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Pedagogical strategy for VOEU (Virtual Orthopaedics European University)

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VŒU PROJECT

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D35.07 – Pedagogical strategy for VOEU

0 General informations

This document is an update of the previous deliverable D34.07. The text is augmented in many places, pedagogical checklists are described and given in Annex. A section “perspectives” is added, describing a work initiated during this year on the basis of VOEU results, and that will be continued after the end of VOEU as a european commission funded project.

1 Introduction

1.1 General context

The pedagogical strategy in VOEU is based upon the creation of a novel learning environment which aims to maximise the relationship between the pedagogical approaches adopted, and the tools and resources available to support them. The project therefore builds on current thinking in educational research on pedagogy, in terms of learning being situated, with learners adopting an active and constructive approach. In this text, and more generally in the framework of VOEU, we refer to apprenticeship as the traditional surgical training (“learning by doing”). We will also refer to the model of the cognitive apprenticeship developed by Collins, as well as some other fields in research in education to build and justify our choices in the instructional design of educational components of VOEU. In particular it builds on the problem-based and case-based learning literature (see for example Savery and Duffy 1996, Gallegher 1997, Hsu 1999), constructivism (Piaget 1954, Papert 1980), communities of practice (Wenger 1998), situated learning (Brown, Collins et al. 1989, Lave and Wenger 1990). The pedagogical strategy aims to create an environment which allows the different benefits of each of these pedagogical approaches to be made explicit. Guidance and exemplars of how, for example, problem and case based learning can be used in conjunction with collaborative learning, through the use of the case studies, the Dynamic Review Journal (DRJ) and the communication environment, will be included as part of the learning environment. See Section 3 of this document for more details on the individual components of the learning environment, and the Integrated VOEU curriculum described in D32.05).

The guidelines and exemplars will be developed and stored in a pedagogical ‘toolkit’. This builds on one of the VOEU partner’s previous research on using toolkits to provide guidance and support, which are developed through a process of co-participation with relevant stakeholders[1]. ‘Toolkits’ provide a pragmatically-based approach to applying theory to practice and can be used to support decision-making.
This is based on a framework for integrating learning technologies into courses which builds on Laurillard’s ‘conversational’ framework (Conole and Oliver 1998). The framework is designed to take the user through the thought processes of re-

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[1] For more details please see : http://www.ltss.bris.ac.uk/interact21/in21p06.htm

engineering a course. It begins with an evaluation of the existing course and an analysis of strengths and weaknesses. Different media types are then assessed, and the different educational interactions they support are considered. A selection process then considers limiting factors, including resource issues and local constraints. The final part of the framework is a mapping of the new course. Toolkits are defined as decision-making systems based on expert models, positioned between wizards and conceptual frameworks. They are more structured than frameworks. A toolkit is a model of a design or decision-making process, with tools provided at key points along the way. Each of these individual tools is designed to help the user access a knowledge base in order to make informed decisions. The format of toolkits means that they can be used in a standard, linear fashion, or can be "dipped into" by users whose level of expertise is stronger in some areas of the design process than others. Toolkits of particular relevance to VOEU are Media Advisor and an evaluation toolkit. Media Advisor is a toolkit which can be use to provide guidance on the appropriate integration of learning technologies into course redesign (Oliver and Conole 2000), whereas the evaluation toolkit guides users through the process of creating an evaluation strategy (Conole, Crewe et al. 2001).

The VOEU project will use Media Advisor in workshops with practitioners to produce examples of ways in which the pedagogy, tools and resources can be combined to suit different aspects and levels of the curriculum. The toolkit will therefore serve both as a guidance for users of the learning environment and a mechanism for generating and storing exemplars of different ways in which the learning environment can be used.

The pedagogical strategy is designed to invoke active participation using the multiple resources available in the learning environments. In addition, it is designed so that the users are motivated to learn about a topic by searching for, evaluating and using information. This learning experience mimics real life in targeting the learner as the routine information hunter and interpreter who constructs knowledge by problem solving with information tools. The advantages to this approach include:

- It represents a student-centred approach to learning;
- It is adaptable for students with different learning styles;
- It promotes the development of thinking skills such as problem solving, reasoning, and critical evaluation;
- It improves the research skills of the students, supporting the research-led mission of the partners;
- The work the students carry out is deeply interrelated with their work on academic and key skills.

The learning environment consists of a supportive underpinning technical architecture and a range of supplementary guidance and tools. The tools and resources will be flexible to enable their use at a number of levels, from major pedagogical re-engineering of courses through to enrichment of aspects of the learning process with engaging and illustrative resources. The process of using the environment will consist of the following stages:

1. Mapping of curricula to pedagogical approaches.
2. Identification of appropriate teaching and learning methods.

3. Evaluation and selection of appropriate resources.
4. Identification and integration of resources and tools.
5. Creation of exemplars.
6. Delivery, evaluation and refinement.

1.2 Precis of VOEU educational objectives

The VOEU project is developing a learning environment which links explicit pedagogical approaches to a set of specialised tools and resources, which will enable orthopaedic surgeons to facilitate the transfer of specialised expertise and knowledge in Image Guided Orthopaedic Surgery[2] (IGOS) techniques. The target audience is:

- Experts (experienced in IGOS surgery) who will use the tools provided by VOEU to facilitate the transfer of expertise and knowledge on specialised techniques amongst a community of experts. This includes the development of a specific surgical course model for creating IGOS surgery multimedia courses, the population and use of a Virtual Observatory for collecting and describing different IGOS interventions. In addition material from the Virtual Observatory will be used in conjunction with the Dynamic Review Journal, as the basis for real life case discussions using the communication tools available in the learning environment.
- Experts (but novices in IGOS surgery) will use VOEU to enhance their knowledge of IGOS techniques, by working through interactive IGOS surgery courses. In addition they will use the communication tools to engage in discussions about the material, work through simulators to train particular points and access the Virtual Observatory for real life materials and data.

1.3 WP07: description of the objectives and main issues of this document

Workpackage 07 describes the pedagogical strategy which underpins the VOEU learning environment. It is in line with some pedagogical aspects described in D32.05. Moreover, it is based on a surgical knowledge specific analysis for didactical aspects (by didactical we mean here domain specific) and on some relevant literature for the instructional design principles (Gagné 1976 and 1985, Mayer 2001, Smith and Ragan 1999). The pedagogical strategy is based on the premise that surgeons have specialised needs in terms of the requirements of a learning environment. Specifically there is a need to analyse and build on an understanding of the:

- Unique nature of the orthopaedic surgical knowledge and in particular the relationship between theoretical and pragmatic surgical concepts
- Rigour and validation requirements of orthopaedic surgery knowledge and the role and importance of situations, transmission of the control component of knowledge.

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[2] Arthroscopic techniques and computer assisted surgery (CAS) techniques

This work package outlines the pedagogical philosophy behind the tools and resources available in VOEU. The instructional design has taken into account the specific nature of the surgical knowledge domain as outline above.

This document is the last deliverable related to the WP07. It describes the framework of the VOEU pedagogical strategy, based on the following issues:

1. The exposed pedagogy is based on a classification of surgical knowledge: types and functions in the professional practice. In particular, notions of exchange and use values are discussed, and related to the types of knowledge and the VOEU educational material. VOEU is focusing upon enhancing the distribution of knowledge in orthopaedic surgery. To address this objective, the VOEU approach is to integrate some practical value into the surgeon's acquired knowledge.
2. The notion of scenarios is dealt with in D32.05, and won't be expanded upon in this document. Instead, we prefer then to deepen here the notion of interaction between the user and the system during learning (action/ feedback).
3. VOEU is aiming to be pragmatically relevant. For this, all the pedagogical trends adopted in VOEU are translated into some checklists. These are intended for developers and give recommendations for the creation of courses and simulators about the description of the problem-solving validation, of the provided feedback, and about some instructional design trends.

2 Learning in orthopaedic surgery

This section describes the analysis of surgical knowledge and illustrates how the pedagogical strategy has been designed to support this.

2.1 Types of domain-specific knowledge

Traditionally, knowledge in orthopaedic surgery is considered to be divided into two main categories: declarative and gestural. The first category includes intellectual, diagnostic and personal abilities. This kind of knowledge is usually learned in a context of formal schooling, and measured by well-established examinations such as multiple-choice questionnaires, other written forms of tests, as well as oral, viva voce, and ward rounds. The gestural skills, also referred to as technical or motor skills, are dexterity, eye-hand co-ordination, and spatial skills. Transmission of these gestural skills occurs by apprenticeship: novices look at experts at work, and these latter give increasing reponsibilities to novices in the activity, until they are able to do it without help. Training and assessment of competence 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.

But this dual classification is neglecting a key aspect of surgical knowledge. Orthopaedic surgery is situated and action based. 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, control, are some issues that cannot be placed at the same level as declarative knowledge. This latter is an explicit and consensual knowledge. Referring to De Oliveira & al. (2000), declarative knowledge deals with anatomy, findings (concepts used in the physician’s investigation process), therapy (kinds of therapy and their features), diagnosis (concepts and characteristics that identify syndrome and aetiology diagnoses), and pathologies (representing different situations whose classification and features are important for the purpose of the domain theory). These are theoretical, explicit, made for comunication (encyclopedic knowledge).

Procedural knowledge complements this in terms of the surgeon using the declarative knowledge and applying it to a particular patient case. In addition to the declarative knowledge, procedural knowledge allows problem-solving, reasoning and prediction. It is an experimental part of knowledge, and is validated by empirical means. However it remains a worded part of knowledge, which enables communication. This is not the case for the last part of surgical knowledge: the operational knowledge is the gestural part of the surgical practice. It is transmitted by ostension, deals with dexterity, eye-hand coordination, spatial skills. It can not be worded, and remains in some pragmatic representation and validation frameworks.

Gagné (1976) proposes different learning outcomes, which can help to illustrate these different types of knowledge. He distinguishes verbal information, intellectual skills, cognitive strategies, attitudes, and motor skills. Verbal information correspond to declarative knowledge: explicit, traditionally taught, the objective is to be able to enunciate it (an example is the anatomic schemas the learner has to complete). In the procedural knowledge category we can put all the other learning outcomes except, however, motor skills which correspond to the operational knowledge. Briefly, intellectual skills represent the capability to interact with the environment. As verbal information is "knowing that...", intellectual skills relate to "knowing how...". Cognitive strategies provide tools to deal with complex problem-solving situations: what strategy to use to catch the new problem, what verbal informations and intellectual skills to use to solve it, etc. Cognitive strategies are concerned with "knowing what to know, how to think", often referred to as "metacognition" (Flavell, 1977; Weinstein & Mayer, 1986). In order to complete, attitudes are referring to more affective capabilities. An attitude is "an internal acquired state which influences the choice of a personal action[3]" (Gagné 1976 p.60).

Taking into account the above remarks, we propose the following classification. This categorization of knowledge in orthopaedic surgery will provide a better understanding of the different VOEU components' roles in learning orthopaedic surgery:

1. **Declarative knowledge** (anatomy, knowledge on syndromes, classifications of pathologies and therapies…): it is a consensual knowledge, shared by all the medical institutions and traditionally taught (lectures, assessment by MCQ and case-based exercises).
2. **Procedural knowledge** (i.e. the process of diagnosis, choice of the surgical indications, etc) is not consensual. There are likely to be different schools of thought and approaches in different institutions. It may even present conflicting arguments, even though there are classifications of indications available (for example SOFCOT in France or BOA in the UK). The Chapel effect is observed in the learning of this knowledge. The Chapel effect is the contrary of what Collins et al. describe as follows : "apprentices have access to several masters, and thus to a variety of models of expertise. Such richness and variety help them to understand that there may be multiple ways of carrying out a task and to recognize that no one individual embodies all knowledge or expertise" (Collins et al. 1991). A chapel can thus be defined as a specific community of practice. This is why surgeons seek the guidance of established experts and will travel to experience this variation. Figure 1 illustrates the three main factors of procedural knowledge which impact on the surgeon's approach and decisions in a particular case, these include:
    - Pathology in terms of the theoretical indications (for example the Tile classification for acetabular fractures);
    - The patient area corresponds to the contra-indications and the social aspects of problems (age of the patient, quality of the bones; social aspects can be the problems of the time of rehabilitation for freelance workers);
    - The hospital environment in terms of the material environment (i.e. what sort of equipment is available in the hospital), along with the surgeons' own experience (i.e. have they encountered this before, what procedures do they have expertise in).

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[3] "un état interne acquis qui influence le choix d'une action personnelle"

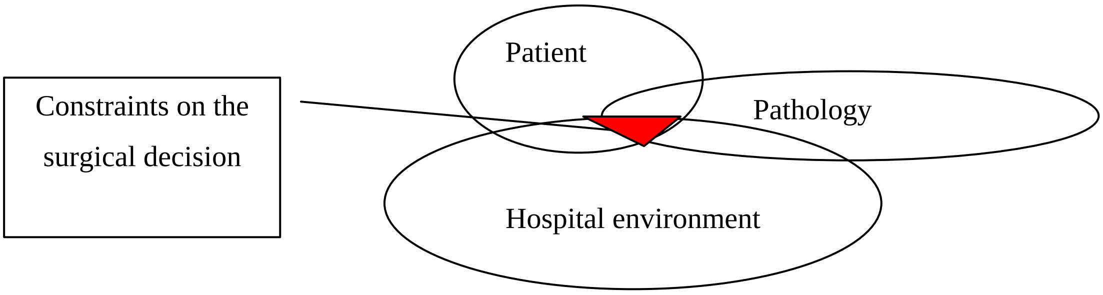

Figure 1 Three main factors influencing procedural knowledge

3. **Operational knowledge** (perceptivo-gestual, psychomotor skills during the operation): the Chapel effect can also occurs in the learning of this type of knowledge; surgical learning is made by observation and by training in laboratories on cadavers, animals, artificial organs and in theatre on real patients (where the apprentice is involved in one to one interactions with the surgeon, and is given progressively increased responsibility).

2.2 The use and exchange values of knowledge: operative and predicative functions

In order to deepen the links between our categorization of surgical knowledge and the VOEU educational resources' instructional design, we will develop hereafter the notions of use and exchange values of knowledge. Some features of the model of cognitive apprenticeship will be first recalled.

2.2.1 Cognitive apprenticeship

As apprenticeship usually designates the traditional learning by observing and doing, Collins et al. (1989) introduce the model of cognitive apprenticeship: "*It is a model of instruction that goes back to apprenticeship but incorporates elements of schooling*". We see this model as presenting some advantages in the case of VOEU.

- First, it focuses on a contextualisation of knowledge : "*the challenge is to situate the abstract tasks of the school curriculum in contexts that make sense to the students*" (Collins et al. 1991). Contextualisation is a key aspect of the apprenticeship in surgery like in other fields (see Weil-Barais 2001)
- Second, it takes into account the learning of control strategies. Collins refers to Schoenfeld[4], who found that it is crucial to teach control strategies in mathematical problem-solving. In fact, the characteristics of the operability of knowledge in professional practice are principally focusing on the key issue of the validation and the control. This is why we focus our pedagogical approach on the role of feedback during the interaction between the learner and the learning environment.

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[4] Schoenfeld, A. (1985). Mathematical Problem Solving. New York: Academic Press.

To apply this model in VOEU, we have to deepen our understanding of the functioning of knowledge in surgery. Because it is the task that will determine the type of reasoning the learner will use, more than the learner's level (Brousseau 1997, Patel et al. 1995 p.420). We will define the notions of use and exchange values of knowledge in the next section.

2.2.2 Use and exchange values of knowledge

First, we will give a definition of these two functions of knowledge, which can also be pointed as the operative and predicative functions of knowledge. The use value is the aspect of knowledge that works during the professional practice. It allows the subject to act, it is the operative function of knowledge. The exchange value is the aspect of knowledge that can be communicated (in the expert community). It is a more symbolic and conceptualized aspect of knowledge than the use value of it. It is the predicative function of knowledge.

Thus, there are two main ways in which the different aspects of a surgeon's knowledge can be used: use (in terms of the surgeon's ability to act) and exchange (in terms of communication of expertise within the community of peers). These correspond to the operative or predicative functions of knowledge in the community.

The declarative part of a surgeon's knowledge is predicative; it can be expressed and transmitted. In contrast, the procedural component of surgical knowledge contains both predicative and operative features, thus it is part of both the exchange and the use values of knowledge. Diagnosis abilities (intellectual skills), attitudes towards patient, cognitive strategies and even motor skills can be partly explicit and transmitted, particularly for continuing education. But they are also some subjective, personal and context-specific knowledge. And last, operational knowledge is obviously dealing with the use value. In surgery, the operative part *(use value)* of the expert practice is both occurring during the diagnosis and the treatment delivery phases, as the following quote illustrates; "Much of the information about the decision processes resides in the mental model of process participants, where it remains tacit."[5] (Ford and Sterman 1998).

Table 1 summarises the different aspects of surgical knowledge and how they map to Gagné's learning outcomes. For a better understanding of our categorization of knowledge, we indicate the validation issue of each category.

Type of Surgical knowledge	**Learning Outcomes (According to Gagné 1976)**	**Function**	**Validation**
Declarative	Verbal informations	Exchange value	Discourse,

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[5] Activity theory can provide an explanation for the notion of "process participants", in that the subject in action has a goal to reach and tools to do so, but is also embedded in a community which implies rules and division of labour. In surgery, the surgeon is far from being alone in the theatre - nurses, anaesthetist, residents, etc. are part of the surgical community. They contribute to the process in terms of the definition of the specific cultural rules (timetable, hierarchy of actions) and the division of labour (i.e. everyone has defined roles and each person's actions are reliant on the actions of the others in the community).

knowledge		(= Predicative function of knowledge)	argumentation, analytic reasoning
Procedural knowledge (intellectual)	Intellectual skills	Use and exchange values (= Predicative and operative functions of knowledge)	Experimental
	Cognitive strategies		
	Attitudes		
Operational knowledge (pertaining to gesture)	Motor skills	Use value (= Operative function of knowledge)	Pragmatic

Table 1: How different aspects of surgical knowledge map to Gagné learning outcomes.

In the next section we describe the different multimedia components and their links with the different type of knowledge they support.

3 VOEU's educational system components and intended learning outcomes

In this section, we present VOEU's educational components and the intended learning outcomes related to each of the components. Among others, we show the interest of including handbooks and interactive courses in order to enhance procedural aspects of knowledge and, thus, the use value of the surgeon's acquired knowledge.

The architecture of the VOEU learning environment is illustrated in Figure 2 and is described in more details in deliverable D32.05.

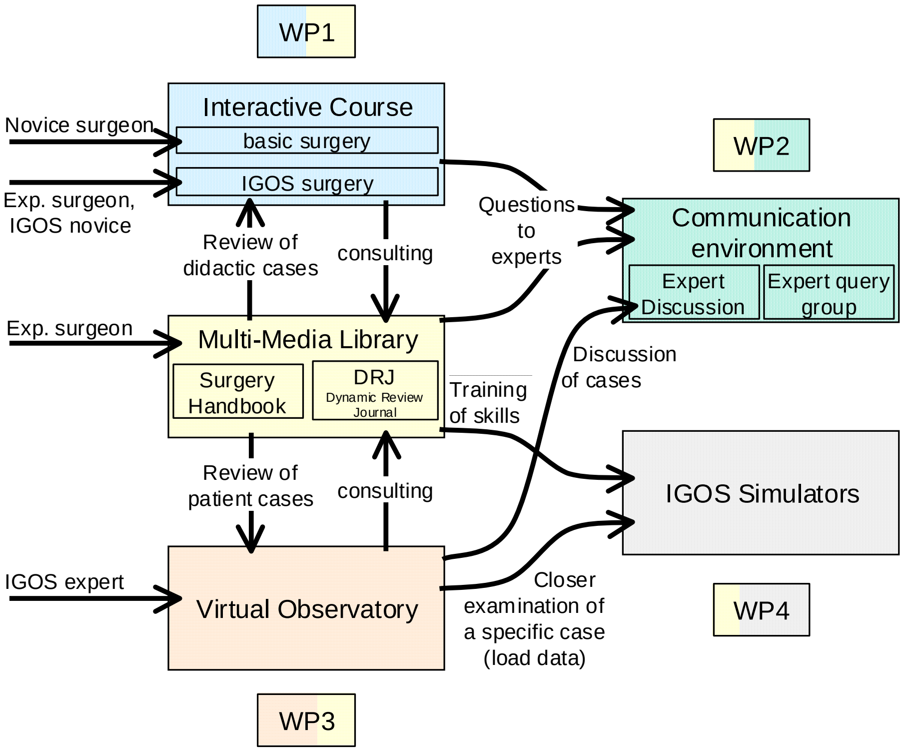

Figure 2 VOEU learning environment architecture

The learning environment consists of six main components; interactive courses, surgery handbooks, a dynamic review journal, a virtual observatory, IGOS simulations and a communication environment. Each one is described here, along with an outline of the types of knowledge each supports.

- **Surgery Multimedia handbooks**

The surgery multimedia handbooks are designed to focus on specific techniques, treating of the surgical indications and the different steps involved in the intervention. Handbooks essentially deal with declarative knowledge. Details on the way VOEU aims to present this knowledge are given in Section 4.1 of this document, in deliverable D07.01 and in its update (deliverable D26.01).

- **Interactive courses**

These courses are interactive case-based studies (see below for more details on this paradigm, section 4.2.1). They focus on medical reasoning in anamnesis, diagnosis, and therapy. As explained by Cicourel (2002), medical reasoning in real conditions involves social interaction, interpretation by the surgeon and the patient of questions and answers according to their own experience. This is particularly the case in the context of anamnesis. Medical reasoning in our Interactive Courses is not taking these socio-linguistics aspects of the problem into account. But it provides the user with an environment in which he can train his ability to make good inferences in diagnosis and treatment. This reasoning makes use of declarative knowledge and focuses on intellectual skills : the “know how”. Cicourel (p.96) is talking about a single level of knowledge, gathering “*the formal, declarative, propositional knowledge database and reasoning*”[6].
Interactive courses give access to a contextualised way to apply declarative knowledge, enhancing the learning of the related intellectual skills.

Both the handbooks and the interactive courses provide declarative knowledge through procedural aspects of professional practice (the technique for handbooks and the diagnosis for the interactive courses), to enhance the use value of the acquired knowledge. By presenting this knowledge in a case-based context, it is anticipated that the value of the acquired knowledge will be enhanced. It is intended that we make the difference between a real case-based approach and a case-based presentation. Conditions for a real case-based approach will be detailed further, in particular in the pedagogucal checklists for the interactive courses. These conditions are related to the nature of the activity, and the nature of the feedback the system is providing to the user.

- **The virtual observatory**

The virtual observatory (V.O.) is a database of real cases, which provides contextualised illustrations of the interactive courses’ contents. It allows the user to experience the discrepancy between generic cases (used in courses) and real particular cases (available in the V.O.). As an example, identifying a fracture on some real patient’s X-rays is more difficult than the identification from a textbook illustrative X-ray. It does not appeal the same knowledge on medical scanning reading.The Virtual Observatory therefore provides a means for enhancing the operative function of knowledge, through contextualisation.
The V.O. also provides data which can be used in the VOEU simulators. Different types of data (X-rays, CT-scans, and the related planning results) can be downloaded from the V.O. into simulators, which can then be used to train certain aspects of an intervention. This is especially useful for the training of the planning session of IGOS interventions (the planning step is the identification of the best possible trajectory on a reconstructed 3D model of the bone – this trajectory will be used to guide the surgeon during the intervention). Users can thus improve their planning abilities using real data. This form of learning through use of real data is complementary with using a generic case, where data is legible, clear and designed to be explicitly representative of the underpinning theoretical case. Work on real cases can provide ways to be confronted to the limits of such a theory, and thus provide a framework to train intellectual skills and cognitive strategies.

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[6] “*la base de connaissance et le raisonnement formels, déclaratifs, propositionnels*”

The Virtual Observatory provides opportunities for learners to train both on diagnosis, surgical indications and treatment delivery (V.O. related to interactive courses and multimedia handbooks) and also on planning session and motor skills (V.O. related to simulators).

Additionally, access to the information of the V.O. is managed to provide further informations to the user : statistical tools, possibility to ask for several cases related by a common factor, keyword research on cases... The Visual Integrator provides these V.O. entries, which give material for evidence-based learning and statistical studies.

- **Simulators**

Simulators focus on two aspects of the professional practice : the planning step of the intervention in CAS treatment delivery (e.g. the iliac simulator in UJF-Grenoble), and the motor skills needed for IGOS procedures (e.g. the knee arthroscopy in SSSA-Pisa or the iliac simulator for the ultrasound surface acquisition with haptic feedback in UJF-Grenoble). Simulators therefore focus on both procedural (intellectual) and operational (gestural) knowledge. Within the simulators, links are provided to related declarative knowledge with references to the relevant aspects of declarative knowledge which are integrated in the provided feedback during the problem-solving activity.

- **Virtual Classroom**

The virtual classroom is a place for surgeons to comment on courses and the Virtual Observatory real cases; providing a mechanism for discussing procedural knowledge. This simulates part of the community model. This can be expected to enhance the exchange value of procedural knowledge. Through discussions between experts, and between experts and novices, cognitive strategies and attitudes are involved and thus are partly elicitated. It may also represent a metacognitive benefit, as knowledge can be partly shaped through experts' discussions.

Table 2 summarizes for each component of the learning environment: the specific types and functions of knowledge involved, and the related learning outcomes.

Educational System Component	**Type of Knowledge Involved**	**Learning Outcomes Expected**	**Function of Knowledge Involved**
Multimedia handbooks	Declarative	Verbal information	Exchange value
Interactive courses	Declarative and procedural	Verbal information	Exchange value
		Intellectual skills	Use value (by the case-based approach)
Virtual classroom	Procedural	Intellectual skills Cognitive strategies Attitudes	Exchange value through discussions

Virtual observatory	Declarative and procedural	Verbal information	Exchange value (through the statistical elements, the research results)
		Intellectual skills Cognitive strategies	Use value by the contextualisation of knowledge
Simulators	Procedural and operational	Intellectual skills Cognitive strategies Motor skills	Use value

Table 2 Components of the learning environment

4 State of the art - Developing VOEU's medical educational system components

This section describes in more details three of the key components of the learning environment: the multimedia handbooks, the interactive courses and the simulators, ways in which these can be considered state of the art, along with the proposed strategy for developing these components. More detailed descriptions of the virtual classroom and the virtual observatory are made apart in deliverables D24.02 and D23.03.

4.1 Surgery multimedia handbooks

Handbooks correspond to traditional lecture scripts which are written down by teachers in order to help students to acquire knowledge. It would be beyond the scope of VOEU to take into account all the literature on designing handbooks for learning and instruction.
The main recommendations for the development of the surgery multimedia handbooks is with reference to the Specific Surgical Course Model, elaborated in WP01 (D07.01 and D26.01). This section will outline and discuss the key features of this.

In this model, we aim at providing authors with two main specifications. First, there is to be a general given structure to courses, managing consistency and contextualisation of information. Second, to ensure the operability of knowledge, key aspects of the presented technique have to be deepened. Thus, each element of the vertical structure may contain different aspects of information, which can be classified into four distinct groups.

4.1.1 Vertical structure

We now give details of the vertical structure. This represents a consensus in the VOEU community of surgeons. It may evolve with the diffusion of VOEU courses to other institutions.
For CAS (Computer Assisted Surgery) treatment procedures, the educational material should reflect the following structure:

a. Indications
    i. Anatomy
    ii. Pathology
        - Classification
            - o Pre-intervention scores for outcome measure analysis
        - Diagnosis
            - o Differential
        - Clinical examination investigations
        - Procedure
            - o Indications
            - o Contra-indications and cautions

b. Technique

i. Planning of the intervention
ii. Set-up of the CAS equipment needed
iii. Treatment delivery
  - Anaesthesia
  - Equipment
    - Standard theatre equipment
    - Specific equipment required for the intervention
  - Patient positioning
  - Surgical approach
  - Procedure, described by task sequence
  - Implant details
  - Imaging
  - Closure
  - Dressing
  - Post operative instructions
iv. Post-operative
  - Complications
  - Rehabilitation and care
v. Postoperative documentation, performance assessment

4.1.2 Internal structure of information

This section gives details about the four levels of information required at each step of the above structure. All these points are to be written by the author of the course.

- Technical/Medical terms
  Is there any specific technical or medical term, which might be unknown to the learner that requires a definition? This may be provided with descriptive text in a hypertext link or a link to specific parts of the handbook. Each key word should be explained in a hypertext glossary.
- Expert problems
  What kind of problems do experts encounter, is there any critical information in this chapter that experts must be aware of ? If it is the case, explain the reason of this importance (with a link, or in the core of the text).
- Criteria for validation
  Control : At the end of the step, what kind of elements do the expert surgeon use to know if this step has been achieved correctly (self-assessment) ? And to know if the learner has acquired all relevant procedural and declarative knowledge (learner assessment)?

  Assessment : Providing criteria for assessment with the learning material enables the student to decide for himself how well he is doing with respect to a set “optimal” strategy. It should be noted however, that it is not always desirable to fix a single “true” solution, a multi-dimensional solution space has to be used instead.

Yet is clear that identification of all these information requires a thorough analysis of the current technique, which needs application of set of procedures for systematically analysis of the techniques. In fact, as the field of IGOS-techniques is rather young, generally approved knowledge on expert and novice problems is not available. This also holds for standardised evaluation criteria. Research in this area to identify these aspects is however on its way, and falls into two broad categories: structured task analysis and recording of critical incidents. In the VOEU project, both approaches are followed. At the beginning of the project, IGOS techniques were analysed in a structured way by using LAURE-forms (see D05.01 *Educational user requirements*), which are build upon the concepts of task analysis, aiming at structured and standardised identification of different task characteristics (see for instance Shepherd 1995, Hacker 1994).

Additionally, the critical incidents technique is also about to be implemented. The critical incidents technique can be defined as recording and analysing behaviours that resulted in critical incidents, allowing to conclude on failure of individuals, equipment or organisations in specific situations (Flanagan, 1954). As it will be implemented in VOEU, surgeons are asked to identify specific incidents which they experienced personally and which had an important effect on the final outcome. As the emphasis is on incidents rather than vague opinions, a surgeons are requested to fill-in document right after the incident occurred. This document provides defined categories for describing the incident from different perspectives, allowing to capture important information from the context of the incident as well.

The specific surgical course model, described in D26.01 (final version), has been implemented in an author tool for the creation of handbooks (GenDoc). Details on this computer-based environment are also provided in D26.01.

4.1.3 Multimedia handbooks' pedagogical checklist

In this section we present the checklist given in Annex.

For the application of the Specific Surgical Course Model into the checklists, we adopt an enhanced description of the above structure. It is based on a 3 directions model:

- **chronology**, as described above
- **topics**, with the description of:
  - equipment (what is required),
  - anatomy (what part of the anatomy is concerned),
  - and gestural skills (what specific skills are involved in the step)
- **information** with description of:
  - the specific terminology,
  - the experts difficulties,
  - and the validation criteria, both regarding control (expert criteria for the action validation) and assessment (expert criteria for the learner evaluation);

Moreover, VOEU handbooks meet some others pedagogical principles. These specifications are exposed in the section "internal structure and content (see the checklist given in Annex). They are based on some instructional design literature (Smith and Ragan 1999, Klauer 1985 and Leutner 1998 and 2002) and some empirically established principles of designing multimedia learning materials, exposed by Mayer (2001) :

- Multimedia principle: Students learn better from words and pictures rather than from words alone.
- Modality principle: Students learn better from pictures or animations and spoken text than from pictures or animation and on-screen text.

- Redundancy principle: Students learn better from animations and spoken text than from animations, spoken text and on-screen text.
- Contiguity (split-attention) principle: Students learn better when corresponding words and pictures are presented near rather than far from each other on screen (spatial contiguity) and when they are presented simultaneously rather than successively (temporal contiguity).
- Coherence principle: Students learn better when extraneous (irrelevant) material is excluded rather than included.

A part of each checklist (for handbooks, interactive courses and simulators) is devoted to these principles.

4.2 Interactive courses

The deliverable on Visual Integrator and learning requirements (D05.01) includes a summary of the educational user requirements for the project and these include the following:

"the learning material needs to be presented in a way which allows for self-directed, problem-based learning"

"the learning material needs to be structured around authentic patient cases to allow for case-based learning"

In this section, we summarise three pedagogical concepts of relevance for achieving this, namely problem-based, case-based and evidence-based learning.

4.2.1 Key learning approaches used in medicine

Problem-based learning (PBL) as an approach has gained significant popularity in medical schools in response to the increasing amount of information to learn and associated cognitive overload. It is an instructional method that challenges students to "learn how to learn", working to seek solutions to the proposed problems. These problems are used to engage students' curiosity and initiate learning the subject matter. PBL prepares students to think critically and analytically, and to find and use appropriate learning resources. PBL uses sort of "real world" problems, not hypothetical case studies with neat and convergent outcomes. A central tenet of PBL is that it is in the process of struggling with actual problems that students learn both verbal informations and cognitive strategies. Learning in the context of the need-to-solve-a-problem tends to facilitate the acquisition of what we call the use value, or the operative aspect of knowledge.

Problem-based learning is thus a learning environment (but not necessarily a case of cooperative learning) in which the problem drives the learning. That is, before students learn some knowledge they are given a problem. The problem is posed so that the students discover that they need to learn some new knowledge before they can solve the problem. The PBL approach is often centred on the understanding of some fundamental mechanisms of medicine (anatomy, study of pathologies, etc).

The **case-based learning** approach is one of the main, traditional ways of recalling knowledge in medicine. The traditional and well-known "case-based approach" may or may not be problem-based learning. Often the case is used to integrate previously learned knowledge and hence would not be, according to the previous given definition, problem-based learning. It can also be used as a means of assessment, i.e. it is a way of managing and then assessing the integration of previously acquired knowledge.

The case-based learning approach focuses on clinical reasoning, on the diagnosis and on the therapeutic solution to the studied case. Usually, cases are hypothetical, with neat and convergent outcomes. The case-based learning approach provides a way to put knowledge into context and thus to deal with some aspects of procedural knowledge. While recalling the declarative knowledge, the user is placed in a problem-solving situation to learn intellectual skills.

Evidence-based medicine is a method of reasoning that integrates both individual clinical expertise and the available external clinical evidence. This external clinical evidence is clinically relevant research, which invalidates previously accepted diagnostic tests and treatments and replaces them with new ones that are more powerful, accurate, efficient and safer.

Reliance on scientific research results is a necessity, particularly in Computer Assisted Surgery, where personal clinical expertise is limited, due to the novelty of these techniques. Evidence-based medicine provides experts with tools to find important new medical research quickly and easily, and to work out its implications for practice.

4.2.2 VOEU’s pedagogical approach

VOEU plans to utilise the best aspects of problem-, case-, and evidence-based learning by providing an engaging and interactive learning environment which helps to facilitate authentic and situated learning opportunities using a range of resources available within the system (such as the simulators, the Virtual Observatory, the surgical handbooks, the interactive courses, the virtual classroom and the Dynamic Review Journal).

Evidence-based medicine is represented in VOEU through the Virtual Observatory associated with the Dynamic Review Journal (DRJ). This VOEU feature is designed to allow the production of scientific results of Image Guided Orthopaedic Surgical (IGOS) techniques. This set of tools supports the collection of data from the clinical environment and prepares it for review by clinicians and scientists so that it may be peer reviewed and added to the canon of established knowledge.

Problem-based and case-based learning are represented in VOEU through interactive courses and simulators. Each one involve different parts of the surgical knowledge (declarative and procedural for interactive courses, procedural and operational for simulators). In this section we detail the development of Interactive Courses.

VOEU aims to reach the operative aspect of knowledge by contextualization of knowledge through problem- and case-based learning. In addition, control aspects of the professional practice are given by the internal structure of information, already described in the previous section for handbooks (4.1.2.). These levels of information are thus also required for interactive courses.

Interactive courses are less specific to the technique than surgery multimedia handbooks. Thus, the structure of the course needs to reflect the general approach to patient healthcare: diagnosis, treatment delivery, and aftercare. Depending on the type of IGOS technique presented, the specific elements of this vertical structure differ due to the difference in diagnosis and treatment of the patient's disease. In the framework of the VŒU project different vertical structures thus can be identified for arthroscopic procedures or treatment by CAS system. It can be assumed that especially for the basic part of the model (the first steps in patient healthcare) a number of elements of both structures match. In the following, both structures are presented:

Arthroscopic Procedure

1. Dialogue of the physician with the patient: e.g. anamnesis, problems, general attitude of patient towards health, attitude towards preservation of personal health.
2. Clinical examination: examinations based on the dialogue with the patient.
3. Identification of the need for arthroscopic diagnosis, dialogue with the patient about the next steps of examination.
4. Confirmation of diagnosis by arthroscopy, exclusion by differential diagnosis.
5. Performance assessment.

CAS Treatment Procedure (basic surgical course)

1. Dialogue of the physician with the patient: e.g. anamnesis, problems, general attitude of patient towards health, attitude towards preservation of personal health.
2. Clinical examination: examinations based on the dialogue with the patient.
3. Identification of the most probable diagnosis, dialogue with the patient about the next steps of examination.
4. Confirmation of diagnosis in the order of probability, exclusion of the differentiating diagnosis.
5. Identification of the method of treatment, based on patient dialogue and best practice.

CAS Treatment Procedure (specific surgical course)

1. Planning of the intervention.
2. Set-up of the CAS equipment needed.
3. Treatment delivery: described by task sequence (actors, cognitive and manual tasks, frequent bottlenecks and problems).

Constraints on the development of the interactive courses are given in details at the end of the document (Annex), as a checklist for developers. The main focus for these specifications are the interactions between the user and the computer-based learning material. These recommendations are based on different VOEU results (described in D07.01 and in D34.07), on some research on medical reasonning (Barrows and Feltovitch 1987, Cicourel 2002) and on some instructional design literature (Mayer 2001, Chou 1999, Smith and Ragan 1999). They are detailed in the next section.

4.2.3 Interactive courses' pedagogical checklist

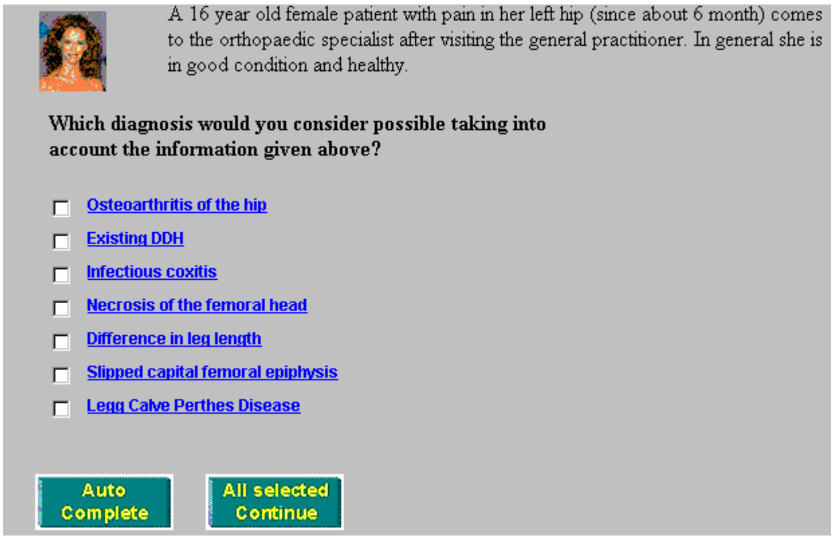
Checklist are presented in Annex.

In this checklist we employ the notions of “step” and “activity”. These are important to be defined, as they are the core of the relevance of some of the checklist’s items.
During the interaction with the multimedia educational resource, the user has several actions to do (based on decisions) to perform a task, composed of different activities (the decision of the different activities to define in a task is took by the authors and conceptors of the courses/ tasks).
The task represents the learning objective, and activities are the different parts to perform in this task.
Below is an illustration of these notions, based on the DDH interactive course (developed by HIA-Aachen).In this module,

- the task (the learning objective) is the treatment of the developmental dislocation of the hip
- the different activities to perform in the interactive course are : the Anamnesis (consists in collecting relevant informations from the patient for diagnosis), the Status examination (consists in deciding and performing relevant examinations of the patient) and the Therapy.

In each of these activities, the user has to perform different actions. These are the steps of the activities, and correspond to the Learning Objects (IEEE Learning Technology Standards Committee (LTSC), IEEE P1484.12 Learning Objects Metadata, Working Draft. URL: http://ltsc.ieee.org/wg12).
In the Anamnesis activity, different steps are :

- Select the possible diagnoses, taking into account the first informations given on the patient case (L.O. “Multiple choice question”);

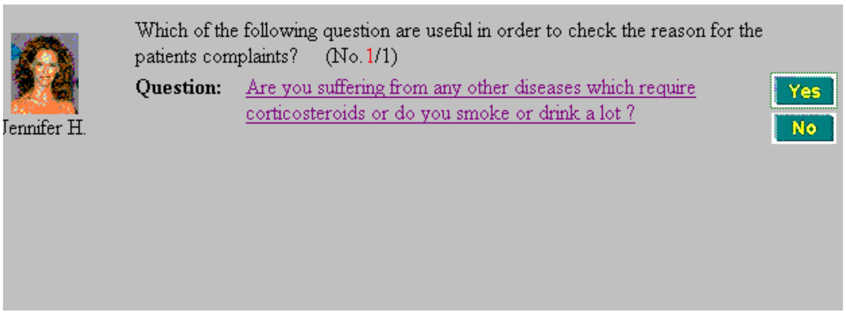


A 16 year old female patient with pain in her left hip (since about 6 month) comes to the orthopaedic specialist after visiting the general practitioner. In general she is in good condition and healthy.

Which diagnosis would you consider possible taking into account the information given above?

☐ Osteoarthritis of the hip
☐ Existing DDH
☐ Infectious coxitis
☐ Necrosis of the femoral head
☐ Difference in leg length
☐ Slipped capital femoral epiphysis
☐ Legg Calve Perthes Disease

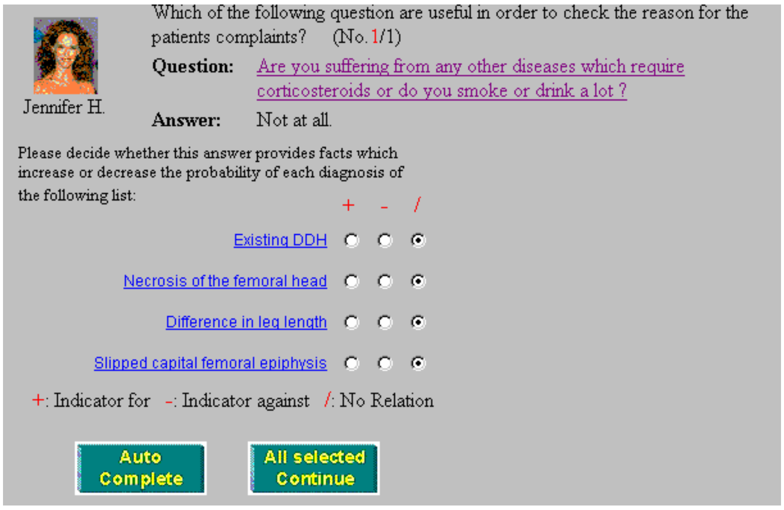
- Select relevant questions to be asked to the patient to confirm and/or reject the different possible diagnoses (L.O. “Yes/No question”);



Which of the following question are useful in order to check the reason for the patients complaints? (No. 1/1)

Question: Are you suffering from any other diseases which require corticosteroids or do you smoke or drink a lot ?

- o Reject and/or confirm the different possible diagnoses, taking into account patient's answers to the asked questions (L.O. "Multiple Single-choice question").



Which of the following question are useful in order to check the reason for the patients complaints? (No. 1/1)

Question: Are you suffering from any other diseases which require corticosteroids or do you smoke or drink a lot ?

Answer: Not at all.

Please decide whether this answer provides facts which increase or decrease the probability of each diagnosis of the following list:

	+	-	/
Existing DDH	○	○	●
Necrosis of the femoral head	○	○	●
Difference in leg length	○	○	●
Slipped capital femoral epiphysis	○	○	●

+: Indicator for -: Indicator against /: No Relation

We now give details on what we mean by "informative feedback" and "evaluative feedback".

The **informative feedback** is every reaction of the computer which intends to give information to the user. That is, reaction to each action, during the problem-solving process. Informative feedback can be :

- answer to a question asked by the user, in a textual and/or visual format (a question can be a simple click on an icon, or on a help box)
- visualisation of the result of an action in the setting of the action and/or in another setting

The **evaluative feedback** is giving elements of assessment to the user. A judgement is made on his/her actions. Evaluative feedback can be :

- "right or wrong" feedback or quantitative feedback (mark) **WITH** justification and relation to the subjacent theory and/or recall of the related theory and/or visualisation of the result of the user's process
- redirection to others steps of the process
- redirection to a prerequisite section or recall of the related theory

An important point of the user's actions assessment is that evaluation criteria have to be related to the theory, not only to the comparison with an expert best-practice.

In a constructivist approach of learning, it is intended that learning occurs when the learner detect his/her own errors by him/herself. The computer-based environment thus must be designed to allow such a constructivist process. For this, we assume that feedback at the end of a step should be solely informative; feedback at the end of an activity can be informative and evaluative.

Pedagogical checklist for Interactive Course is structured in three parts : “Pedagogical approach”, “Assessment methodology”, “Internal structure and Content”.

The first section is dealing with general constructivist orientations. It gives recommendations on the way the learner can navigate in the task and on the nature of feedback at the different stages of the task (as explained above):

- The problem-solver has the opportunity to start a single step of the activity again;
- Feedback do not prevent the problem-solver to access next steps of the activity until he has not succeed in the previous step;
- No evaluative feedback is given during an activity.

It also gives some constructivist instructional design recommendations, based on Barrows and Feltovitch research on medical reasoning:

- The problem-solver must be presented with only the little information that is characteristically available initially;
- The problem-solver is allowed to investigate freely, employing any question or examination item in any sequence;
- The problem-solver must be given the information obtained from the investigation overtime, allowing reasonning to occur at every step.

The second section is treating the assessement aspects of the task. It gives recommendations on using evaluative feedback:

- Conduct assessment of learner performance in terms of a quantitative evaluation (mark);
- Provide feedback : “right/wrong” feedback **WITH** justification and relation to the subjacent theory and/or recall of the related theory and/or the visualisation of the result of the user’s process;
- Provide remediation :
    - redirection to others steps of the process
    - redirection to a prerequisite section or recall of the related theory

The last section is dealing with multimedia instructional design, giving recommendations for the development of the unit. This latter is considered to be divided in three classical parts (Introduction, Body and Conclusion), where Body is the core of the interactive course. This part is constituted of the three activities: Anamnesis, Examination and Therapy. This structure is relevant according to medical reasons, and is implemented in GenDoc as a rigid structure (see D26.01 for more details).

4.3 Surgical simulators

4.3.1 VOEU’s position

In this section we define the terms “simulation” and “learning environment based on simulation”. First, we can point out that VOEU is concerned with the simulation for learning, in particular through a constructivist approach of learning (i.e. learning by discovery, doing and problem-solving).

Simulators are designed to provide approximations to reality as part of the process of situating and making the learning real. Theoretically simulators intend to be as realistic and lifelike as possible. However, they are obviously compromising as illustrated in the following schema:

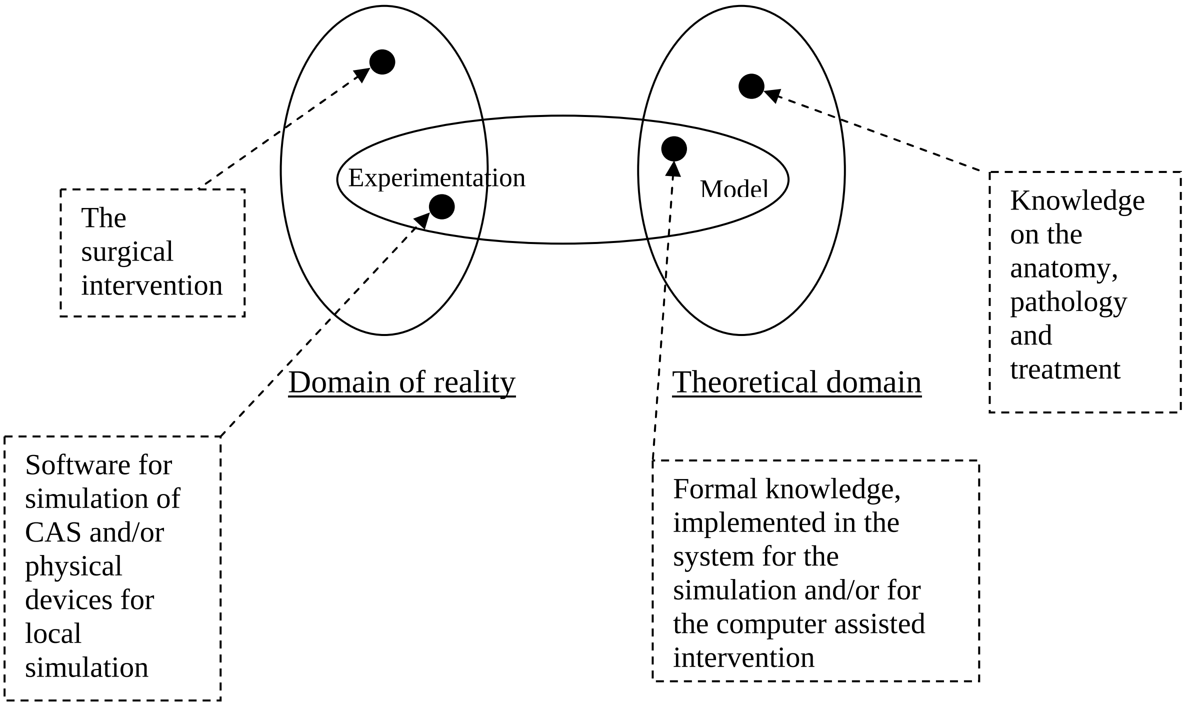


Figure 3 Simulation as an approximation to reality

The problem-solving activity through the simulator is the experimentation, characterized by an action / feedback loop. It defines the functioning area of the model, thus it is the domain of reality of the model. It is through the experimentation that subjects can validate the knowledge they get from the theoretical domain. The simulation links the model and the experimentation through concrete manipulations.

A simulation can thus be defined as follows: the user manipulates a device in which some theoretical knowledge is implemented, both in the internal system and at the interface. With respect to this, de Jong and van Joolingen state that *"A computer simulation is a program that contains a model of a system or a process.... the main task of the learner is to infer, through experimentation, the characteristics of the model underlying the simulation"* (de Jong & van Joolingen 1998). We can add that the user infers the characteristics of the model through the interface, which is not neutral in regard to the model. These characteristics of the simulator define the possible actions for the user: the available tools and their relative rules (the set of problems which can be posed, the nature of the possible solutions it permits and the ones it excludes).

Simulations perform different educational roles. Principally but non-exclusively, simulators can assist users with the understanding of phenomena (with calculation through a mathematical model – like in meteorology), or they can be embedded in an environment for learning. In this latter case, it can be a simulation for the learning of gestural skills (like the manipulation of surgical tools, with a local device) or simulation for the learning of scientific concepts (simulators for the training of planning and manipulation of the software associated with CAS surgery). These devices can be designed as case- and problem-based learning environments for operational knowledge.

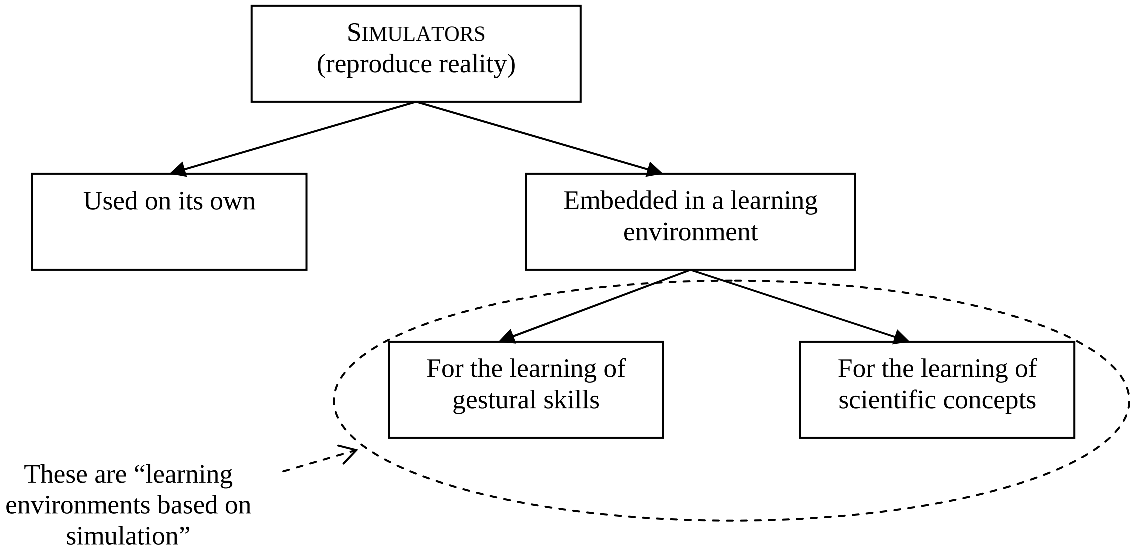


Figure 4 Gestural and conceptual aspects of learning in simulators

All VOEU developped learning environments based on simulation are about the two aspects of learning cited above: gestural and conceptual.

- The UJF sacro-iliac simulator is about planning and performing the screwing insertion, and involves echographic simulation with a local device and haptic feedback.
- The Knee Arthroscopy Surgery Simulator of SSSA is about the different aspects of performing a knee arthroscopy, on how to navigate in the knee joint with the arthroscope and interpret the images captured.
- The Hip Replacement Surgery Simulator of MIB is about monitoring the different steps for planning and performing the cup replacement in total hip arthroplasty, and providing relevant feedback in case actions of the student differ from the a predefined set standard of an expert surgeon.
- The Hip Repositioning Surgery Simulator of HIA is about planning and performing a repositioning osteotomy supported by individual templates. Students are able to follow the specific planning decisions of experts on real patients, and they get feedback on the extent on how their decisions and action results differ from those of an expert.
- The RCS Shoulder Arthroscopy Simulator is designed to train surgeons in pattern recognition skills required for shoulder arthroscopy. It is based upon actual video of surgical operations structured around a navigable matrix that relates the frames to the spatial positions of the operator's instruments. It forms the foundation for a process of building patient specific simulation environments.

An issue is raised by the learning of gestural skills with local devices in the framework of a virtual and obviously partly distant university like VOEU. Possible responses are given by several research projects which are working on telemanipulation. This could break the spatial restrictions of the simulators. Examples of such projects are PEARL, http://kmi.open.ac.uk/projects/pearl/ and the Educaffix

society, created in Grenoble in January 2003, which allows the distant manipulation of devices for chemical experiences.
The pedagogical approach adopted by the project has also taken account of the nature of the system/user interactions which occur during learning. Figure 5 illustrates the relationship between the user and the computer-based environment.

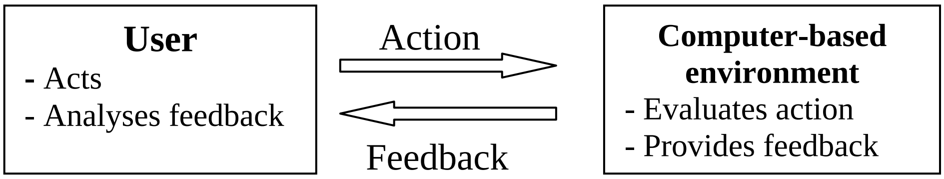


Figure 5 Relationship between user and computer-based environment

Action on the side of the learner is a combination of decisions, choices and implementation of actual action either in a perception/gesture or symbolic sense. Learning occurs during the interaction of the user with the computer-based environment. The issue of validation during this interaction is crucial, because it drives the learning. Control occurs at each step of the interaction, both on the side of the user and of the system engaged in acting processes and consists of the following:

1. Control within practice:
    a. The user takes a decision for acting on the system. This decision relies on an analysis (explicit or implicit) of some environment's indications.
    b. The user analyses feedback provided by the system. He reflects upon the validity of his actions.
2. The system evaluates user's actions and provides feedback
    a. Validation of the action: decision about its validity.
    b. Provides feedback.

The validation process occurs if the user is able to reflect on his/her actions. Feedback must be of significance; in depth work on the nature of feedback to integrate in the environment is thus crucial.

4.3.2 VOEU simulators'pedagogical checklist

A study on learning and learning objects leads to choices about the timing and the nature of the given feedback in the learning process. This study must occur during the conception of the device.

The conception of a learning environment based on simulation can begin with the following questions:

- What are the characteristics of the "to be acquired" knowledge through the system?
- What is the set of problems that the system can propose?
- What is the set of possible solutions allowed by the system, and what is the set of non-available solutions?
- What is the nature of the controls the user can have on his actions, and what sort of feedback is the system providing?

Answers to these questions are specific to each environment. But some guidelines are given by the pedagogical approach adopted by the project as a whole, described in this document. These guidelines are integrated into the checklists given in annex. We give here a brief description of its items.

Simulators checklists are almost the same as Interactive courses checklists. They contain three sections : “pedagogical approach”, “assessment methodology” and “internal structure & content”. These are based on the general constructivist approach of learning adopted in the project, and on some relevant litterature for the design of multimedia educational modules. As for interactive courses the notions of step and activity is important because it is establishing the kind of feedback the system will provide to the user:

- during an activity, solely informative feedback and hints should be provided to the user, to be in accordance with a constructivist approach of learning by doing and by errors;
- at the end of an activity, evaluative feedback should be given to the user. It provides an indication relative to the learning objective. **These assessment criteria should be related to the theory, not only to the comparison with expert best-practice** (as an example : a screw insertion can be correct even if it is not exactly the same as the expert trajectory planning ; assessment criteria can be based on different clues – intra-osseous trajectory, sensible areas avoided....)

These recommendations are particularly relevant for simulators, where visual aspect is very important. Providing two different views, as e.g. a simultaneous 2D and 3D view of the action performed, or a.p. and lateral x-rays on the same region of interest. This is helpful for the user to control his action.

Feedback should be an opportunity to combine expert advice and instructional support with links to multimedia handbooks, reminding that “*providing information at exactly the moment it is needed by the learner is much more effective than providing all necessary information before interaction with simulation begins*” (de Jong & van Joolingen 1998

5 Perspectives

This section describes a research initiated this year on the basis of the VOEU results. It is centred on the creation of a computer-based learning environment using the sacro-iliac planification tool developed in UJF-Grenoble. This project is of interest for the Grenoble hospital surgery department, as it will provide a tool to enhance the procedural apprenticeship of student in surgery. We assume that it will allow to decrease the "one to one time" necessary to acquire surgical knowledge.
Moreover, this tool will be used for initial learning in anatomy (declarative knowledge), providing contextualisation with the re-sliced CT-scan images.

5.1 Architecture

In our learning environment (Figure 1), we separate the simulation component from the system component dealing with didactical and pedagogical intentions (de Jong 1991, Guéraud & al. 1999). The simulation is not intended for learning: it is designed to be used by an expert who wants to define a screw placement trajectory.

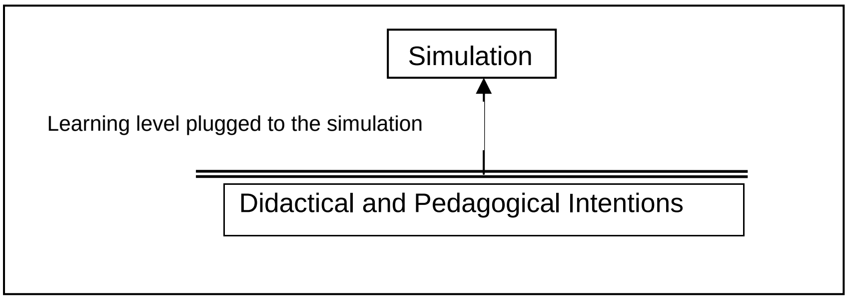


Figure 1
Learning environment

From the software point of view, we would like to respect the simulation architecture. The system part concerned with didactical and pedagogical intentions is to be plugged 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).

We will specify here the adopted methodology for designing the validation interactions.

Concerning interactions, there are two kinds of architecture (Figure 2) to associate the simulation system, the didactical and pedagogical system and the user (Lenne & al. 2001):

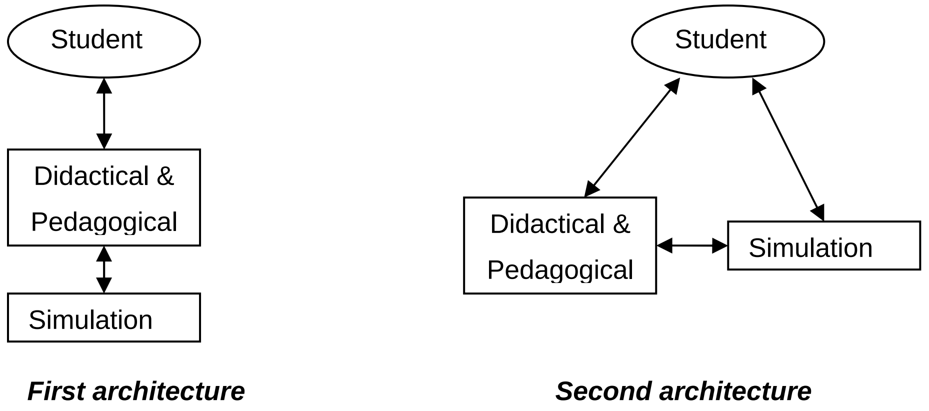


Figure 2
Types of architectures

We choose the second architecture because we would like to observe the student's activity while he/she uses the simulation. The 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.

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. We have to specify how the simulation system will transmit this information to the learning level.

The traces produced by the simulation are not necessarily in terms of knowledge: for example, the system can send feedback about the segmentation of the images or about the gestural process. On the other hand, the didactical and pedagogical system has to determine the feedback in relation to the knowledge that the user manipulates.

For this, we differentiate two kinds of feedback: feedback related to the validity of the knowledge, and feedback related to the control activity.

We define the first kind of feedback as a function of the knowledge object.

A 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, the expert uses his/her own controls to validate or invalidate the novice action and consequently he/she determines the feedback to the novice.

In the next parts, we describe the simulation system and we propose a methodology to find the two kinds of judgement interactions.

5.2 Tool presentation

The system we use is an image-guided system for the percutaneous placement of screws, developed in UJF. The goals of this computer-assisted approach are to decrease surgical complications, with a mini-invasive technique, and to increase the accuracy and security of screw positioning. The general procedure of this kind of computer assisted screwing surgery is the following. Pre-operative planning is performed. It is the identification of the best possible trajectory on a reconstructed 3D model of the bone from CT-scans – this trajectory will be used to guide the surgeon during the intervention. During surgery, tools are tracked with an optical localizer. An ultrasound acquisition is performed and images are segmented to obtain 3D intra-operative data that are registered with the CT-scan 3D model. The surgeon is assisted during drilling and screwing processes with re-sliced CT-scan images displayed on the computer screen and comparison between pre-operative planning and tools position. In the context of VOEU, the Grenoble partner, UJF, develops a training simulator for the first two aspects of this computer-assisted procedure: the surgical planning and the intra operative ultrasound acquisition. The components of the simulator correspond to the different components of the computer-aided system for screw placement and are designed to answer the potential difficulties of the clinician when using this computer-aided procedure.

Concerning the ultrasound acquisition, the simulation can be split into a visual and a gestural part. The visual part concerns the generation of realistic images to be displayed on a screen from the position of the probe relatively to the anatomical structures. The gestural part deals with the force feedback to be sent to the user so that he can feel the reaction of the tissues to the pressure exerted by the virtual probe onto the modelled part of the body. Concerning the planning step of the procedure, the simulator provides a reconstructed 3D model of the relevant anatomical structures, and allows the visualisation of re-sliced CT images along the screw axis (see figure 3). This training solution consists in learning by doing thanks to a virtual environment. Using this system, the learner is able to train the gestual parts of the procedure and to make use of declarative knowledge on the surgical screwing (choice of the number and the position of screws).

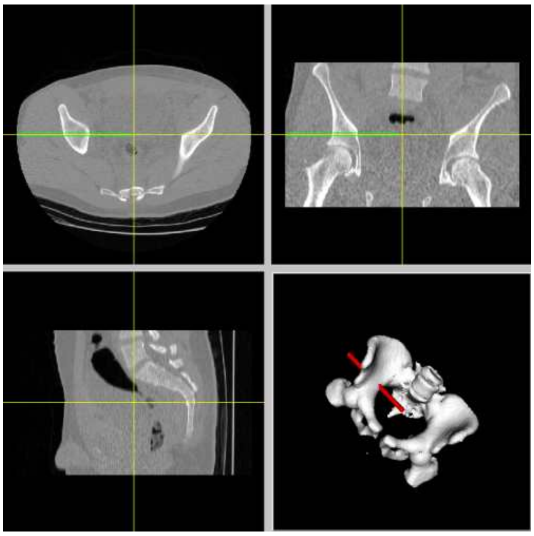


Figure 3
Re-sliced CT images along the screw axis and 3D model for the sacrum

In the work we present here, we focus on the planning step of this surgical tool.

5.3 Methodology

In our methodology, we take into account didactical and computers considerations. For this, we have two students in two “masters”. One master is “EIAH-D” (Informatics environment for a human learning and didactic) and the other master is ISC (Computer and Communication Systems). The idea is to associate two kinds of research to produce a learning system centred in the knowledge feedback.

5.3.1 Didactical considerations

The aim of our research is to allow the acquisition of procedural knowledge in surgery. The adopted methodology is based on two linked phases. In the first phase, we must identify some procedural components of the surgeon’s knowledge. This is done by observation of expert and learner interactions during surgical interventions, and by surgeon’s interviews. In this part 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 will present just after. During the second phase, we must implement this knowledge model in the system, in order to link the provided feedback to the user’s actions. These two phases are closely interrelated, as shown in the following schema (Figure 4).

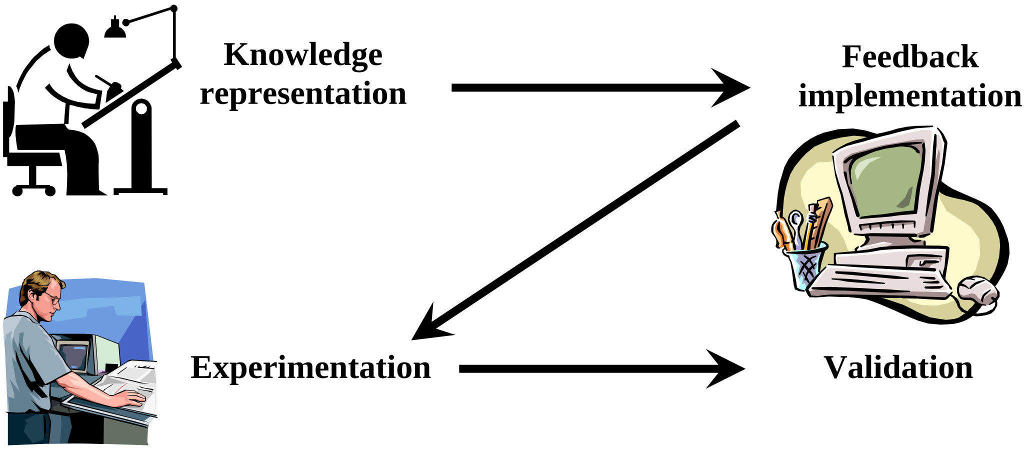


Figure 4
The methodology of two phases

We adopt the point of view described by Balacheff to define the notion of conception, which “has been used for years in educational research, but most often as common sense, rather than being explicitly defined” (Balacheff & Gaudin 2003). To shorten the presentation of the cK¢ model, we will just describe its structure and specificity.

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 $p\in P$. In 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 cK¢ model.

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 (see fig.5).

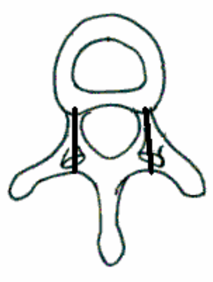


Figure 5
Vertebra with rough position of the screws

In a general way, the screw trajectory is defined according to anatomical landmarks and to knowledge on the vertebra (and spine) 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 & 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, operators and controls which will act during the problem-solving are the same ones as for the 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 a symmetry. Other controls, like perceptual and visual elements, are also present in this case. The main problem of this second way of P2-solving is that it is neglecting 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.

5.3.2 Computer considerations

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 didactical 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 compare this model to the student activity. Our objective is to follow the consistency of the student’s work. Thus, if there are automatic deduction tools, it is not to produce an expected solution because it would constrain the student’s work (Luengo 1999b) but rather to help the interaction between the system and the student. We can use this kind of tools to give the system the capacities to argue or to refuse through counter-examples.

We identify four kinds of knowledge (table 1) with a set of properties:

Table 1. Classification of knowledge

Pathology Type of illness **Morphology** Age of patient bone Size bone Density bone Status	**Anatomy** Vertebral column part Vertebra Name of vertebra Pedicle Width Transverse diameter Transverse process Nerves Spinal cord other nerves (according to vertebra) Vascular Aorta Other (according to vertebra) Muscle Paraspinal Short rotator	**Planning** Screw Trajectory (angle) Entry point (position) Diameter Screw size Position of vertebra in the planning space

We also identify the relationships between these knowledge objects (Figure 6).

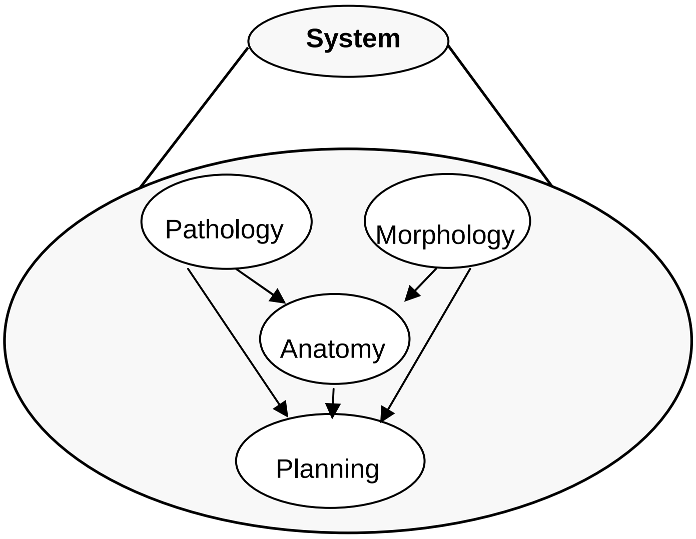


Figure 6
Relationships between kinds of knowledge

We can identify the kinds of knowledge that intervene in the planning activity. We can see that 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 a nerve.

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 have a set of conceptions (that we obtain with a didactical analyse) and we have to identify the conceptions that the user applies in his/her activity. From the computer point of view, we choose to use a system of vote for this identification (Webber and Pesty 2002).

The Webber approach considers diagnosis as the emergent result of collective actions of reactive agents under development. Conceptions are characterized by sets of agents. The society of agents is composed of four categories: problems, operators, language and control. Each element from the quadruplet C (P, R, L, Σ) is the core of one reactive agent.

The general role of any agent is to check whether the element it represents is present in the environment. If the element is found, the agent becomes satisfied. Once satisfied, the agent is able to influence the satisfaction of other agents by voting.

This approach has been created for a geometry proof system. We identified a set of differences. In particular, the representation of knowledge in geometry is only procedural and this knowledge references only one set of knowledge (the geometry). In our system, we showed how the declarative and procedural knowledge can intervene in the student activity. Furthermore, we identified in our representation four sets of knowledge (pathology, morphology, anatomy and planning). For the diagnostic system, we would like to identify the type of knowledge.

Consequently, we tried to adapt the system to our knowledge representation. For this system, we choose to use a “computer mask” that we apply to a set of conceptions in order to “see” the piece of knowledge that we try to identify. We define two levels of validation:

1) The first level is the “a priori” analysis of the expected vector. We use a mask that identifies the declarative knowledge. This level has two other levels. The first one reduces from pathology and morphology to the anatomy knowledge. The second one generates from pathology, morphology and reduced anatomy the mask vector of conceptions that must help to identify this kind of errors.
2) The second level is during a planning activity. The conception agents that intervene in the problem vote based on the simulation traces and the learning situation, the result of this vote being the vectors of conception. Finally, from the produced masks and vectors, we can identify the validation situation and we can produce a validation feedback.

5.4 Current work

The researchers involved in this work 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; the latter concerns the design of a computer system of this model and the definition of feedback, and is conducted by computer scientists.

We searched to use a didactical methodology in the design of a computer system in order to give a feedback in relation to the knowledge at stake during the student’s prblem-solving activity.

Interactions between these two parts are necessary during the entire project, and will be given a concrete aspect with some experiments. These will involve some junior surgeons in the task of defining good screw trajectories in a given vertebra in the simulator. The provided feedback and the users’ reactions will be analysed in terms of apprenticeship (that is, regarding knowledge at stake).

6 Conclusion

This final deliverable focus on the pedagogical approach developped in VOEU. This is first a theoretical work, with the development of the overall VOEU architecture based on an analysis of surgical orthopaedic knowledge and on the application of different core reasearch in education such as Brousseau and Gagné. But this work is also a pragmatic and applied work, as it leads to the description of pedagogical checklists for the development of VOEU multimedia educational resources. These checklists are intended to be guidelines for developers and surgeons when developing some educational contents. They are the translation of the VOEU pedagogical approach into clear guidelines, understandable for non educationalists people.

In the VOEU framework, these checklists have already been used by developers to enhance their productions. Traces of these enhancements are presented in each related deliverables. In the framework of the “after VOEU”, these enhancements will be continued.

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8 Annex : VOEU checklists

8.1 Handbooks (multimedia library)

8.1.1 Pedagogical approach

Pedagogical principle	Present?	Specific Implementation
Information is presented in accordance with the chronological structure of the surgical intervention	1---2----3----4---->5 (not --------> well implemented)	
At each step of the chronological structure, information includes the following topics: - equipment	1---2----3----4---->5 (not --------> well implemented)	
- anatomy	1---2----3----4---->5 (not --------> well implemented)	
- gestural skills	1---2----3----4---->5 (not --------> well implemented)	
At each step of the chronological structure, information includes the following: - explanations on specific terminology	1---2----3----4---->5 (not --------> well implemented)	
- description of possible expert difficulties	1---2----3----4---->5 (not --------> well implemented)	
- description of validation criteria, both regarding control (expert criteria for the action validation) and assessment (expert criteria for the learner evaluation)	1---2----3----4---->5 (not --------> well implemented)	

8.1.2 Internal structure and content

	Present?	Specific Implementation

	Present?	Specific Implementation
1. Introduction		
Inform learner of the purpose of the educational unit.	1---2----3----4---->5 (not --------> well implemented)	
Inform learner of the professional interest of this educational unit	1---2----3----4---->5 (not --------> well implemented)	
Provide overview of the instructional unit	1---2----3----4---->5 (not --------> well implemented)	
Provide explicit required background in terms of : - user profile (professional issues)	1---2----3----4---->5 (not --------> well implemented)	
- prerequisites (knowledge issues)	1---2----3----4---->5 (not --------> well implemented)	
2. Body		
Meet multimedia learning design principles :		
- multimedia principle (words and pictures associated)	1---2----3----4---->5 (not --------> well implemented)	
- modality principle (spoken text and pictures associated)	1---2----3----4---->5 (not --------> well implemented)	
- redundancy principle (spoken text and animations, not spoken text and animations and on screen text)	1---2----3----4---->5 (not --------> well implemented)	
- contiguity principle (corresponding elements given near and simultaneously)	1---2----3----4---->5 (not --------> well implemented)	
- coherence principle (no irrelevant information)	1---2----3----4---->5 (not --------> well implemented)	
3. Conclusion		
Provide summary of the educational unit: - in terms of learning objectives ("now you should be able to..."	1---2----3----4---->5 (not --------> well implemented)	
Provide further readings.	1---2----3----4---->5 (not --------> well implemented)	
Restate motivation aims.	1---2----3----4---->5 (not --------> well implemented)	

Please indicate below eventual suggestions, proposed corrections, further work....

8.2 Interactive course

8.2.1 Pedagogical approach

Pedagogical principle	Present?	Specific Implementation
The problem-solver must be presented with only the little information that is characteristically available initially in real situations	1---2----3----4---->5 (not --------> well implemented)	
The problem-solver is allowed to investigate freely, employing any question or examination item in any sequence	1---2----3----4---->5 (not --------> well implemented)	
The problem-solver has the opportunity to start a single step of the activity again	1---2----3----4---->5 (not --------> well implemented)	
Feedback during a single step will not prevent the problem-solver from accessing the following steps of the activity	1---2----3----4---->5 (not --------> well implemented)	
No evaluative feedback is given during the activity	1---2----3----4---->5 (not --------> well implemented)	
The problem-solver must be given the information obtained from the investigation overtime, allowing reasonning to occur at every step	1---2----3----4---->5 (not --------> well implemented)	

Please indicate below eventual suggestions, proposed corrections, further work....

8.2.2 Assessment methodology

	Present?	Specific Implementation
Conduct assessment of learner performance: - in terms of a quantitative evaluation (mark)	1---2----3----4---->5 (not --------> well implemented)	
Provide feedback : - evaluative feedback **WITH** justification and relation to the subjacent theory and/or recall of the related theory and/or the visualisation of the result of the user's process	1---2----3----4---->5 (not --------> well implemented)	
Provide remediation : - redirection to others steps of the process	1---2----3----4---->5 (not --------> well implemented)	
- redirection to a prerequisite section or recall of the related theory	1---2----3----4---->5 (not --------> well implemented)	

Please indicate below eventual suggestions, proposed corrections, further work....

8.2.3 Internal structure and content

	Present?	Specific Implementation
1. Introduction		
Inform learner of the purpose of the educational unit.	1---2----3----4---->5 (not --------> well implemented)	
Inform learner of the professional interest of this educational unit	1---2----3----4---->5 (not --------> well implemented)	
Provide overview of the educational unit	1---2----3----4---->5 (not --------> well implemented)	
Description of how to use the educational unit.	1---2----3----4---->5 (not --------> well	

	Present?	Specific Implementation
	implemented)	
Provide explicit required background in terms of : - user profile (professional issues)	1---2----3----4---->5 (not --------> well implemented)	
- prerequisites (knowledge issues)	1---2----3----4---->5 (not --------> well implemented)	
2. Body		
Explicit recall of prior knowledge (“please use knowledge on ...”)	1---2----3----4---->5 (not --------> well implemented)	
Implicit recall of prior knowledge (for example a reference to a generic situation)	1---2----3----4---->5 (not --------> well implemented)	
Meet multimedia learning design principles :		
- multimedia principle (words and pictures associated)	1---2----3----4---->5 (not --------> well implemented)	
- modality principle (spoken text and pictures associated)	1---2----3----4---->5 (not --------> well implemented)	
- redundancy principle (spoken text and animations, not spoken text and animations and on screen text)	1---2----3----4---->5 (not --------> well implemented)	
- contiguity principle (corresponding elements given near and simultaneously)	1---2----3----4---->5 (not --------> well implemented)	
- coherence principle (no irrelevant information)	1---2----3----4---->5 (not --------> well implemented)	
3. Conclusion		
Provide summary of the educational unit: - in terms of learning objectives (“now you should be able to...”	1---2----3----4---->5 (not --------> well implemented)	
Provide further readings.	1---2----3----4---->5 (not --------> well implemented)	
Restate motivation aims.	1---2----3----4---->5 (not --------> well implemented)	

Please indicate below eventual suggestions, proposed corrections, further work....

8.3 Simulators

8.3.1 Pedagogical approach adopted

Pedagogical principle	Present?	Specific Implementation
No evaluative feedback is given during the activity (a series of steps).		
The problem-solver has the opportunity to start a single step in an activity again	1---2----3----4---->5 (not --------> well implemented)	
Feedback during a single step will not prevent the problem-solver from accessing the following steps of the activity	1---2----3----4---->5 (not --------> well implemented)	
The problem-solver must be given the information obtained from the investigation overtime, allowing reasonning to occur at every step of the activity	1---2----3----4---->5 (not --------> well implemented)	

Please indicate below eventual suggestions, proposed corrections, further work....

8.3.2 Assessment methodology

	Present?	Specific Implementation
Conduct assessment of learner performance: - in terms of a quantitative notation	1---2----3----4---->5 (not --------> well implemented)	

	Present?	Specific Implementation
Provide feedback : - evaluative feedback **WITH** justification and relation to the subjacent theory and/or recall of the related theory and/or the visualisation of the result of the user's actions	1---2----3----4---->5 (not --------> well implemented)	
Provide remediation : - redirection to others steps of the process	1---2----3----4---->5 (not --------> well implemented)	
- redirection to a prerequisite section or recall of the related theory	1---2----3----4---->5 (not --------> well implemented)	

Please indicate below eventual suggestions, proposed corrections, further work....

8.3.3 Internal structure and content

	Present?	Specific Implementation
1. Introduction		
Inform learner of the purpose of the educational unit.	1---2----3----4---->5 (not --------> well implemented)	
Inform learner of the professional interest of this educational unit	1---2----3----4---->5 (not --------> well implemented)	
Provide overview of the educational unit	1---2----3----4---->5 (not --------> well implemented)	
Description of how to use the educational unit.	1---2----3----4---->5 (not --------> well implemented)	

	Present?	Specific Implementation
Provide explicit required background in terms of : - user profile (professional issues)	1---2----3----4---->5 (not --------> well implemented)	
- prerequisites (knowledge issues)	1---2----3----4---->5 (not --------> well implemented)	
2. Body		
Meet multimedia learning design principles :		
- multimedia principle (words and pictures associated)	1---2----3----4---->5 (not --------> well implemented)	
- modality principle (spoken text and pictures associated)	1---2----3----4---->5 (not --------> well implemented)	
- redundancy principle (spoken text and animations, not spoken text and animations and on screen text)	1---2----3----4---->5 (not --------> well implemented)	
- contiguity principle (corresponding elements given near and simultaneously)	1---2----3----4---->5 (not --------> well implemented)	
- coherence principle (no irrelevant information)	1---2----3----4---->5 (not --------> well implemented)	
Provide feedback to the learner's actions: - evaluative feedback (only at the end of an activity)	1---2----3----4---->5 (not --------> well implemented)	
- recall of related theory	1---2----3----4---->5 (not --------> well implemented)	
- provide a different setting of viewing the result of the user's action	1---2----3----4---->5 (not --------> well implemented)	
3. Conclusion		
Provide summary of the educational unit: - in terms of learning objectives ("now you should be able to..."	1---2----3----4---->5 (not --------> well implemented)	
Provide further readings.	1---2----3----4---->5 (not --------> well implemented)	
Restate motivation aims.	1---2----3----4---->5	

	Present?	Specific Implementation
	(not --------> well implemented)	

Please indicate below eventual suggestions, proposed corrections, further work....