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► **To cite this version:**

Lucile Vadcard, Vanda Luengo. Embedding knowledge in the design of an orthopaedic surgery learning environment. CALIE04 International Conference on Computer Aided Learning in Engineering Education, 2004, Grenoble, France. pp.6. hal-00190293

HAL Id: hal-00190293

<https://telearn.archives-ouvertes.fr/hal-00190293>

Submitted on 23 Nov 2007

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Embedding knowledge in the design of an orthopaedic surgery learning environment

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KEYWORDS: learning system, simulator, validation, knowledge, computer assisted surgery.

Abstract

This paper deals with an ongoing work involving surgeons, didacticians and computer scientists. The objective is to design a computer based environment for learning screw placement in orthopaedic surgery on the basis of a computer assisted surgical (CAS) tool. We describe our methodology to create a didactical plug-in component for the CAS system. The created system will consider the user's knowledge employed for the task to provide linked and relevant feedback.

INTRODUCTION

Training in surgery is principally based on an apprenticeship model. Novices learn by watching and participating, taking more active roles in the operation as their experience increases. However, recent years have seen the advent of computers in surgery with the development of computer assisted surgery techniques (CAS). In particular, numbers of surgical procedures are now performed using minimally invasive surgical (MIS) techniques, in which trauma to external tissue is minimized. These techniques introduce computers into the operating rooms to assist the perception of the surgeon during the operation. Also, the skills of MIS present unique perceptual-motor relationships which are very difficult to master: the surgeon is no longer looking at the patient, but at the computer. Eraut and du Boulay (2000) pointed out that Information Technology in medicine is divided into tools and training systems. Tools support surgeons in their practice, while training systems are dedicated to the apprenticeship. Our aim is to use tools developed in the framework of CAS techniques to create training systems for learning conceptual notions useful in both computer assisted and classical surgery. The approach adopted is generally suitable for CAS planning tools but is developed specifically for iliac and spinal surgeries.

METHODOLOGY

In this paper we present two main points of our methodology. Firstly, the choice of knowledge that we target. We mentioned above “conceptual” notions, but this term remains complex and needs further development. Secondly, we describe the architecture of the software component. The training system must be able to diagnose a user's state of knowledge and provide a linked feedback in response to the user's actions. We explicitly take into account this issue of the provided feedback by embedding a model of knowledge in our system.

Surgical knowledge

Knowledge in orthopaedic surgery is traditionally considered to be divided into two main categories: declarative and gestural (Tendick et al. 2000). The first kind of knowledge is usually learned in a context of formal schooling, and measured by well-established examinations such as multiple choice questionnaires, written and oral tests. The gestural skills, also referred to as technical or motor skills, are dexterity, hand to eye coordination, and spatial skills. Transmission of these gestural skills occurs by traditional apprenticeship, training and assessment of such skills also involves the use of cadavers, animals, artificial organs and, increasingly, various computer-based simulation systems. Assessment is usually done through observation by an expert surgeon.

However, this dual classification neglects a key aspect of surgical knowledge: surgery takes place in a specific context and is based on actions. Regarding the question of learning, expert practice cannot be solely divided into a formal part and a gestural part. Medical reasoning, reaction in the case of complications, validation and control are some issues that cannot be placed at the same level as declarative knowledge, which is explicit and consensual. We thus propose an original analysis of knowledge that introduces the notion of procedural knowledge (Vadcard 2002). Declarative knowledge deals with anatomy, therapy, diagnosis, pathologies (De Oliveira et al. 2000). These elements are theoretical, explicit, and made for communication (encyclopaedic knowledge). Procedural knowledge allows the surgeon to use the declarative knowledge and apply it to a particular patient case. It involves problem solving, reasoning and prediction. It is an experimental part of knowledge, and is validated by empirical means. However, it still remains a worded part of knowledge, which enables communication. This is not the case for the third part of surgical knowledge: operational knowledge, the gestural part of the surgical practice. As described above, it deals with dexterity, hand to eye coordination, spatial skills. It is transmitted by ostension; cannot be worded and remains in some pragmatic representation and validation frameworks.

In our work, we target on the acquisition of procedural knowledge, because we assume that the transmission of this kind of knowledge is traditionally implicit, despite of its crucial role in surgical practice. As procedural knowledge allows the use of declarative knowledge, our system will thus deal with declarative and procedural knowledge. Operational knowledge requires some hard and local devices with functionalities such as haptic feedback (Tendick et al. 2000), which are out of the scope of this paper.

Design

Tool presentation

The system we use is an image-guided system for the percutaneous placement of screws in sacro-iliac and spinal surgeries. The goals of this computer-assisted approach is to decrease surgical complications with a minimally invasive technique, and to increase the accuracy and security of screw positioning. In the pre-operative phase, this tool allows planning of the screwing trajectory, on a reconstruction of the patient's bone based on CT-scans. During the operation, the surgeon uses the tool to target the planned trajectory with a system of localised tools and targets on the screen (Figure 1).

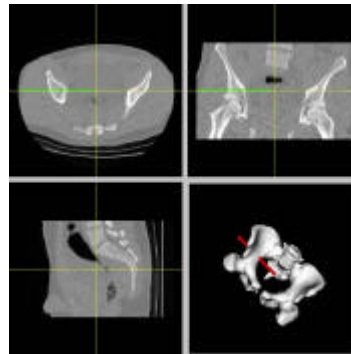


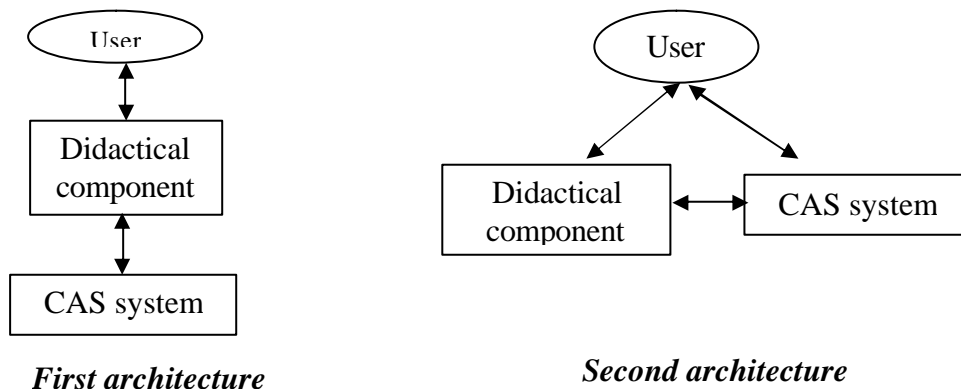
Figure 1

Re-sliced CT images along the screw axis and sacrum 3D reconstruction

Architecture

In our learning environment we separate the CAS component from the system component dealing with didactical and pedagogical intentions (de Jong 1991, Guéraud et al. 1999).

From the software point of view, we would like to respect the initial CAS system architecture. The system component concerned with didactical intentions is plugged in only in learning situations; we call this complete configuration the learning level. The learning level must also allow the construction of learning situations. We use the framework of the didactical situations theory (Brousseau 1997). This implies that the system has to allow interactions for actions, formulations and validations. In this case, the system will be a set of properties (Luengo 1999a). In this paper, we focus on the methodology for designing the validation interactions. Concerning interactions, there are two kinds of architecture to associate the three components (see Figure 3): the CAS system, the didactical system and the user (Lenne et al. 2001):



First architecture

Second architecture

Figure 2

Types of architecture

We chose the second architecture because we would like to observe the student's activity while using the simulation. The system must intervene when it detects a didactical reason, and then generate an interaction. We do not want to constrain *a priori* the student in his/her activity with the system. In this case, the simulation will produce traces about the user's activity. We want these traces to give information about the piece of knowledge that the system has detected (Luengo 1999a). In this work, we try to determine this information from the actions on the interface and to deduce the knowledge that the user manipulates.

The didactical system has to define feedback in relation to the knowledge the user manipulates. For this, we differentiate two kinds of feedback: feedback related to the validity of

the knowledge (concerning the declarative knowledge), and feedback related to the control activity (we check the validity of the user's actions at the interface to control his/her actions). We define the first kind of feedback as a function of the knowledge object. Control feedback is defined according to the knowledge of the expert and to the manner the expert wants to transmit his/her expertise to the novice. The idea is to reproduce the interaction between expert and novice in a learning situation. In this case, it is the expert control that validates or invalidates the novices action and who thus consequently determines the feedback to the novice.

In the next part, we propose a methodology to find the two kinds of judgement interactions.

Methodology

In our methodology, we take into account the didactical and computing considerations. Concerning the didactical part of the work, the adopted methodology is based on two linked phases. In the first phase, we identified some procedural components of the surgeon's knowledge. This has been done by observation of expert and learner interactions during surgical interventions, and by surgeon's interviews. In this work we focus on the control component of knowledge, because we assume that control is the main role of procedural knowledge during problem solving. This hypothesis is related to the theoretical framework of knowledge modelling, which we present in the next paragraph. During the second phase that is in progress, we must implement this knowledge model in the system, in order to link the feedback to the user's actions. These two phases are closely interrelated, as shown in the following schema (Figure 4).

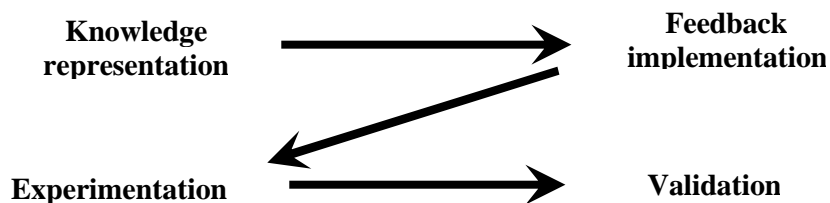


Figure 3
The methodology of two phases

We adopt the point of view described by Balacheff to define the notion of conception. He introduces the notion of conception to refer and to model a user's knowing in a situation and related to a particular notion (Balacheff and Gaudin 2003). To shorten the presentation of the cKç model, we will just describe its structure and specificities.

A first aspect of this model is rather classical: it defines a conception as a set of related problems (P), a set of operators to act on these problems (R), and an associated representation system (L). It also takes into account a control structure, called Σ . The crucial role of control in problem-solving has been already pointed out by Schoenfeld (1985). In the problem-solving process, the control elements allow the subject to decide whether an action is relevant or not, or to decide that a problem is solved. In the chosen model, a problem-solving process can thus be formally described as a succession of solving steps: $\sigma(r(p))=\text{right}$, with $\sigma \in \Sigma$, $r \in R$ and $p \in P$. From an apprenticeship perspective, we will focus on differences between novice's and expert's conceptions. Below is an example of formalisation, to illustrate the way we use the cKç model.

For illustration, let us consider the problem P2: "define a correct trajectory for a second screw in the vertebra". Indeed, the surgeon has often two screws to introduce, each on one

side of the vertebra, through the pedicles. In a general way, the screw trajectory is defined according to anatomical landmarks and to knowledge of the vertebral structure. Control of the chosen trajectory is partly made by perceptual and visual elements like the feeling of the bone density during the drilling, and X-rays (Roy-Camille et al. 1986). When a first screw has been correctly introduced, there is at least two ways to solve P2. First, the second screw trajectory can be defined regardless of the first one. In this case, the operators and controls which will act during the problem-solving are the same ones as for the former problem P1 (“define a correct trajectory for a first screw in the vertebra”). A second approach is to consider the symmetrical structure of the vertebra. In this case, the involved operators are not the same. They are linked to the construction of a symmetrical point in relation to an axis. Controls are partly the ones involved in the recognition of symmetry. Other controls, like perceptual and visual elements, are also present in this case. The main problem of this second way of solving P2 is that it neglects some false symmetrical configurations: a slight scoliosis, a discrepancy between the spinal axis and the table axis due to the patient position, etc. This is why the expert will always solve P2 with the same approach he used to solve P1.

The didactical analysis of the knowledge objects will be the key to the success of our model implementation. The choice that will be suitable in relation to knowledge will determine the main characteristics of the design.

For the judgement interaction design, we identified a set of pedagogical constraints: no blocking feedback, no true/false feedback, feedback after every step. From the point of view of the expert model, we do not want to use it only to mark the student activity. Our objective is to follow the consistency of the student’s work. Thus, if there are automatic deduction tools, they should not be used to produce an expected solution because it would constrain the student’s work (Luengo 1999b), but rather they should be used to help the interaction between the system and the student. We can use these kind of tools to give the system the capacities to argue or to refuse through counter-examples.

We identify four kinds of knowledge (pathology, morphology, anatomy and planning) with a set of properties, and relationships between these knowledge objects. The procedural knowledge (planning) can have a relationship with a declarative knowledge (anatomy). In our computer learning level, this implies that we have to link a judgement interaction with a declarative knowledge. For example, if the user chooses a trajectory that can touch a nerve, the interaction can be to link to the anatomy knowledge in order to explain (to show) that in these body parts there can be nerves. In other words, one kind of judgement interaction is the explanation of an error. We try to identify the declarative knowledge in relation to the procedural knowledge in order to produce an explanation related to the error. For control interactions, we construct a set of conceptions (that we will obtain with the didactical analysis) and we have to identify the conceptions that the user applies in his/her activity. For the moment, we choose to use a voting system for this identification (Webber and Pesty 2002). This approach considers diagnosis as the emergent result of collective actions of reactive agents. Others architectural solutions will be considered this year, before the implementation.

CONCLUSION AND FUTURE WORK

The researchers involved in the work presented here come from computer science and didactic fields. By its nature, this project consists of two interrelated parts. The first is related to the modelling of surgical knowledge, and is conducted by didacticians with close interactions with surgeons; the latter concerns the design in a computer system of this model and the definition of feedback, and is conducted by computer scientists. Our aim is to use a

didactical methodology in the design of a computer system in order to give feedback in relation to the knowledge at stake during the student's activity. The learning component we will obtain is designed to be plugged on CAS tools, and will be generic enough to be used for different applications, with the condition of conducting a didactical analysis of the concerned domain of knowledge.

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