INTELLIGENT TUTORING SYSTEMS TO ACQUIRE NEW COMPETENCES IN VIRTUAL ENVIRONMENT

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Abstract

This article deals with computer systems designed for training purposes. We demonstrate the advantages of using both of Virtual Reality (VR) and Intelligent Tutoring Systems (ITS) for learning new competences. Using models, ITS allow to represent information about domains, learners, pedagogies and interfaces. ITS analyze the learner's activities and propose individual pedagogical assistance. VR is defined according to three main points: autonomy, interaction and immersion. Autonomy leads to variability of contexts, an essential condition for constructing transferable competences. We evaluate ITS integration in existing Virtual Environments for Training (VET) on three levels: The VETs which integrate no ITS, those which have a domain and/or student model, and finally, those which also use a pedagogical model. We show that this integration is currently limited but has promising prospects for the future.

Keywords

Virtual Reality, Learning, Competence, Intelligent Tutoring System

Introduction

In many kinds of training, such as learning to drive, or the training of professional firemen, learners need to be able to access the "real-life" situation, as they must acquire not only knowledge, but real competences. Competences are characterized by the power to act, allowing the expert to become capable of that action across a variety of situations within a certain domain of reference. In this paper, expertise is considered as competence in context (Mieg, 2001). In order to become progressively expert, the learner must learn by doing. Indeed, putting learners into real-life settings can prove costly (from a material point of view) or risky (from a human point of view). Such is the case when learning to react when faced with accidents (disrespect of the usual rules for road settings by a driver), unforeseen occurrences (a child unexpectedly crossing the road), or malfunction (material or psychological breakdown when intervening in a high-risk situation). The ability to resolve problems in dynamic context (uncertain, evolving, and with strict time constraints) is particularly difficult to address in a classic training environment: presentation of general rules, instructions relating to foreseeable situations, etc. On the contrary, computer-generated simulations enable to immerse learners in environments where they can make attempts, make choices, take initiatives, fail, and start again.

In this article we advocate the use of computer-generated simulations, and particularly virtual reality (VR), as efficient training environments. If the transfer of acquired competences from a simulated environment to a real one depends particularly on the variability of pedagogical context, we hypothesize that autonomy in VR should be an essential resource in order to constructing effective competences. Complementary, we argue that the integration of capabilities from intelligent tutoring systems (ITS) at the heart of virtual reality improves the personalized learning process and the acquisition of transferable competences. We show that the assimilation of ITS in virtual environments for training (VET) is today only partial, but has promising prospects for the future.

This article is divided into four main sections. The first part looks at the different ways in which computer-generated simulations can facilitate the learning of new competences. This analysis leads to present intelligent tutoring systems in the second section. In section three, having defined virtual reality, we will clarify its contribution to the transfer of learning. This will enable to make an evaluation of the assimilation of ITS within existing VET in section four.

Learning and computer-generated simulation

To introduce the relationship between computer-generated simulation and the learning of competences, we shall compare two main conceptions of learning. This leads to focus our research on individually adapted pedagogy thanks to ITS. Then, we shall consider competences as blocks of various components, ready to be transfer to various setting. This leads us to focus on learning conditions, promote thanks to different computer-generated simulations.

The learner at the heart of the training system

The different theoretical models of learning have had a direct influence on the production of computer systems designed for training purposes. Most of theoretical models in education sciences area propose two higher order orientations: the teacher-centred / content-oriented / instructive conception and the student-centred / learning-oriented / constructivist conception.

The instructive conception was characterized by a focus on the content rather than the learner, the behaviour as a result from learning rather than the learning cognitive process. Skinner (1974) contributed to the evolution of classical conditioning and directly inspired the first "teaching machines". These training systems work from the principle that a concept or a piece of knowledge can be broken down to reveal its more basic elements. Each element is then successively presented to the learner using a system of questions and answers. This “programmed teaching” is linear (the elements of information are sequentially presented to the learner) and “material-centered” (the information required by the system is based on the knowledge program to be acquired).

The constructivist conception was described as conceiving teaching as a facilitative process to help student develop problem solving skills and critical thinking abilities. This learner oriented conception is used to promote interactive sessions and to provide motivation thanks to game or realistic setting. Student has to think for himself and social interactions should enhance the active processing of information. The computer-based information systems which come close to this line of thinking are known as Interactive Computer-Assisted Learning Environments (ICALE) as they often evolve, being modified according to the successes and failures of the learner. As they become more and more advanced, these machines are considered intelligent. When they are capable of reasoning about the domain which is being taught, and to adapt to the characteristics of each learner, these systems are referred to as Intelligent Computer-Assisted Teaching (ICAT).

In studies on the implementation of computers, it is possible to recognise the change of theoretical frameworks from instructivist, individual and behavioural model of teaching and learning, to constructivist, social and cognitive perspectives (Triantafillou & al., 2003). This “pedagogy-centered” perspective leads to the promotion of personalized assistance for learners at the heart of computerized environments. This mediation between the learner and that which is to be learnt which we refer to as “pedagogy” can take many different forms, such as independent simulated characters (tutors, companions, “trouble-makers”), personalized performance evaluations, problem-solving aids etc. Attributing value to pedagogy means giving value to individualized interaction in the learning process: that is the goals for intelligent Tutorial System.

What is a competence? Conditions for learning and transfer processes

Competence is considered as block of components, linked in memory, to be put into practice. But competence also refers to the ability to perform in various settings within a domain. Learning competence thanks to computer should take care of transfer process. The transfer of learnt competences becomes even more random when the activation contexts of the competence (real-life situations) are perceived as being distanced from the context in which they were learnt (simulation). Different learning conditions, which facilitate transfer, could be defined according to the characteristics of the desired competence (Dillenbourg & al., 1990). Both of skills or knowledge can be describe as components of expertise (Stenberg, 1998).

Skills engage the body (sensory-motor abilities: coordination of movement, maintaining a safe posture, etc.) or enables the learner to act on the symbolic environment (information processing procedures in uncertain situations, shape recognition, etc.). These components mainly develop through action and repetition. More precisely, when competences essentially rely on skills, and in this case, the transfer of procedural learning can be aided by "the random and systematic variation of contexts" (Dillenbourg & al., id.).

In contrast to this active manifestation, a competence within a certain domain also relies on the possibility of clarifying and describing operations as well as the optimal conditions for that operation. This "knowing what to do" or "knowing how to do" represent the information used to direct the action (rules of action). Other information that can be verbalized might concern the actions or the contexts in which they are carried out ("know what") but without influencing the execution of the task itself. Such information is referred to as declarative knowledge (the general rules about the way a system functions, the theoretical aspects of a domain, safety regulations, etc.).

Procedural knowledge can be acquired through instruction. It can also be assimilated through actions or through being distanced from them: focus on responses, confrontation between learners, consultation of additional information when faced with a problem, etc. Declarative knowledge (which is more general and less dependant on the situation), often requires the addition of exterior information. This kind of knowledge is important during training as it facilitates the transfer of procedural knowledge, and thus competences, to different situations and even beyond the initial domain for which it was taught.

Metaknowledge compiles the information that the learner assimilates according to his/her own knowledge or competences. This information is available when the learner calls upon meta-cognitive processes: auto-evaluation, autoscopy, analysis of personal activity, etc. This knowledge of the self is particularly important in order to become competent in contexts which are "high-cost" for the learner (high risk or emotional load) and thus justifies the use of simulation-style training which does not put the learner in danger.

When competences primarily call upon knowledge, transfer can be facilitated if the learner recognizes conditions in which they are used. He needs knowledge about context. For example, the learner should be informed of the analogies between the context of the training program (simulation) and the context in which the competence will be applied (real life): notion of "informed transfer" (Gick & Holyoak, 1983).

Learning transfer is a challenge (Bossard, 2008) which must imperatively be resolved for computer-generated training environments, whatever the aim of the training. How can competences learnt in computer-generated simulation conditions be applied to real-life situations?

Competences and Computer-Based Learning Environments

We have shown why computer-generated training environments must offer pedagogical assistances adapted to the learners, and that it is necessary to highlight the importance of competences transfer as central to any training program using computer-generated simulations. Now we must ask ourselves about the solutions that a computer-generated training environment might offer in order to meet this double objective.

"Computer-based learning environments" bring together all of the research on e-learning and interactive or computer-generated learning environments. They are defined as a computer-generated environment designed to improve human learning. This kind of learning mobilizes both human and artificial agents and gives them the opportunity to interact as well as to access formative resources. Research into the design of computer-based learning environments originates from a number of different elements which we have grouped into three categories: hypermedia, microworlds and intelligent tutoring system.

Hypermedia aim to facilitate access to pedagogical resources. They group together the essential tools for designing and setting out multimedia presentations for the internet or for an intranet. Hypermedia does not impose a particular course, but rather enables the learner to navigate through the data. In order to learn, one must first gather knowledge, thus this approach is based on symbolic cognitive design. We might suspect that memorizing this verbal data, this knowledge linked to a particular domain would be enough to construct real competences. Indeed, in complex professional situations, the transition from learning to doing cannot be considered simply the result of adequate background knowledge.

Microworlds simulate learning situations. They are open computer systems which allow the learner (or user) to explore a domain or a device with a minimum amount of systems constraints by combining elementary operations, which are generally analogical, with familiar schema (movement, construction, selection, etc.) Microworlds draw on the constructivist principle of learning by experience whilst at the same time highlighting the contribution of pedagogy which focuses on discovery and interest. The role of the teacher here consists of providing a rich and structured environment so that the learner might discover the contradictions him/herself and hereby invent new structures. This concept of learning is particularly prevalent in scientific teaching. For example, Papert (1980) suggests using microworlds as teaching tools. The pedagogical objective assigned to these environments is often challenging. The student must learn by doing, or even learn how to learn. S/he uses the environment to adapt and consolidate new skill, but is also supposed to think about his/her own knowledge and learning techniques (acquisition of metaknowledge). However, these microworlds do not offer any pedagogical assistance. These systems thus do not take into account elements which are currently recognized as essential to learning: mediation, guidance and assistance.

Intelligent Tutoring Systems (ITS) provide assistance to each of the different actors in the learning process (both instructor and learner). They draw on Artificial Intelligence techniques to interpret knowledge, and in order to reason. They aim to create systems that simulate human teaching, by adding the ability to resolve problems (Intelligent) and thus to call upon the learner should s/he make mistakes when completing the exercise (Tutorial). From now on, an ITS shall be considered a system which enables the training environment to adapt to different learners. They can also provide computer-based learning environments with the means to meet their main aim: assuring the acquisition of competences in a specific domain by providing personalized information. Using these techniques, the learner is encouraged to think about the way s/he approaches the task (method) in order to solve it (learning how to learn). Finally, an ITS can provide the instructor with one or many pedagogical scenarios which are specifically adapted to each learner. The following section presents these systems, describing the elements from which they are composed and their uses for training purposes.

Intelligent Tutoring Systems

ITS represents a specific approach to ICALE which focuses on tailoring training to the learner. The idea is to introduce a system which concentrates on the specific needs of the learner, identifying and evaluating his/her problem and providing the necessary assistance. Thus, ITS respond to the need to situate the learner “at the heart of the learning process".

ITS offer reasoning and problem-solving abilities through the gathering of knowledge and expertise about the learner. They evaluate the learner’s acquired knowledge, comparing his/her activity with the information about the domain and then offering personalized assistance. There are many different kinds of assistance: monitoring of the learners activity, analysis of the difficulties with which the learner is faced, instructions for helping the learner within the competence-learner learning relationship, proposing teaching methods to aid the instructor (the learner-instructor pedagogical relationship).

Designing systems such as these requires the intervention of AI specialists in the domain of teaching (Zampa, 2003). Each of these specialists has an important role to play in designing each of the systems’ composite elements.

Composite elements of intelligent tutoring systems

ITS are designed using many functions or major elements (Wenger, 1987). Thus, ITS are made up of models, each playing a particular role and contributing to the ITS decision-making process. Early ITS were composed of expertise about the domain, expertise about what must be learnt, and a representation of what the learner has or has not acquired. Burns & Capps (1988) identify these elements as the three models of ITS. They correspond to an "expert module", (Anderson, 1988), to a "student diagnostic module" and to a "curriculum and instruction module" (Halff, 1988). Later, a fourth module was added, the "interface module", representing knowledge within a given environment. The four models of ITS, as defined in Woolf (1992) are as follows:

- The domain model, representing the expert's knowledge of the domain,
- The student model, which establishes the state of the learner's knowledge at a given time
- The pedagogical model, assists in the choice of teaching aids depending on the student's model and behavior,
- The communication model, facilitating the exchange of information between the system and the person using it.

Intelligent Tutoring Systems and Training

The effectiveness of these systems has been demonstrated (Shute & Regain, 1990), most often by comparing two groups of learners in a training environment either with or without help from ITS. For example, an experiment controlling learners using the LISP tutor (Anderson, 1990) showed that those using the tutor completed their exercises 30% faster than those with traditional training. The final exam showed a 43% difference between the two methods in terms of results (Ong & Ramachandran, 2000).

Many traditional teaching methods now use ITS to present learners with facts and concepts. These methods are effective in exposing large quantities of information and in examining the learner's understanding of this information (often by using control questionnaires). However, they often also instill "inert knowledge": learners acquire the required knowledge but they are unable to apply them correctly, i.e. they have knowledge but not skill. These teaching methods are insufficiently adapted to learning competences.

However, systems which use simulations and other highly interactive environments offer the opportunity to apply knowledge. These active environments help the learners to put their knowledge into action. These simulations, combined with ITS, offer the possibility to improve learners' competences, as they associate knowledge and skill.

Interactive simulation environments share a number of similarities with virtual reality. Using adapted peripheral devices, they can provide natural interactions, and greater immersion in a simulated model; in short a greater "presence". Virtual reality must not, however, be considered only on its technological aspects (i.e. uniquely on the specifics of its interface model). It is already considered a technology which can improve learning in computer-based learning environments (Lourdeaux et al., 2001; Querrec et al., 2003) and is a real plus in terms of learning and transfer (Winn, 2002), which we shall now go on to discuss.

Virtual Reality

From an operational point of view, virtual reality is defined as a system composed of software and material elements simulating the realistic interaction of a human with virtual objects which are computer-generated representations of either real or imaginary objects. As with reality, virtual reality is accessible to human subjects via three indistinguishable methods (Tisseau, 2001):

- Mediation of sense: Is the object accessible to our senses? If so, it is perceived.
- Mediation of action: Does it react when prompted? If so, it is experienced,
- Mediation of the mind: Can it create a mental representation? The object is therefore imagined (modeled).

The aim of a virtual reality system is for a human subject to experience a particular dynamic situation (Deutsch, 1997).

Components of virtual reality

A virtual reality system differs from other computer applications in that when using it, one has the sensation of being in the virtual world and interacting with it. This notion of the user's presence within the virtual environment is composed of two elements: immersion, which is generally multi-sensorial, and interaction. In order to be truly complete, a virtual environment must not simply involve the user's presence; something must also occur within it, and not merely as a result of the user's actions. The objects within the environment must therefore behave independently.

Tisseau (2001) suggests three points which characterize systems of virtual reality: (A, I, I) or Autonomy, Interaction and Immersion. Any computer system can be located as a point within a cube in which the length of each side has the value: 1 (figure 1). This figure effectively illustrates the two dimensions of the notion of presence (interaction and immersion). Let us now analyze the extreme situations corresponding to the vertices of this cube which, for illustration, have been attributed "idealized" examples.

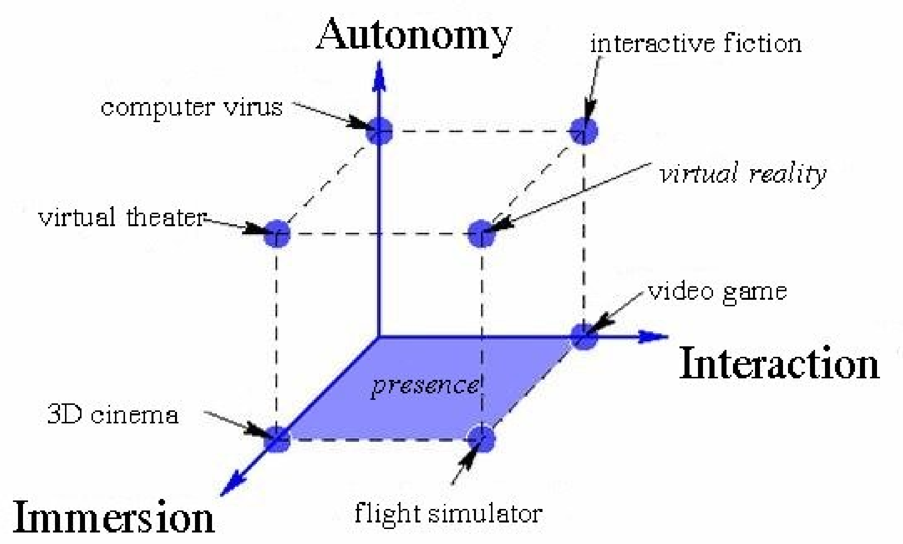


Figure 1

To confer to a system's independence is to accept to share the control of its evolution between the user and the digital models from which it is composed. This definition corresponds to that of U-autonomy (Carabelea et al., 2003), that is to say, autonomy with regards to the user. The general definition of autonomy given by these authors is as follows: "an agent X is autonomous from Y for p in a context C, if in C, its behavior regarding P is not determined by Y". One consequence of autonomy is that, in a certain context C and regarding an object P, the behavior of X is not calculable from Y and thus not predictable. According to the axis A, one goes from a system which is completely under the user's control, to a completely autonomous system (controlled by its models) and thus users have no control over it (at least directly). One extreme case is a mutating software virus which is completely out of the user's control when the computer is infected, which offers no interaction whatsoever, and within which we cannot be immersed: no intervention is possible to stop its behavior. Its coordinates within the (A, I, I) mark are (1, 0, 0). Luckily, to our knowledge, no entity of this kind yet exists (but would be an "ideal" for a virus designer)!

Within the second point, we increase the possibilities of interaction with the system. A (0, 1, 0) system for example is a first generation video game (such as the infamous "Pong"). The system is highly interactive, reacting to the player's requests, but doing nothing by its own initiative (it has no autonomy) and immersion is extremely limited.
The third point reflects the feeling of immersion within the system, and is linked to the fact that the environment is directly ("naturally") accessible via the senses. For (0, 0, 1), the example is given of a movie theater, surrounded by

images, the theater is equipped with surround-sound and the seats might be mounted on jacks. We find ourselves literally in the film, but we cannot interact with the story, changing the course of events, and the system is controlled (whichever screening we go to, we will always see the same film).

A flight simulator is situated in (0, 1, 1). Its behavior is predefined and the situations that can be experienced using such a system are finite (even if a great number of combinations are possible). Focus is here placed on the realism of the return associated with total immersion (the pilot is in a cockpit which is identical to a real cockpit in every way), and on interactivity i.e. the presence of the user in a virtual world. This is subject to the definition of competitive behavioral interfaces

In (1, 0, 1), we find virtual theater: the virtual humans (actors) partly improvise their acts, and can have different reactions depending on the actions of other actors. Their behavior is therefore not entirely controlled by the scriptwriter. Because of this, the smooth running of the play is not calculable prior to its performance. The user must provide different context information for each recital and therefore encounters a different external experience each time.

The extreme system is evidently situated at (1, 1, 1). Immersion in an environment perceived by the senses; we can experiment on it through action. This perceived and experimented world acts more or less independently and thus to understand and continue to interact with it, one must construct a mental representation of it in order to "calculate" oneself and one's own behavior. A subject thus experiments the world in three ways, as spectator, actor, and creator at the heart of an “ideal” virtual reality environment.

Virtual reality and training

The referential (A, I, I) provides a frame in wich the computer-bases simulations may be situated, regarding their uses of virtual reality. This position is of course relative and imprecise: the most important is the side or the vertex closest to a given application. However, this analysis will enable to better grasp the significance of virtual reality in training, notably with regards to the transfer of competences.

The first CA teaching systems are closest to the point (0, 0, 0) and the shift towards Interactive CA teaching effectively illustrates a movement along the second axis towards the vertex (0, 1, 0). Immersion in learning systems is minimal (as they are seldom realistic); the system’s behavior is perfectly predictable and repetitive; interaction generally consists of selecting one answer and obtaining feedback. These systems are therefore useful for teaching skills, i.e. contextualized procedures, but have proved not to be transferable.

Multimedia CA teaching systems are dependent on the Immersion axis: the learner is presented with images, sound documents or videographs which are static (pre-calculated); they are close to the (0, 0, 1) vertex; interaction is similar to that of CA teaching systems.
Autolearning software for children is generally situated in the (0, ½, ½) region of the cube: interactivity is greater or lesser and immersion generally insignificant. The sensation of presence is undeveloped and these kinds of software are often reproached due to the difficulty children have “entering into” the situation. The potential for competences transfer thus seems to be a minimum as the meaning of perception of the learning situation is distanced from the meanings that could be interpreted from real-life situations.

Driving simulators and microworlds in general are at (0, 1, 1), with a great deal of realism in terms of sensory and behavioral return. Reinforcement processes are thus used and the acquisition of skill facilitated. Learning transfer thus depends of the realism and the variety of contexts offered by the simulator.
The nearer a VET to the vertex (1, 1, 1), the more complex and variable the situations the learner will be confronted with. This variability (supplied by the independence of certain entities in certain contexts) is particularly interesting for constructing new adaptable actions via abstraction. Either the knowledge is procedural when acquiring competences dominated by skill, or learning can be declarative when the competence requires a comprehension effort, mobilizing prior knowledge.

Few studies (for a review see Bossard & al, 2008) have dealt directly with the transfer of competences assimilated in virtual reality simulations and applied to real-life settings (Wilson, 1999). If simulation assists learning, it does not always facilitate learning transfer (Kozak et al., 1993). However, the results are particularly encouraging when constructing a space (Regian et al., 1992), memorizing locations (Witmer et al., 1996; Johnson, 1994), learning to pilot a helicopter (Johnson & Wightman, 1995), adopting emergency behaviors (Bliss et al., 1997), acquiring skills or sensori-motor abilities (Rose et al., 2000), or when aiming to acquire complex competences in terms of cognitive, affective and social capacities. The strict dependence on the efficacy of the training and training conditionscharacterize these studies thus highlighting the role that ITS might play in the learner-competence relationship.

The Integration of Intelligent Tutoring Systems in Virtual Environments for Training

This section unifies ITS and virtual reality in computer-based learning environments. We shall study the extent to which current virtual environments for training accommodate the ITS models discussed previously. We shall present the contributions currently generated for training. In order to structure this presentation we propose three categories of virtual environments. This division is based on the ITS models that they integrate.

The first category (section 4.1) groups together the applications which fail to integrate any of these models. The system can therefore supply no reasoning or explanation regarding the domain of learning, neither can it adapt the environment as it has no representation from the learner. Finally, as it has no pedagogical knowledge, it cannot guide the learner through his/her training, nor can it assist the instructor in organizing his/her training sessions. These environments nevertheless offer the possibility of apprehending and manipulating the environment as one would do in real life. They are therefore destined for the acquisition of competences.

The second category of virtual environments for training (sections 4.2) is made up of applications which accommodate a domain model and/or a student model. The system can therefore adapt the environment to the learner, offer explanations about the subject being taught and even act in the place of the learner. These systems can also assist the instructor in monitoring and evaluating the learner's progress. They can therefore be used not only to manipulate the environment and to facilitate the acquisition of skill, but also to access knowledge concerning the content of the training. This thus concerns two elements of the competence to be acquired. However, the system does not have access to pedagogical knowledge which could have enabled it to decide (helping the learner) or to suggest (helping the instructor) when, how and why to intervene in a training session.

The final category (section 4.3) regroups the virtual environments which present not only student and domain models but also a pedagogical model. Thus the system can adapt itself to the learner and offer help as well as being able to intervene independently to facilitate the learner's acquisition of transferable competences.

Environments Which Accommodate None of the Models

The first level of virtual reality's use for training purposes is represented by simulators. None of the models presented previously are explicitly represented in the system. Knowledge of the domain, used during the simulation or during configuration, is not reified (no internal representation) (Winn, 1993). The system is therefore incapable of reasoning for pedagogical purposes. Finally, the use of tools like these is the instructor's responsibility; it is s/he who must manage the scenarios or the levels of difficulty, even if some of these simulations offer tools which might help him/her. The most commonly known and used examples stem from professional training which we shall briefly study below. These applications are located within the (A, I, I) referential proposed in section 3 at (0, 1, 1).

EDF R&D are developing a workshop to help with the maintenance and driving of polar cranes. The "polar project" simulates the use of a crane for lifting loads in the reactor building at nuclear power plants (Levesque, 2003). The bridge operator, who cannot always see the load s/he is transporting, must rely on communication with the person in charge of the operation. The bridge operator is immerged in the environment via a head-mounted display (HMD) and a console of levers controlling the crane. The person in charge of the operation is represented by an avatar controlled by a joystick or by voice command. The consequences of the choices made during the maneuver can be recreated by the simulator (see figure 2). The role of the instructor here is to watch, accompany and to evaluate the learner rather than to transmit his/her knowledge. In this environment, the pedagogical objective is not the use of the crane but rather communication between the participants.

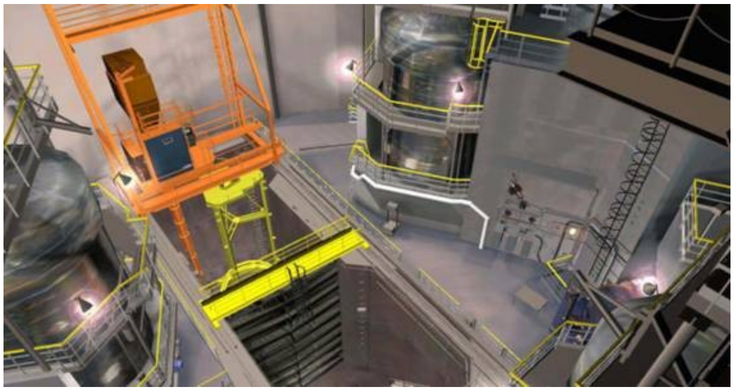


Figure 2

Thales Training & Simulation also offer a training simulator in which the aim is to train how to use a professional tool and to put the learner into real-life or even extreme conditions. The simulator is designed for use in learning to drive TRUST 800 heavy goods vehicles (Westra et al., 2001). It is presented as a tool for education purposes as the instructor can simulate particularly dangerous situations. Learning is divided into three stages. The first corresponds to driving-based learning. The second is to transfer the competences to a “real-life” situation, with the simulator used to go back over non acquired competences. The final stage develops the behavioral competences linked to dangerous or critical events (lorry turned over, ice, etc.) After each usage, a "debriefing” stage is organized to improve awareness and the representation of the competence, which should increase the development of generalizable competences and an awareness of “risk assessment”.

These last two environments were designed for professional training. Let us now analyze two virtual environments for scholastic education. The EVE application (Virtual Environments for Children) is a virtual environment designed for primary-level children (Popovici et al., 2004). It concerns learning to read, understanding written texts and sentence construction. It also teaches children to work in groups, with children from Romania, Morocco and France cooperating via the Internet. During the sentence-construction stage (see figure 3), the system tells the child if the words are in the correct position or not. In the first scenario, the children work in parallel in different rooms. In the second scenario the children work together in a common room to reconstruct a story using an electronic voting system. Social interactions are used to make majority decisions (introduction to democracy). EVE enables social interactions and cooperative learning or socio-cognitive conflicts which facilitate the development of new competences (socio-constructivist model of learning. See section 1.3). According to the standards suggested for classing virtual environments EVE is closer to the origin on both the immersion and interaction axes than either of the two preceding applications. The main characteristic of EVE is the virtual environment shared between multiple users.

These examples of virtual environments use simulation which has a number of advantages in terms of training (Patrick, 1992). Indeed, using such environments enables to simulate situations similar to reality, but without the real-life constraints (Mellet d’Huart et al., 2001). Furthermore, additional functions can be added to a simple reproduction of reality and thus provide training materials (freezing actions, replay, repetition and practice, etc.). In addition, the learner intervenes in a computer-generated environment and can observe the consequences of his/her actions. Retroactive use of this information is both a characteristic and a necessity for learning by doing. Therefore these environments favor learning, although they do not accommodate the possibility of refined automatic assistance. The real responsibility of training is delegated to the instructors. Even if some environments offer assistance to the instructor, s/he remains responsible for integrating them into the curriculum. However, in professional training, the instructor is often not a "teacher" but an expert in a particular domain, and thus is unlikely to worry about the pedagogical impact of such tools.

Figure 3

Environments integrating the domain and/or student models

A higher level of usage of virtual reality for training purposes is represented by environments which integrate domain and/or learner models. Using the domain model, one can notably answer questions automatically or carry out a task instead of the learner. By comparing the domain model and the student model, the system is able to detect potential errors. However, these environments do not integrate pedagogical knowledge which could guide them to react to the learner's mistakes.

MASCARET is a model which enables the creation of virtual environments for training in realistic and collaborative situations (Querrec et al., 2003). Using this model, one can describe the physical environment in which the learner will evolve, as well as his/her collaborative social environment. The social dimension is not here used as a means to ameliorate learning, but rather represents one of the elements of the competence to be acquired (see definition of competence, section 1.3). MASCARET bases itself on multi-agent systems methodology in order to represent the constituent elements of these environments and their interactions. SécuRéVi (security and virtual reality) is one application of MASCARET to civil security (Querrec et al., 2003) (figure 4). It is designed to train firefighting officers in operational management and command.

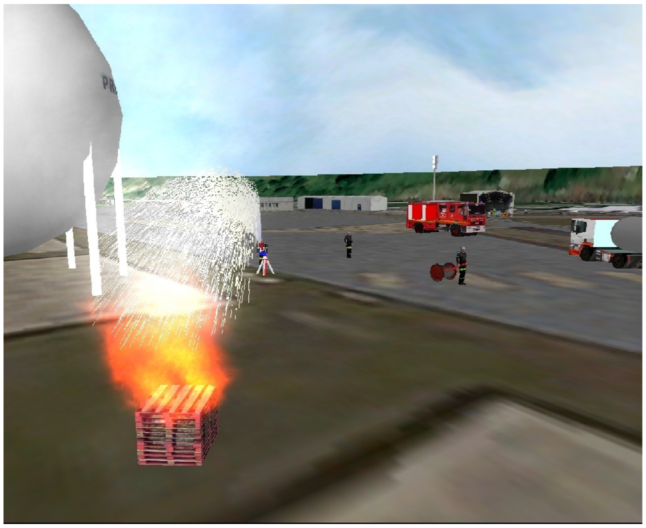


Figure 4

Mechanical, chemical and thermal phenomena (fire, gas cloud, etc.) experienced or influenced by the learner are modeled by a group of interacting agents. The effects between the elements making up the phenomenon are set by the expert and form an influence graph governed by an organization of agents. The ensemble of these organizations forms the domain model for the physical environment. This model can therefore inform the user (learner or instructor) of the causal links between the phenomena (i.e. the wind determines the direction of the spread of a cloud of gas) and also enables the instructor to modify the behavior of these phenomena (altering wind direction for example). The social environment is made up of those participating in the collaborative task to be completed by the learner. This task is defined by a procedure which organizes the actions to be carried out. MASCARET represents this social environment with an organization of agents. Each actor (agent) is represented within it by the role that it plays in that organization. A role describes all the actions for which the agent is responsible. The procedure authorizes the actions (both before and during) as they are defined by their pre- and post-conditions. The ensemble of these organizations forms the domain model for the social environment. The system provides explanations of the actions, procedures and roles of each team. In consequence, it is able to provide deductive and explicative synthesis of the procedure. The learner can dynamically give or take the hand of an agent which will then become his/her avatar. S/he has knowledge about the domain and is also aware of the actions which have been carried out. Using the MASCARET model, one can therefore clearly represent the behavior of and the interactions between agents. The SécuRéVi applications use this ability for deductive, rather than explicative purposes. Agents can therefore act independently within the environment using this knowledge. According to the point of reference presented in section 3, SécuRéVi, and more generally, the applications derived from MASCARET, can be located at the coordinates (1, 1, 1). If Buche et al. (2004) have shown that MASCARET effectively represents the domain model and part of the student model, the mechanism that will enable to accommodate pedagogical argumentation still remains to be defined.

STEVE is an animated virtual agent (Rickel & Johnson, 1999). He evolves with the learner in an environment designed for teaching procedural tasks. STEVE provides automatic pedagogical assistance. He can demonstrate the procedure, explain it by answering the learner's questions, and above all observe and confirm (or reject) the learner's actions. STEVE has been applied to maintenance training for boat motors (figure 5). Another version, ADELE includes the capacities of remote learning (Shaw et al., 1999).

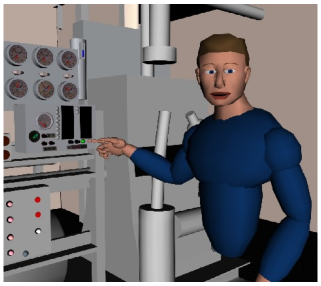
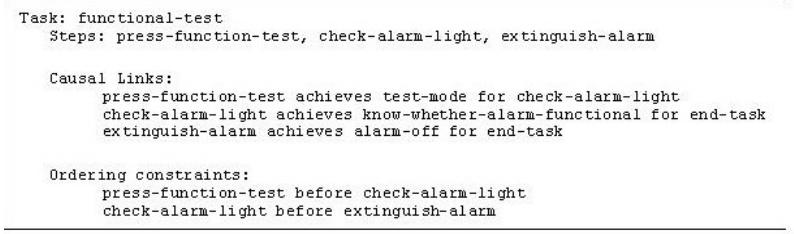


Figure 5

In STEVE, domain expertise is modeled according to a group of tasks. The example given in figure 6 shows a task defined by an ensemble of atomic actions or sub-tasks (press-function-test ...), of the explanation of the effects of particular actions (achieves test-mode...) and their organization (press-function-test before check-alarm-light..). A text is assigned to each task and each action, so that STEVE might be able to answer the learner's questions. Therefore, if the learner asks the question "Why?", STEVE can reply. If, after the answer has been given, the learner asks the same question again, STEVE will give the answer assigned to the task directly above it. STEVE constantly memorizes the state of the world, and can thus follow the learner's progress in order to advise him/her on "what should I do next?" explain "why?" or even carry out the action himself. According to the marker (A, I, I), the STEVE application is near to the coordinates (1, 1, 1), even if only the tutor is autonomous, and the rest of the environment is not.

Through these two examples, we can see that an important stage in virtual environments for training has been reached, as they enable to access knowledge about the domain and/or the learner. This information can be used to improve the competence-learner learning relationship. For example, in the Hubble Space telescope, the information about the domain can be used to identify objects linked to the task to be carried out and to color them an intense green (Loftin & Kenney, 1995). Furthermore, knowledge of the domain of the learner can be automatically analyzed in order to recognize the learner's mistakes (Aka & Frasson, 2002), and to determine their cause. More generally, this knowledge can be used to automatically evaluate the learner. The instructor can therefore use this information in the pedagogical relationship linking him/her to the learner. Nevertheless, these computer systems do not have "pedagogical competences" which would enable them to take the initiative that might allow them to regulate the teaching-learning process. Even if some of them offer various tools for teachers, they will be considered as a educational tool in its own right when they are able to relay the instructors' interventions and independently provide pedagogical assistance adapted to the diversity of the learners.



```
Task: functional-test
   Steps: press-function-test, check-alarm-light, extinguish-alarm

   Causal Links:
         press-function-test achieves test-mode for check-alarm-light
         check-alarm-light achieves know-whether-alarm-functional for end-task
         extinguish-alarm achieves alarm-off for end-task

   Ordering constraints:
         press-function-test before check-alarm-light
         check-alarm-light before extinguish-alarm
```

Figure 6

Environments integrating the domain, student, and pedagogical models

Using a pedagogical model means either that the instructor can be replaced by auto-training (tutor, guidance system, assistance, etc.), or that s/he will receive assistance and thus will be able to manage multiple learners at the same time as in real-life situations.

HAL (Helpful Agent for Learning) is a pedagogical agent designed to optimize the learning process in virtual environments (Lourdeaux et al., 2001). Using this tutorial agent, virtual reality is used to train high-speed train (TGV) drivers to intervene in the railway infrastructure of the French railway network (SNCF), i.e. to climb down onto the tracks and to control track equipment. This application is near to the coordinates (1, 1, 1) of the (A, I, I) reference; indeed, the environment is defined using a multi-agent system. HAL assists instructors in constructing pedagogical discourse by presenting two types of adaptive "pedagogical strategies". The first modifies aspects of the scenario (breakdown, weather conditions, etc.). The second provides assistance for understanding the situation (suggesting where learner might locate a piece of information, explain a rule, demonstrate the consequences of mistakes, etc.). These strategies can be implemented using different kinds of pedagogical assistance managing different levels of representations (enrichment, visualization of hidden mechanisms, modeling abstract concepts, etc.). HAL depends on the learner's knowledge (student model), the activity being learnt (domain model), knowledge of teaching strategies (pedagogical model), and the different ways of explaining them (diagnostic module) (see figure 7). The learner's knowledge is made up of individual characteristics (level, experience, profile, ability), of his past actions, and of a representation of his/her initial competences. The competence to be learned is made up of a plan of tasks and relative criteria. Finally, the pedagogical strategies' settings correspond to the type of intervention and to pedagogical interventions. The analysis compares the model of the learner with the reference model in order to evaluate, examine, identify and quantify the learner's behavior.

For each expected or problematic behavior of a task, the pedagogical assistance and levels of realism are described (figure 8). As a result, the instructor must make an exhaustive list of expected behaviors (typical mistakes) for each element of knowledge to be acquired. For each error (column 2), s/he must specify the manner in which the pedagogical strategies (column 3) are conducted by the pedagogical aids (column 4) and s/he must do so for every exercise.

HAL begins by identifying the learner's behavior and the knowledge brought into play due to his/her activities. It quantifies the extent to which this knowledge has been assimilated by the learner (calculation of performance criteria). This criteria evolves according to time and the actions completed by the learner. During this exercise, the instructor chooses a "pedagogical method" (either explicative or active). For each of these methods, HAL presents a knowledge base about the choice of pedagogical strategies according to the learner's level and performance criteria (figure 9). As soon as the performance criteria drops below the threshold specified in this knowledge base (column 1), HAL selects the next strategy (see below). Let us examine the example of a beginner: after having "demonstrated knowledge", HAL "demonstrates the discrepancy" before "explaining" and finally "demonstrating the consequences".

The instructor only has access to two kinds of pedagogical methods and the model must be reworked if s/he wishes to integrate other pedagogical methods or strategies. Furthermore, the sequence of pedagogical strategies is fixed and unavailable to the instructor. This example shows that the pedagogical models currently used in virtual environments remain very ad hoc and are not necessarily based on pedagogical concepts, but rather on domain expertise.

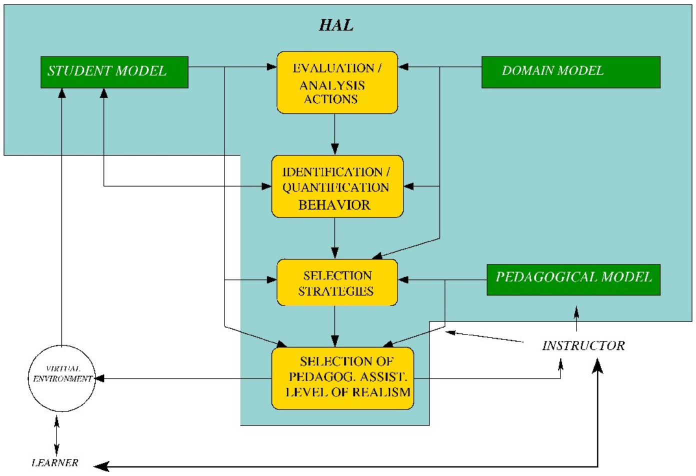
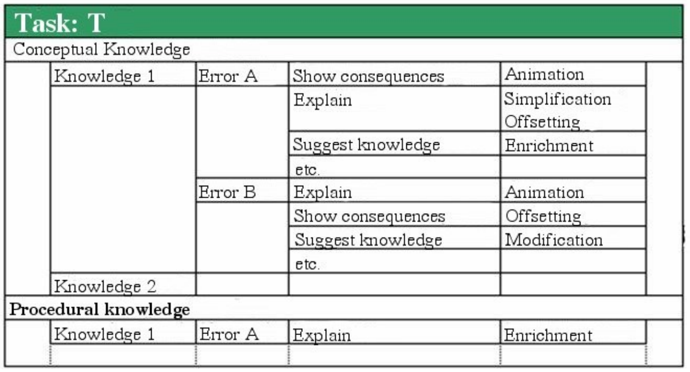
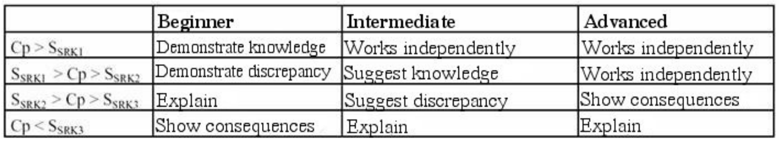


Figure 7



Task: T				
Conceptual Knowledge				
	Knowledge 1	Error A	Show consequences	Animation
			Explain	Simplification Offsetting
			Suggest knowledge	Enrichment
			etc.	
		Error B	Explain	Animation
			Show consequences	Offsetting
			Suggest knowledge	Modification
			etc.	
	Knowledge 2			
Procedural knowledge				
	Knowledge 1	Error A	Explain	Enrichment

Figure 8



	Beginner	**Intermediate**	**Advanced**
$Cp > S_{SRK1}$	Demonstrate knowledge	Works independently	Works independently
$S_{SRK1} > Cp > S_{SRK2}$	Demonstrate discrepancy	Suggest knowledge	Works independently
$S_{SRK2} > Cp > S_{SRK3}$	Explain	Suggest discrepancy	Show consequences
$Cp < S_{SRK3}$	Show consequences	Explain	Explain

Figure 9

Conclusion and prospects

The aim of this article was to advocate the use of ITS within virtual reality in the context of learning new competences. We have presented virtual reality as a promising domain for developing training situations with good transferability potential. In addition, we have shown that ITS offer the possibility of personalizing the learner-competence (learning) relationship and diversifying the instructor-learner (pedagogical) relationships at the heart of computer-based learning environments. Integrating ITS at the center of the training situation offers support and assistance to both learner and instructor. More precisely, using virtual reality means that learning conditions can be varied and that ITS adapted to the learner can be used. These two factors facilitate the transfer of acquired competences, at least theoretically. We have analyzed a few uses of ITS within virtual environments for training. Most of them accommodate only the representation of knowledge of the domain. The systems which present a diagnostic model only rarely provide a pedagogical assistance mechanism. We consider HAL to be the most successfully completed system. However, the instructor must list the errors and specify the pedagogical strategies for each exercise.

Future research should focus on defining an intelligent tutoring system at the heart of a virtual reality application. Prior knowledge of the pedagogical model and the experiments that have already been conducted could be used to automatically propose appropriate interventions whilst at the same time considering the learner and the context of the simulation. Unlike classical training, where instructors are not always teachers or experts in virtual reality (Lourdeaux et al., 2001), this system would also provide simulated educational considerations, as well as the full potential of virtual reality. We believe that the final decision about the intervention should be made by the instructor, rather than being applied automatically, as elements that a computer program cannot take into account will always exist: environmental elements, characteristics linked to the group of learners, learners' past experiences, stress levels, direct interactions between humans, etc.

Experiments on the impacts of the uses of virtual reality and ITS in the assimilation of competences should also be conducted. Indeed, even if the advantages of the use of assistance provided by ITS in virtual environments for training have been supported in a few applications (Loftin & Kenney, 1995), the results of the few evaluations thus far (see section 3.3) attest to the difficulties in identifying optimal learning conditions. For example, a study by Wilson (1999) aimed to evaluate the respective difficulties of two learning conditions in virtual reality. In the first, subjects had to memorize objects and their locations within an environment whilst moving around within this virtual environment (active condition). In the second, "passive" condition, the subjects simply watched the screen, next to an "active" subject. Although the author expected higher levels of performance on recall and recognition tests in the "active" subjects, ANOVA results showed no significant difference between the two groups. This study thus demonstrates the need for caution in future training experiences using virtual environments. Not only is it necessary to test their effectiveness in terms of transferring competences to the real world, but optimal learning conditions in a computer-generated environment or in alternation with simulated conditions and real-life situations still need to be defined and evaluated. This variability of contexts within and around the simulated situation remains an indispensable condition for the transfer of competences, both actually and theoretically.

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