# Designing Adaptable Virtual Reality Learning Environments

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## ABSTRACT
The EAST (Scientific and technical learning environments) project aims at stimulating the interest of young people for science through virtual reality environments, based on industrial assets. Although training and learning environments are classical applications of virtual reality, the design of these environments is generally *ad hoc*, hence requiring the intervention of programmers whenever a modification of the pedagogical scenario is required. In this paper, we propose a methodology to design virtual environments which can be adapted by teachers to implement different scenarios according to the level of the trainees and to the pedagogical objectives. Current demonstrators include a windmill with three different learning situations: simulator, safety training and preventive maintenance training.

## Categories and Subject Descriptors
H.5.1 [**Information Interfaces and Presentation**]:
Multimedia Information Systems — *Artificial, augmented, and virtual realities, Evaluation/methodology*

## Keywords
Virtual reality, pedagogical scenario, UML meta-model

## 1. INTRODUCTION
Although there is an increasing production and use of digital resources in the industry, they are rarely used in the context of human learning and training. A major technical issue to use industrial assets for training purposes is the lack of generic tools to integrate pedagogical contents with these assets. The EAST (Scientific and technical learning environments) project aims at proposing a methodology and tools to facilitate the design of activity training in virtual environments (VEs). This methodology is based on the use of 3D models of industrial equipment or objects on which or through which a pedagogical activity is performed, and on an analysis of the activity targeted by the learning action. The major challenge faced by the project is the abstract description of (1) the semantics of the VE components, (2) their behavior, (3) how humans interact with them, and (4) pedagogical assistances provided through the scenario or continuous help.

Although the advantages of using virtual reality (VR) technologies to develop professional skills have already been demonstrated, their design (and the modifications of existing VR environments) necessitates computer scientists, even for modelling and implementing expert actions or pedagogical actions. Their modelling and implementation choices impact the final environment, and generally the result poorly reflects the actions achieved in real professional life.

In the following, we first present the state-of-the-art related to the design and implementation of pedagogical scenarios. Then, we present our methodology and how it is applied in the context of the EAST project. Finally, we conclude and discuss some open issues for virtual reality environments for human learning.

## 2. MODELING OF EDUCATIONAL SITUATION IN VIRTUAL ENVIRONMENT
Technical training in industrial systems is one of the privileged areas of application of VR [1]. In this section, we present the related works of this domain.

### 2.1 Virtual Reality for Training
The advantage of VR in this area and the impact of immersion modes (Desktop, Helmet RV etc.) and interactions (mouse, Motion Capture etc.) in learning has already been evaluated [2,3]. Beyond the relevance of VR for training, one of the disadvantages of VE design approaches, as raised above, is the inevitable intervention of the computer scientist during all phases of implementation. This requires them to understand the relevant profession, which can lead to misinterpretations and approximations, and to design the pedagogical scenarios, which can introduce implicitly his own representation of pedagogy and


VRIC 2016, March 23–25, 2016, Laval, France

ACM 978-1-4503-4180-6/16/03…$15.00
DOI: http://dx.doi.org/10.1145/2927929.2927937

of learning process. To overcome these problems, outsourcing these expertise is a proposed solution. In this way, the representation of the activity and of how it should be taught becomes external data to the computer program, while this knowledge becomes explicit when running the VR simulator. Such systems are named informed or intelligent VEs.

Informed VEs [4] advocate the use of artificial intelligence techniques to represent explicitly the task knowledge in the VE. Several models have been proposed, such as Smart Objects [5] which aim to integrate the knowledge necessary to the interaction within VE, or STORM [6] that allows to define interaction not only between an agent and an object but also between multiple objects. Concerning user activities, several models to express the human activities to be performed in VEs have been proposed. HAWAII-DL [7] is used in ergonomics to describe human activities. The LORA scenario language (Language for Object Relation Application) equates the VE with the prescribed procedure to be performed by the user [6].

The disadvantage of these models or languages is that they cover only a part of the representation of the system and require to assemble several of them in order to cover the whole pedagogical scenario. More generally, the design of these languages has been guided more by the possibility of being automatically interpreted by a computer, and not by its own capacity of expression. In our case what interests us is not only a language that allows to describe the different components (structural, static and dynamic) of a system by the expert, but also that this language is directly executable by a computer (especially the dynamic aspect of the system) to avoid the biases introduced by the computer scientists. This is one major constraint that our project intends to solve.

## 2.2 Pedagogical scenario modeling

Current methods for the modelling of pedagogical scenarios can be divided into two groups: 1) design methods for the learning activity; 2) operationalization methods of the learning activity. Among the methods of design of the learning scenarios, we can cite LDL [8] and Isis [9]. LDL (Learning Design Language) focuses on content management, enabling to describe and design collaborative learning situations. Isis (Intentions, Strategies, and interactional Situations) is rooted in previous work on active learning situations, and proposes a specific identification of the intentional, strategic, tactical and operational dimensions of a learning scenario. The operationalization methods of the learning activity allow the translation of elements defining the learning activity (action, actors, and resources) into machine language (usually XML). Educational Modeling Language (EML) [10] and its standardized version IMS-LD [11] describes the content and process within a ‘unit of study’ from a pedagogical perspective in order to support reuse and interoperability. Considering another perspective, the MASCARET-CHRYSAOR model [12], which extends the meta-model based MASCARET approach, is tailored for the operationalization of learning environments of types *micro-world* simulator or *serious games*, because they allow describing activity scenarios taking into account the interactions with the VE and with objects within it.

These two groups are complementary methods. Although, Isis is operationalized via IMS-LD, it has been noted in [13] that IMS-LD is suitable for the development of distance learning scenarios, which lead to “pedagogy oriented” intelligent tutoring system (ITS). This approach is therefore not relevant to ITSs that supports the learning environments of micro-worlds simulators or serious games types, although they offer the greatest opportunities for the creation of new learning modalities. In the second family of approaches, the composite MASCARET-CHRYSAOR approach allows this kind of pedagogical settings. However, these approaches have not formalized the links with design methods for learning activities, and they do not make their models accessible to teachers and trainers. The EAST project combines Isis approach for designing learning activities and operationalization through the MASCARET approach.

# 3. Design methodology for pedagogical scenarios in virtual reality

The main principle of our methodology is to externalize both the expert knowledge on the application domain and the pedagogical elements from the VE. The VE only contains 3D components of the scene. All the other information is considered as data, produced by protagonists of the learning environment design process. In order to achieve this, we propose to define a unified modeling language that enables to represent the two aspects of the learning situation: its contents (expert gestures or procedure) and its presentation (pedagogical scenario). In this way, the pedagogical scenario is a particular expert procedure – from the pedagogical field- that is intertwined with application (expert) procedures. This enables both procedures to share a common modelling language and to be instantiated from the same meta-model.

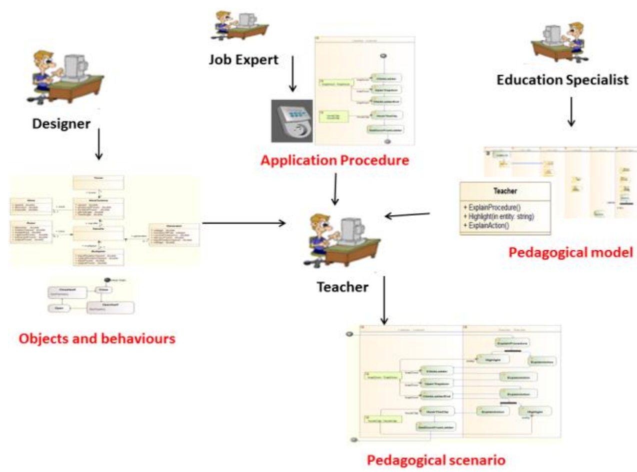


**Figure 1: Pedagogical scenario design workflow**

We have chosen the UML language because its formalization enables it to be automatically interpreted by the VE player (in our case MASCARET) and its graphical representation can be manipulated by non-computer scientists. Hence, the pedagogical scenario formal model is an UML extension. The pedagogical organization is a collaboration made up of roles. Roles are UML interfaces, which mean that they provide a set of services without implementing them. The agent, whether artificial or human; playing a role supplies the actual instantiation of those services. Each role participates to the pedagogical scenario, which is an activity putting together pedagogical actions that modify the VE (the system and the pedagogical resources).

In figure 1, we show the four main roles in our design methodology:

- The education specialist defines the pedagogical actions that can be used to guide or correct the trainee in the VE settings, as well as the pedagogical action forms (typical sequences of actions, reactions and interactions with the objects of the system). These actions are independent from the application domain, from the technological environment and from the pedagogical strategies. However, they depend on the type of learning environment, for example interactive simulations.

- The job expert, who knows the activity which has to be learned, formalizes the sequence of actions and interactions with the objects of the environment. He also describes good practices and procedures that have to be learnt and different behaviors (proactive or reactive) of the objects. This description is independent from the execution platform.
- The designer creates the VE: the objects and their behavior (based on the job expert specifications), based on heterogeneous sources such as industrial assets, pictures and behavior libraries. He also enables the instantiation of the learning environment by interfacing the geometries and scripts with the pedagogical roles of the different actors.
- The teacher (or trainer) defines pedagogical scenarios (the sequence of situations in which the trainee acts in the environment) and the pedagogical assistances provided by the system in real time. To define the scenarios, the teacher uses (1) the environment and the objects it contains (created by the designer), (2) the potential actions of the learner on the objects and the good practices (defined by the job expert), and (3) the models, the pedagogical action forms and generic pedagogical actions (defined by the education specialist).

Although these roles are separate, some of them may be played by one person, *e.g.*, the job expert and the teacher / trainer. The model defined through different roles is then exported from the UML editor to be interpreted by the MASCARET module in the VR platform. The models semantics are detailed in [14].

As we mentioned before, the data produced by the job expert and the applicative teacher are dependent on the application domain. However, it is not the case of the data produced by the education specialist: this pedagogical library can then be re-used in different settings. The use of a common language based on UML model for both job activity and pedagogical activity description also enables to extend these libraries *a posteriori*. The library developed until now contains the following action types:

- Pedagogical actions on the VE: *highlight an object, play an animation…*
- Pedagogical actions on user interactions: *change the point of view, block a position…*
- Pedagogical actions on the structure of the system: *describe the structure or an element of this structure; display an entity's documentation…*
- Pedagogical actions on the system dynamics: *explain the objectives of a procedure, explain an action*
- Pedagogical actions on the scenario: *display a pedagogical resource, explicit the objective of the scenarios…*

Indeed, these actions have to be instantiated in the platform chosen for the specific application. The MASCARET interpreter is available for the Unity3d platform and already contains these pedagogical actions.

## 4. EAST project: application to a Windmill

The first step of our methodology is achieved by the job expert: the definition of the system structure and of the procedures and actions that can be applied to it by technicians.

**Applicative model.** Figure 2 illustrates a part of the UML model defining the structure of the windmill. The system consists of a series of equipment which collects and transforms the energy from the wind into electrical power. The system is directly described in the model, which enables to easily modify (outside of the VE) its behavior, for example to define several windmill models. The classes and attributes are documented in order to generate pedagogical actions (such as *explaining the system).*

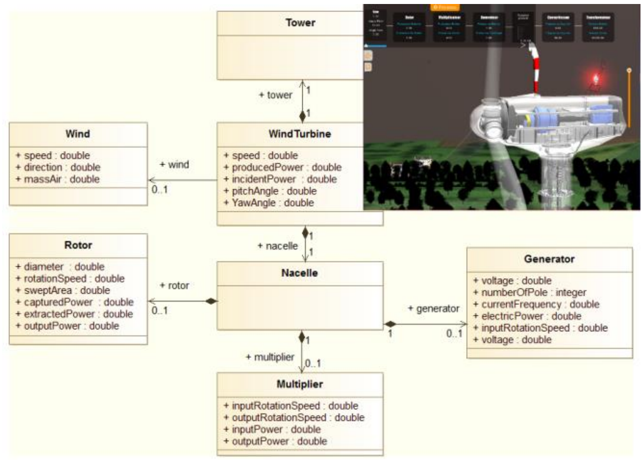


**Figure 2: Windmill Structure and VE representation**

Concerning the procedures defined by the job expert, several scenarios have been implemented in the windmill environment: system physics presentation, safety training, and maintenance training. In this article, we focus on the safety training. The UML description enables to describe complex activities through loops, sequences, parallelism, events, *etc.* The hierarchical structure is used and interpreted by MASCARET as a knowledge base to reason on the procedure and track the activity of the trainee.

**Pedagogical scenario.** The safety scenario is designed to teach trainees the safety measures to intervene in a windmill, such as ladder climbing, opening / closing trapdoors, and hooking to safety rings. The interaction mode chosen is a metaphor using either a keyboard (through lateralized keys) or a joystick (through triggers) for VR headsets. Figure 3 is an extract from the scenario with two parts (or roles) played in parallel: the trainee and the virtual teacher. The principle is to repeat the procedure until it is acquired by the trainee (transferred to its long-term memory). However, pedagogical assistances are adapted according to the number of sessions of the trainee.

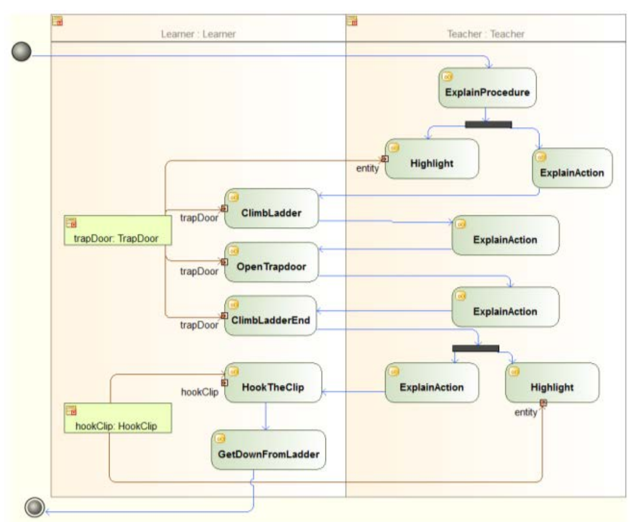


**Figure 3: Extract from the safety procedure**

The pedagogical scenario shown in figure 3 is dedicated to a first session with the virtual environment, and therefore contains a number of explanations on the environment and actions, because the learner does not know *a priori* all the actions and resources to be used in the environment. These pedagogical elements are not necessary in further scenarios, or may be focused by the teacher on specific parts of the windmill in the context of special sessions, only by the manipulation of graphical boxes.

The first action of the pedagogical scenario explains the objective of the procedure so that the learner knows that his objective is to attain the top of the windmill. During his ascent, he has to keep a stable balance on the ladder and always keep his lifeline attached to a *runner* or to a safety ring. This explanation exploits the UML description of the scenario, and can thus be modified by the teacher without changing the implementation of the VE.

Finally, the scenario has two more pedagogical actions, executed in parallel; the first action enables to explain the next action to be performed, (climbing to the trapdoor), while the second enables to highlight the trapdoor (changing its color to a salient red as shown in figure 4). These pedagogical actions are generic and can be used on any element of the environment.

**Figure 4: Pedagogical security scenario; trapdoor highlight.**

## 5. Conclusion

The purpose of this work is to redefine the roles of the different actors playing a part in the design of VR learning environments. The main idea is that the job expert and the education specialist should be put forward in the design of such environments, and that the teacher / trainer should be able to reuse and adapt the pedagogical scenarios without the help of computer scientists. In order to achieve this, we propose a methodology that externalizes the applicative models and the pedagogical models from the application. These models, expressed through UML diagrams, are then interpreted by the VE to instantiate scenarios based on the meta-model of the system and of the assistances used by the teacher. This methodology also allows to develop generic pedagogical actions that can be reused for different scenarios.

Massive experiments are being conducted to assess the relevance of the learning environments in real settings. More than 1,000 students have already used the windmill simulator, ranging from 9th grade to engineering schools, in scenarios which are adapted to the students' grades.

In this article, we have shown a short example of application through a windmill environment. Other scenarios in the same environment (such as a preventive maintenance training), as well as another environment (a power plant with cogeneration unit) are being developed as part of the EAST project. They all share a part of the UML meta-model. In the future, we plan to introduce a virtual agent to implement two new types of actions: cooperative actions and pedagogical assistances based on dialogue and *show by example* actions. Another perspective of this work is to design applicative models with higher degrees of genericity. For example, a part of the maintenance procedures are similar in several application domains.

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