a quasi-continuum of surgical interventions. Learning in this space allows a fluent transition between patients, surgeons and various stages in the intervention. The more natural one is by tracing the treatment by one surgeon in one patient through the natural chronology of the operation. But there are good reasons to switch between patients as it shows typical morphologies that clarify the reason why the initial treatment was needed there.

5 Imagining VR as interconnected expertise

VR as representation of the targeted object world may be propagated sufficiently. More intriguing is the question how learners may benefit from the prior experts and successful peer-learners. This question was recently addressed and it was felt that three main dimensions need to be articulated before a meaningful navigation by the learner may take place.

**Figure 5** Three main dimensions for allowing the learner to navigate in prior vascular interventions

- The first dimension (called *Cases*) is the set of indexed patients who vary from obeying the prototypical standard medical problem as listed in the study books; in this case the AAA is clearly there, but with a minimum of complicated side-effects and the patients are in an overall good condition. At the other end of the continuum there is the patient who suffers from a severe AAA phenomenon, but at the same time a large number of constraining factors can be discerned like stenosis, aneurisms before and after the bifurcation and a complex artery morphology in the range between the stent insertion point and the place of stent placement.
• The second dimension (called Trainees) varies between the highly experienced vascular surgeon, who performed the endograft stent in the VR model with correct AAA interventions, and most of the embedded cases. At the other end of this dimension one can find recorded AAA interventions by freshmen demonstrating the many thinkable flaws. At each of the suboptimal interventions the expert surgeon marked the reason for labelling the flaw as being suboptimal and activated links to the real good solutions that should have been made.

• The third dimension (called episode) captures the subsequent stages in the AAA intervention. Two criteria for ordering them can be taken: the chronology of subactions from early to later, vs. 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 chronological order.

6 TwoCents: a self-learning VE for surgical training

Based on the arguments that follow in the rest of this section, a VE is proposed for surgical training. The novelty is the use of a dynamic database that gathers annotated experience of previous users in such a way as to open a direct, adaptive and relevant frame of reference for the trainee. This framework could be of use in other VEs also, especially those which prepare trainees for work in environments where knowledge of different complex procedures and the ability to correctly assess a complex situation is critical.

6.1 Relevance of medical simulations

The field of surgical knowledge is becoming increasingly complex due to several factors:

• more pathologies require surgical treatment
• more specific techniques for different cases are being developed
• the techniques themselves are becoming more complex due to:
  • the continuous creation of more sophisticated equipment
  • the patient’s expectation of the outcome of the procedure (loss of function is hardly acceptable)
• the increasing age of patients ready 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 of these, the learning curve to master these techniques is getting steeper and longer, and in addition a need for ‘life-long learning’ emerges. Two educational practices are recognised in conventional surgical learning.

One is the conventional surgical teaching method: a close daily working relation is established between the experienced teacher (trainer) and the relatively unskilled pupil
(trainee). In a setting where more trainees must learn more in less time, this places an unrealistically high burden on the trainer. This is also a rather cost-intensive teaching method. The other is related to the way new techniques find their way to the clinic: surgeons hear of new techniques at congresses, through demonstrations in centres 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 technique is well established, which obviously is not beneficial for the patients. The lack of sufficient training opportunities and formal assessment of skills in this scenario is problematic.

The disadvantages of both training methods could be overcome using a VE for surgical learning and skills assessment, and not surprisingly considerable work has been done in this area.

6.2 TwoCents: outlining the project

The heart of TwoCents will be a dynamic, annotated database that can be investigated by the trainee. The interface to this database is imagined as a cube; a 3D form reflecting the next dimensions:

**Figure 6** The dynamic, annotated cubic space for learners’ navigation

![Figure 6](image)

The X-axis represents generalised surgeons with differing levels of expertise (made anonymous).

The Y-axis represents different medical cases, each different in complexity and optimal surgical strategy.

The Z-axis represents the different episodes or actions that constitute a procedure.

An episode always consists of a scene taken from the procedure of a specific case with a specific trainee, what this trainee has done in that scene and the annotations of the VR-root and other VR-users in that scene. These annotations can consist of written notes, video material, animations, photographs and graphics.
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-click once and press-enter on any cubette brings the corresponding episode on-screen.
- Point-click once on one cubette and shift-click once on another cubette selects both cubettes. When up to four cubettes are selected, press-enter opens all episodes in a split-view.
- When more than four cubettes are selected, press-enter brings annotated thumbnails on screen (each thumbnail corresponding to the selected episode). These thumbnails can be selected and activated in the usual way 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. Press-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}) brings the corresponding plane on screen as a field of annotated thumbs (figure).

So, depending on the plane from which the cube is advanced:

- a complete procedure from one trainee for a specific case can be assessed (Figure 7)
- all trainees for one case and episode can be selected, allowing assessment of the surgical strategies of different trainees for an episode in a specific case (Figure 8)
- all cases for one trainee and one episode can be selected, allowing assessment of the surgical strategies of one trainee in the same episode on different cases (Figure 9).

**Figure 7** Selecting a trainee/patient intervention history
The rational for supporting new surgeons to navigate through the case/trainee/phase library is that we apprehend learning as the saturation of all possible combinations of situations. The cells (cubettes) contain the VR episodes and allow new trainees to observe medical interventions and add alternative episodes created for other patients or make new episodes by themselves. The DIME project intends to implement and evaluate the effectiveness of this navigational mechanism and generalise it into an architecture for medical training at a more global scale.
In this mode the VE-user is studying the procedure for a specific case while having access to the reference cube. The case under study is presented without annotations and the reference cube contains only different cases. The user can practice and make his/her own solutions and annotations or sample solutions and annotations found in the reference cube. If the user feels that a mistake is made, he/she can step back through the episodes to make corrections.

Figure 11  The VE-user row only (operation room mode)

Here the trainer can evaluate the progress made by the trainee. In the final situation we expect the entire surgical training curriculum to consist of multiple big cubes and episode-collection row (mega store mode). Each of the cubes is then a treatment category like inserting the AAA endograft stent, the stitching in the Lichtenstein method, etc.
7 Experimental design

Stereo-vision in a medical VE pertains to the question of how to quantify effects on visual–spatial performance and learning. Visual–spatial ability is an important predictor of endoscopic surgical proficiency. Recent research, however, shows that visual–spatial ability is a heterogeneous construct: spatial ability is a separate capacity from visual ability. While the classic visualiser–verbaliser dimension appears to be valid, both extremes on this scale can be spatially proficient or not proficient, where spatial ability for verbalisers has a normal distribution and spatial ability for visualisers is either high or low.
In surgical training a lot of effort is directed at developing computer-based learning environments. One salient feature of these environments is the possibility to explore their content in stereo-vision. What we would like to know is the contribution of stereo-vision to visual–spatial performance and learning and whether trainees with different learning styles and abilities (visualiser/verbaliser; spatial ability) are benefiting differently from this condition. The medical subject of this VE will be the anatomico-functional parameters of the AAA. An AAA is a pathological swelling in the belly part of the aorta.

7.1 Abdominal aorta aneurism in stereoscopic 3D view

Traditional textbooks have visuals as long as it is evident that students need a learning sequence in order to fulfil the final tests. At the same time, we know that retention and application effects become much stronger if learners arrive in an active position and feel as if already their contribution counts for the well-being of a virtual patient. Three-dimensional models can be derived from scanning procedures like MRI and MRA. Learners nowadays can trace ongoing medical diagnostics, interventions and final health prospects without causing a time load to physicians.

7.2 Research questions

- What is the contribution of stereo-vision on visual–spatial performance tasks in a medical VE for users tested on spatial ability and visualiser/verbaliser preference?
- What is the contribution of stereo-vision on learning in a medical VE for users tested on spatial ability and visualiser/verbaliser preference?

7.3 Method

Independent variables are stereo-vision and visualiser/verbaliser preference. The covariable is spatial ability. A group of people from whom the experimental subjects are to be selected are tested for visualiser/verbaliser preference using the questionnaire. Based on the results of this test, two groups will be formed: one consisting of explicit visualisers and the other consisting of explicit verbalisers. The total number of experimental subjects will be around 30. Also, some general demographic information will be gathered. Subjects are tested in two groups of mixed visualisers and verbalisers. Subjects are first tested for spatial ability using a subset of the Cognitive Laterality Battery. After this the groups are given 30 min for investigating their VEs that contain 3D models of one AAA-patient’s aneurysm, kidneys and pelvis/spinal column with added textual anatomical and physiological information on right-clicking a particular anatomical structure. The aneurysm/kidneys and the pelvis/spinal column will be on separate pages of the VE. Two groups study a VE in which the aneurysm/kidneys are rendered for stereo-vision and the pelvis/spinal column is not; in the other group’s VE this rendering is reversed. All conditions except the stereo/non-stereo condition will be kept identical.
Subjects will be asked to perform the following tests (in a non-stereo-vision set-up):

- recognise the aneurysm/kidneys studied amongst several other aneurysms/kidneys in a series of increasingly unconventional views
- recognise the pelvis/spinal column studied amongst several other pelvises/spinal columns in a series of increasingly unconventional views
- after a short introduction to Dicom files, subjects will be asked to identify the right kidney in a series of Dicom slices (that can be shown caudally or cranially)
- identify stenosis in Dicom slices and draw the stenosis in a (given) frontal view of the studied aneurysm
- fill in a questionnaire that is based on the information available on right-clicking the anatomical parts.

8 Predictions

Dependent variables are different aspects of VSP (mental 3D rotation, mental 3D reconstruction and pattern recognition) and medical learning:

- both low spatial verbalisers and low spatial visualisers will benefit most from the condition that includes stereo-vision because no appeal is made in the learning phase on the (visual–spatial) ability to translate a 2D (screen) image to a 3D (mental) image
- verbalisers will score better on the mental 3D rotation post-test than pre-test because the information presented in the learning phase will make it easier for them to memorise specific anatomical features that appear again in the post-test
- verbalisers will score better on the anatomical questionnaire
- visualisers will do better in the anatomy recognition tests.

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c. fill in a questionnaire that is based on the information available on right-clicking the anatomical parts:
   a. dependent variables are different aspects of VSP (mental 3D rotation, mental 3D reconstruction and pattern recognition) and medical learning
   b. both low spatial verbalisers and low spatial visualisers will benefit most from the condition that includes stereo-vision because no appeal is made in the learning phase on the (visual–spatial) ability to translate a 2D (screen) image to a 3D (mental) image
   c. verbalisers will score better on the mental 3D rotation post-test than pre-test because the information presented in the learning phase will make it easier for them to memorise specific anatomical features that appear again in the post-test
   d. verbalisers will score better on the anatomical questionnaire
   e. visualisers will do better in the anatomy recognition tests.

9 Preliminary conclusions

Though VR is one of the prime candidates in vitalising learning by its realism and direct appeal to the students’ natural affordance to act upon urgencies rather than to ‘know’ what experts are saying; VR in itself is not enough to make the learning more effective. By logic: realism in VR does not suffice to exceed the real situation itself. We know from, for instance, link trainers for airplane pilots that the simulation can be more effective, once it elicits the novice to go into critically complex situations; exactly those situations that we never hope to meet in reality. Its added value is not only that the learner’s reflexes are trained to survive in the panic of precisely decisive seconds. Its value also lies in the fact that after understanding all the fundamentals of complex mechanisms, the learner is allowed to walk on the edge of what is a success vs. a failure. Training through real-patient interventions are not allowed to approach this area. That is why the VR-based medical intervention is an even better preparation for the first clinical steps compared to witnessing dozens of impeccable operations performed by the master. This paper showed: the need for an adequate and more articulated learning paradigm like constructivism, and also the need for additional background processes during the execution of VR in learning situations. What is most important is that there is a continuum between the literal recordings of video and voice-over of real surgical actions and the vectorised model of how meaningful parameters describe and predict the critical effects, for instance, the morphological, textural and hydro-mechanical processes of blood in the stented aorta, and also the scaffolding of learning the complete vascular intervention by other surgical skills like endoscopy, micro-venereal stitching and reinforcing the mechanical functions of the abdominal regions like in the Liechtenstein methods.
References and Notes

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