# Design of adaptive feedback in a web educational system

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**Abstract**. This paper presents our interdisciplinary approach for the design of a technology-based learning environment for orthopaedic surgery. We present how we designed a part of this environment. This part is in relation to the web environment. The key idea is to produce an intelligent feedback in relation to the learner's activity. The didactical analysis of teaching and learning in the workplace gives a framework to build the computational representation of knowledge. This analysis is shown within the context of the apprenticeship of concepts of anatomy and orthopaedic surgery.

## 1. Introduction

This paper deals with the design of a technology-based learning environment in the domain of surgical apprenticeship. This work combines theories from artificial intelligence, computer science and didactic in order to model and represent didactic and expert knowledge. The application field is orthopaedic surgery, more precisely the screw placement of pelvic fractures. The technology-based environment we designed deals with the learning of declarative and decisional concepts of this surgical procedure. Gestural apprenticeship will be treated later. In this paper we describe the design of adaptive feedback for declarative knowledge.

Surgical training is usually divided into formal learning (involving the acquisition of declarative knowledge) and practical training. The gap between these two aspects of learning has been shown in some of our previous work [1]. Our aim is thus to create a learning environment which allows the use of formal knowledge before the training step in the operating theatre. It will be used in an intermediate phase of learning, between formal learning and apprenticeship in situation. It will thus provide an operative dimension of knowledge [2, 3] before the real situation, with its stress and time constraint aspects, is encountered.

Our work is inscribed in the research domain on the design, implementation and use of technology-based learning environments [4, 5].

## 2. Theoretical framework for adaptive feedback architecture

The "milieu" for the apprenticeship [6] must be organized to favour learning. In particular, the system must produce relevant feedback according to the learner's actions on the problem-solving situation interface. We assume that the system can produce relevant feedback if it reacts according to an internal validation of the learner's solution process. This means that we are basing the system feedback on consistency checks of learner's actions rather than on a priori solutions [7, 8], we choose to work in the Interactive problem solving support technology [9].

The architecture of our system is shown below :

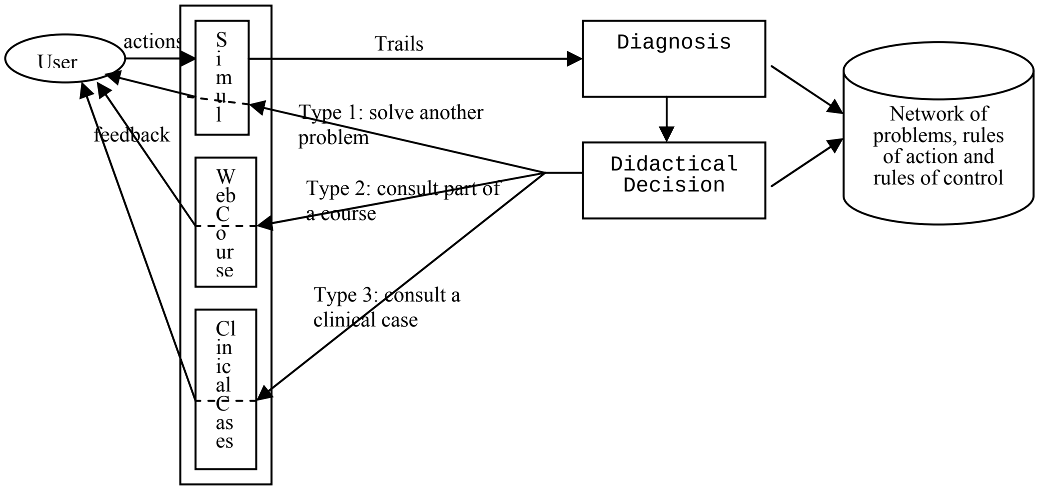


**Figure 1 –** Global architecture

The user solves a problem using web simulation software. Tracks of the user's actions are analysed in terms of their possible relationship to identified conceptions. A conception is an organised set of problems and pieces of knowledge. This diagnosis allows to take a didactical decision, which determines the feedback to give to the user. This feedback can be a proposition of another problem to solve, a redirection to a precise part of the online associated course, or a clinical case to consult.

Among the required components, the online course already exists; we have developed the tracking of the user's actions, and a module which allows redirection to precise and relevant parts of the course. This module allows not only syntactic links, but also semantic ones. The development of the knowledge and problems database is ongoing and will evolve with usages and future experiments. The development of the diagnosis and didactical decision components is also in progress.

In this paper we describe our methodology to design and produce the second type of feedback, feedback related to declarative knowledge represented by the semantic web. We show the construction of the knowledge model, which takes into account constraints from the knowledge analysis and from the computing aspects. This leads to an internal validation of the user's activity, taking into account his or her own problem-solving process.

## 3. Simulation tool description

In our learning environment, we separate the simulation component, the online course and the system component dealing with didactical and pedagogical intentions [10], [11]. To illustrate the parts of these specifications described in this paper, we briefly present an on-line training simulation of the sacro-iliac percutaneous screw placement, developed in Grenoble and available at http://www-sante.ujf-grenoble.fr/SANTE/voeu/visfran/vissage.htm (follow the links “protocole fluroscopique”, then “exercice”). This exercise is designed to be close to certain aspects of the real activity of the surgeon in situation. The user is shown a 3D pelvis representation, with skin and cutaneous landmarks. He/she has to position a pin and introduce it in the body. His/her actions are unconstrained, the allowed movements are continuous, and he/she can go back (remove the pin, change its entry point, etc.). At any time the user can ask for an X-ray control. The three available orientations (inlet, outlet and lateral) are those used the orientations used by the expert in real situations. At the moment of validating the trajectory, the user has obtained hints from the system, but not any evaluation. It thus belongs to himself/herself to use knowledge to decide on the validity of his/her trajectory.

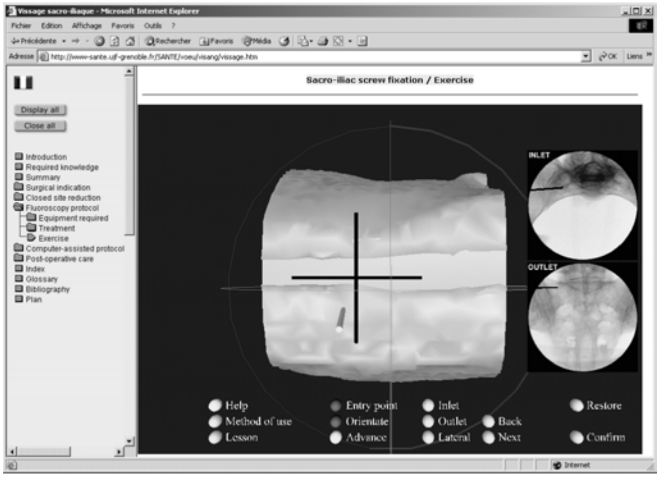


**Figure 2,** Screenshot of the on-line simulation module

Once the validation is made, by clicking a button, the system supplies him/her with various feedback: a "transparency" cursor which makes the skin disappear and which thus allows the visualisation of the pin's course through the bone; a qualitative judgement on the trajectory (for example "warning: extra-osseous trajectory") and a quantitative feedback on the number of attempts, the number of extra-osseous validated trajectories, the number of performed X-rays.

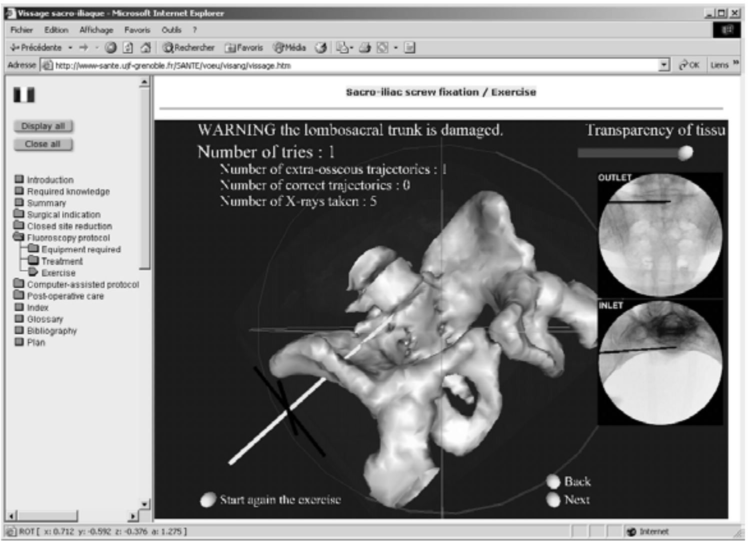


**Figure 3,** Various provided feedback after validation

The simulation feedback is not necessarily in terms of knowledge. Our system must intervene when it detects a didactical or pedagogical reason, and then generate an interaction. We do not want to constrain "a priori" the student in his/her activity with the simulation. On the other hand, the didactical and pedagogical system has to determine the most adequate feedback in relation to the knowledge that the user manipulates during the learning session [9].

## 4. Model of declarative knowledge

The aim of this research is to allow the acquisition of declarative knowledge in surgery. The adopted methodology is based on two linked phases. In the first phase, we must identify some declarative components of the surgeon's knowledge. The declarative knowledge model is based on online courses and academic documentations, and is improved by interactions between the didactical expert and surgeons. The identification of errors, for our model, is done by observation of expert and learner interactions during surgical interventions, and by surgeon's interviews. In this phase, we focus on the control component of knowledge, because we assume that control gives us key information for feedback design. This hypothesis is related to the theoretical framework of knowledge modelling, which we will present just after. During the second phase, we must implement this knowledge model in the system, in order to link the proper feedback to the user's actions

We adopt the point of view described by Balacheff to about the notion of conception, which "has been used for years in educational research, but most often as common sense, rather than being explicitly defined" [12]. The cK¢ model [12] gives a framework to didactical research for computational modelling in artificial intelligence. For brevity, we describe here only its structure and main characteristics. The first aspect of this model is inherited from earlier research in psychology and didactic: it defines a conception as a set of related problems (P), a set of rules (R) to act on these problems, and an associated representation system (L). Assuming that validation is a key aspect of conceptualisation, this model also takes into account a control structure, called Σ, which aims at making explicit a meta-level with respect to action. The crucial role of control in problem-solving has been already pointed out (by Schoenfeld for example [13]) : the control elements allow the subject to decide whether an action is relevant or not, or to decide that a problem or sub-problem is solved.

To illustrate the model functioning, we present two case studies related to declarative knowledge. This kind of knowledge comes from reference (academic) knowledge described in the online course. This course presents the planned actions to be carried out. They are schematised below:

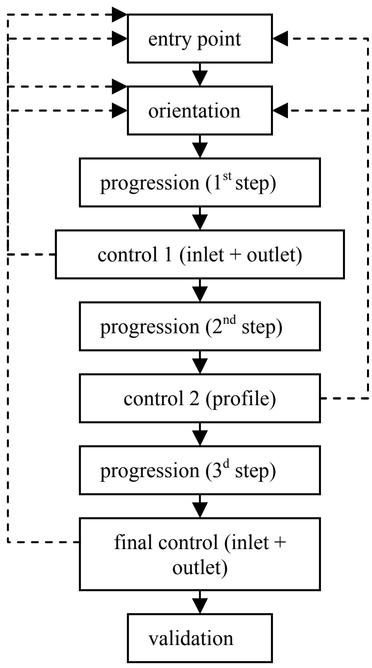


**Figure 4,** planned actions schema

Case-study n°1:

Let us consider a user who simulates a correct trajectory: entry point and orientation are correct (acceptable values); the three validation controls (inlet, outlet, lateral) are done and correct.

However, even if the trajectory is intra-osseous and doesn't provoke any neurological damage, we consider that the problem-solving process is incorrect in this case, because it lacks different important steps of the prescribed situation. In particular, the progression is done in a single step and thus the first control (inlet + outlet) is missing. The missing X-rays are not only missing actions, but they indicate that the user is missing an important aspect of his/her actions' validation.

The related feedback will thus be both positive: "Congratulations, your trajectory is strictly intra-osseous / number of X-rays: 3" and negative, with a redirection to the web page related to the mid-progression control criteria ("Pin progression"). We would like to produce, with our didactical component, the second kind of feedback. In this case the trajectory is correct but we would like to be sure that the student has the control criteria ("Pin progression").

Case-study n°2:

Let us consider a user who scrupulously respects all the different planned steps. This time, after the validation step, the system diagnoses an extra-osseous trajectory, probably causing neurological damages. The feedback will then be: "Warning: your trajectory is extra-osseous / number of X-rays: 5"; and will redirect the user to the web pages related to the diagnosed problems: entry point position ("Pin introduction") and validation criteria associated to the interpretation of the X-rays taken at the first control step ("Inlet control" and "Outlet control"). In this case we are sure that the student has a lack with declarative knowledge.

## 5. Computer representation of declarative knowledge and feedback

In this section we describe the computer system used to build our dynamic feedback in this module. The next schema illustrates the steps for producing a web feedback in relation to the online course:

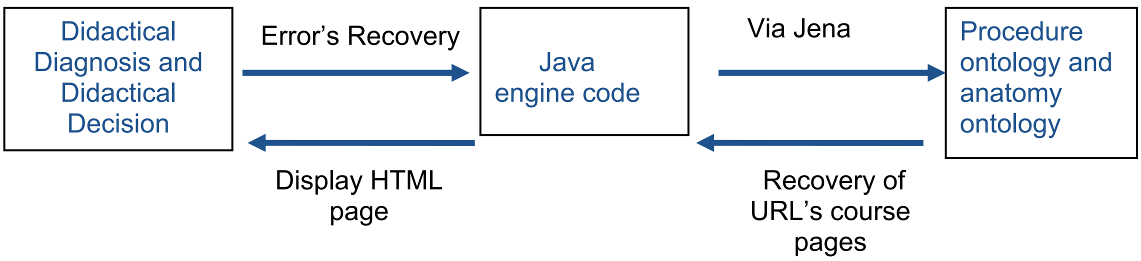


**Figure 5,** Technological solution for produce feedback to declarative knowledge

Our component, for produce this kind of feedback, receives, from the didactical component, the error(s) that must be considered. The error is analysed by the java program, using the ontology, and finally it produces a web page with a set of links to the online course, this set of links being related to the error(s). The Java Engine code use the open source tool Jena which offers libraries that allow to work with OWL files [14].

Our component is based on two ontologies, one related to the pelvis anatomy which is based on Standford university anatomy ontology [15], and the other one related to the screw placement procedures.

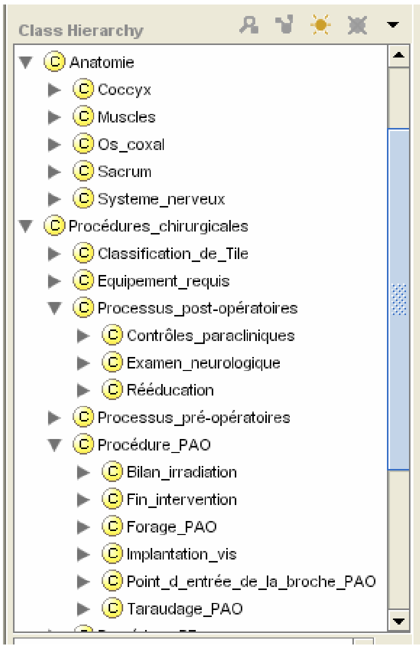


**Figure 6,** ontology for orthopaedic surgery learning system

In order to show how our component works, we propose to consider the two case studies presented above. In the first case study, if we give the error "pin progression", which is in relation with the procedural ontology, the java engine produces this set of links related to the procedure:

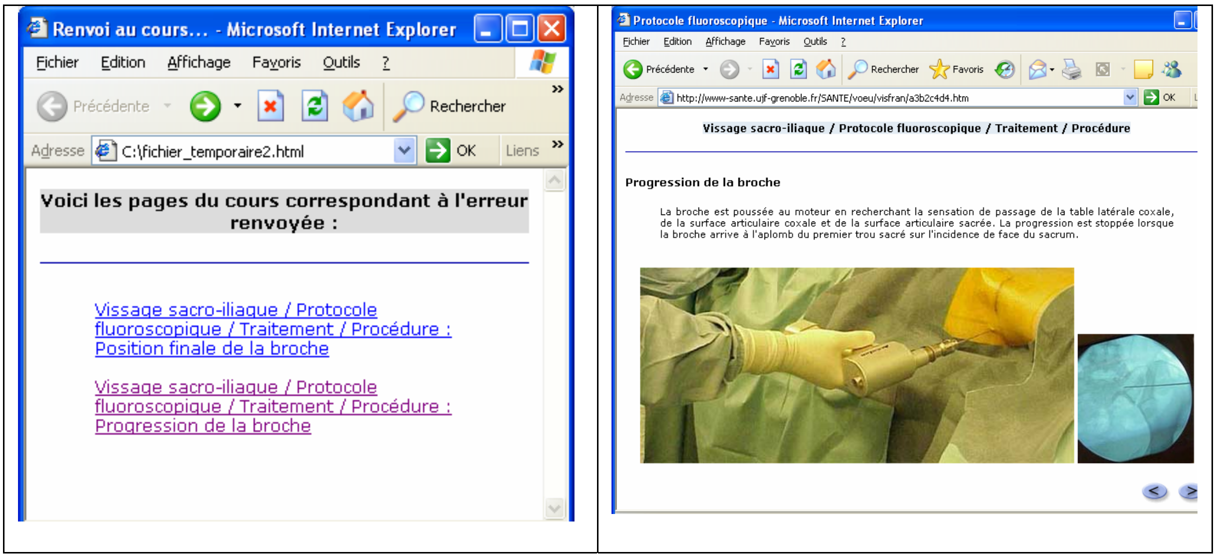


**Figure 7,** production of dynamic feedback in relation to the error "pin progression"

In the second case study, if we give the error "Inlet control and Outlet control", which is in relation with the anatomical ontology, the java engine finds the classes related to this error and produces this set of links (left image) which allow to go to the related links (right image):

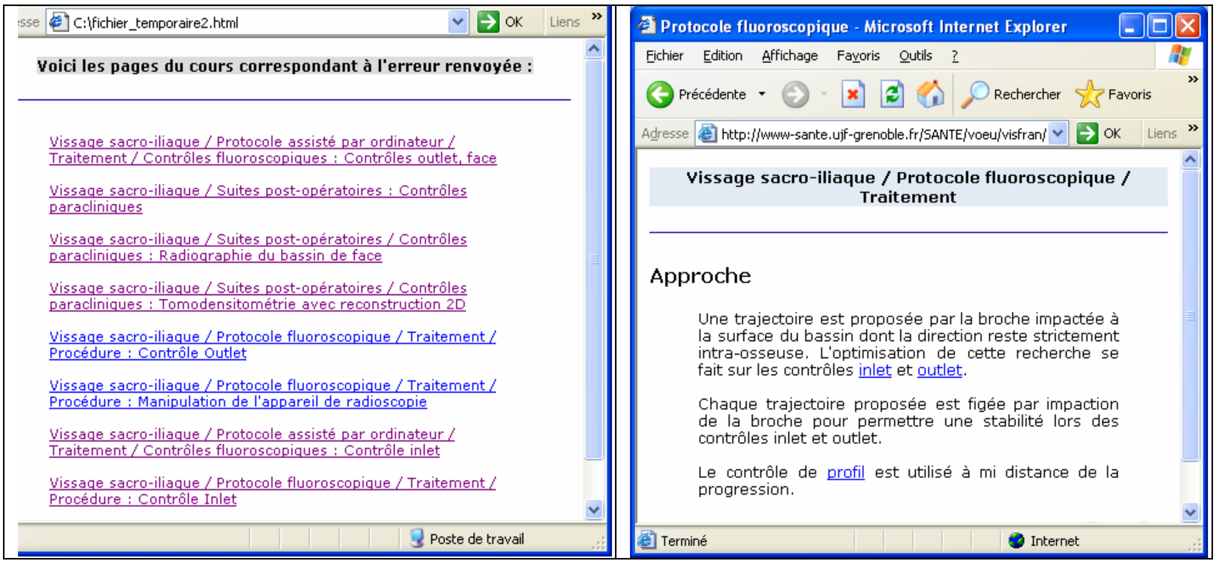

**Figure 8,** production of dynamic feedback in relation to the error "Inlet control and Outlet control"

We choose this methodology and architecture for interoperability, maintainability and reusability reasons.

- The interoperability reason is in relation to the integration with the others modules, i.e. the others kind of knowledge and feedbacks (see figure 1).
- Maintainability reason is in relation to the progress in the medical domain and the work with the expert for the knowledge representation. In our project the online course will be modified, particularly in relation to the procedure protocols which are continuously evolving. Also for an educational aspect, because we would like to propose an open environment where the teacher can add clinical cases and problem situations.
- Reusability reason is about the possibility to apply the same methodology to others systems or to use another validate knowledge modelling and to integrate it in the system. For example, in our case we integrate one ontology produce in Standford University (see § 4).

Protégé [16] is a good tool for edition and maintainability of the knowledge. With this tool we can edit, visualize and verify the knowledge used by our java engine. Moreover, it is designed for hierarchical structure knowledge.

The declarative knowledge is an academic knowledge validated and shared by the expert community. The ontology representation gives a good frame to describe these kinds of knowledge. Also, this knowledge can be described by hierarchical classification. The ontologies are expressed in OWL because it adds more semantic vocabulary for describing properties and classes: among others, relations between classes (e.g. disjointness), cardinality (e.g. "exactly one"), equality, richer typing of properties, characteristics of properties, etc.

With this architecture we can generate an adapted user interface related to the error diagnosis and the learning situation. We can also respect our cK¢ knowledge model [12] based on the student's control actions. For us this last aspect is a key aspect because the others parts of the systems are modelled with cK¢, because we build the feedback in relation to the controls actions, identified by the systems.

## 6. Conclusion and future work

Our research deals with the design of a technology-based system for the learning of some concepts of orthopaedic surgery and pelvis anatomy. This environment provides feedback related to the knowledge used by the user during the problem-solving activity. In other words the knowledge, in the learning situation, is the object of feedback. In this article we have presented our declarative knowledge component in a web platform. It allows integrating a model of knowledge in the system, in order to link didactical decision-making to the user's diagnosed state of knowledge.

The component system is developed in the framework of the TELEOS project [11] whose goal is a complete learning system for orthopaedic surgery. A part of this system is dedicated to the declarative knowledge and is constituted of a user interface, medical protocols and anatomy expressed in an object-based representation formalism, and one solver to find the best feedback in relation to a given error. This part of the system is accessible for the knowledge engineers and contains several modules embedded in the PROTÉGÉ architecture for the editing, visualisation and maintenance of declarative knowledge. One goal of this paper is to show that the technologies of knowledge representation are useful for maintenance of this kind of knowledge.

The current research in computer science within the TELEOS project follows two main directions. The objective of the first one is to embed this component system in a multi-agent architecture with a web server relying on the principles and technologies of the semantic web, in order to provide an intelligent access to knowledge and services that are useful for the learning situations. One of the main issues of the semantic web relies on interoperability for knowledge and applications. Thus, building a semantic web system implies a standardisation for knowledge and software components of the TELEOS system. For the knowledge bases, standardisation relies on a sharable domain model and leads to the definition of general ontologies in surgery. This kind of knowledge base takes into account the knowledge representation formalism of TELEOS with knowledge representation formalisms for the semantic web, such as OWL. The second direction is in relation to decisional knowledge: for this kind of knowledge we work with bayesian networks, which we have to integrate in the same multi-agent platform.

The first validations are planned for September 2005 and will use two complementary approaches, a qualitative evaluation of the learning situations, with a classical didactical methodology (called didactical engineering); and a quantitative evaluation of the educational added value of the technology-based learning, with a classical methodology of ”with” versus ”without” sets of users, measurement of progress, etc. Concerning the computational aspects of the declarative knowledge component, our evaluation will be in relation to maintainability, completeness, and flexibility of the system.

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