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VR-Peas: A Virtual Reality PEdAgogical Scenarisation tool

Lahcen Oubahssi¹, Claudine Piau-Toffolon¹ and Oussema Mahdi¹

¹*Le Mans Université, LIUM, EA 4023, Laboratoire d'Informatique de l'Université du Mans, Avenue Messiaen, 72085 Le Mans Cedex 9, France*

Lahcen.oubahssi@univ-lemans.fr

claudine.piau-toffolon@univ-lemans.fr

Oussema.Mahdi@univ-lemans.fr

Abstract: Virtual reality (VR) has become a key component of modern educational technology and offers many educational benefits, such as engagement of learners and better comprehension of the subject. However, when learning design forms part of their activities, teachers have difficulty in designing and realising virtual reality scenarios. In this paper, we address the issue of the design and deployment of VR-oriented pedagogical scenarios by teachers as designers. To provide practical and theoretical solutions, we analyse the various existing models and tools for assisting teachers in the design and deployment of virtual reality learning environments (VRLEs). We identify a need for a model that covers the pedagogical needs of teachers, including the modelling of pedagogical structuring and the consideration of the specificities of the VR environment. Our main contributions are a pedagogical scenario model and the development of an editor called VR-PEAS (Virtual Reality PEdAgogical Scenarisation tool), which provides a solution that can support and help teacher-designers to design, adapt and reuse pedagogical scenarios oriented towards VR. We proposed a literature review to identify the main concepts of pedagogical scenario design and developed the computer solution according to an agile approach. To validate the basic concepts of our contribution and the impact of our implementation, we define a case study evaluation based on four different pedagogical situations using a qualitative method based on questionnaires. Our findings indicated that teachers could design VRLEs that were aligned with their pre-defined scenario and operate them successfully.

Keywords. VRLEs, TEL, VR-PEAS, Pedagogical Scenarios, Authoring Tools, Instructional Design.

1 Introduction

Virtual reality (VR) technologies have become a key component of modern educational technology, and allow educational teams to use interactive means of developing captivating and immersive learning experiences (Suri et al., 2023). Recent technological advances in computer hardware and VR technology offer great potential for the development of different VR learning environments (VRLEs), which are semi-immersive three-dimensional (3D) virtual learning systems (Vix et al., 2023). These environments combine characteristics such as representational fidelity, learner interactions and identity construction (Fowler, 2015). However, we observe that the design of a VRLE is a complex and expensive process, posing challenges of both a technical nature, involving interdisciplinary aspects intrinsic to VR (computer graphics, haptic devices, distribution, etc.) and a cognitive nature, such as the need to respect the characteristics of the task to be learned, and transfer of learning to the real world (Bossard et al., 2008). VR is not educationally useful in itself, and *ad hoc* methodological approaches using VR are needed (Vergara et al., 2017; Martín-Gutiérrez et al., 2017). In such a rich learning environment, we have to look at activity from both the perspectives of both design and use (Wasson & Kirschner, 2020). Many research studies have investigated the use perspective of VR, and have demonstrated its educational benefits in different contexts (Matovu et al., 2022; Villena-Taranilla et al., 2022; Kaminska et al., 2019; Suri et al., 2023; Toyoda et al., 2022). Our aim is to study the design perspective of VRLEs. According to the model of technology integration (Mishra & Koehler, 2006), the design of a VRLE should combine three sources of knowledge: technology, pedagogy and content. A VRLE includes an educational simulation that is built around a set of educational objectives. The description of an educational simulation must take into account the specificities of the technological

environment (its structure and its dynamics); however, to fully describe the learning experience, VRLEs also need to specify pedagogical requirements, meaning that designers need to exactly describe the operationalisation and the control of the activities in the environment.

Instructional design provides a framework for designing and implementing learning experiences with VR. In general, in the domain of technology-enhanced learning (TEL) and hence in VRLEs, the pedagogical situation is considered as a composition of activities carried out by various actors in a specific environment. The sequencing of these activities is described in a hierarchical form, and activities may be organised sequentially or in parallel. The aim of instructional design is to formalise the process of designing pedagogical activities. In our context, this process must take into account the specificity of the learning environment (immersive), the materials used (VR headsets, VR controller, etc.) and the theoretical aspects of implementing a virtual learning environment (Vergara et al., 2017). In view of these aspects, our first aim is to model the scenarisation process of VR-oriented pedagogical activities. Given that research on pedagogical scenarisation in the context of VR is recent, we have extended our study to methods applied in the domain of TEL. This exploration allows us in the first place to identify the characteristics that seem to be essential when designing learning activities in a VR environment for human learning. In addition, we aim to identify the characteristics that a pedagogical scenario tool must possess to enable such environments to be designed and deployed. Learning design involves several steps, and the process consists mainly of (i) specifying a scenario, (ii) making it available to users and (iii) promoting its execution (Abedmouleh et al., 2012; Paquette et al., 2008; Hernández-Leo et al., 2017). In the TEL field, specific research issues are associated with each of these stages. We therefore explore the question of the pedagogical scenario

in its totality, with the aim of achieving our main objective of helping and supporting teachers to design, adapt and reuse their educational scenarios based on virtual reality. Our first research problem thus concerns the design of pedagogical activities in the context of VR. Learning design forms an integral part of teaching practice (Goodyear, 2015; Wasson & Kirschner, 2020), and consists of specifying and modelling pedagogical situations based on a particular pedagogical approach. It is "*above all a work of content design, organization of resources, planning of activity and mediations to induce and support learning, and orchestration*" (Henri et al., 2007), taking into account the pedagogical approach used.

Our second issue concerns the operationalisation of VR-oriented pedagogical scenarios and the generation of VRLEs. This second aspect represents an intermediate phase that lies between the learning experience and scenario design, and involves making the scenario described by the teacher usable and manipulable within a VRLE while preserving the pedagogical semantics described (Oubahssi et al. 2013) (Tadjine et al. 2016) (Bakki et al. 2019) (Bakki & Oubahssi 2022)(Oubahssi & Piau-Toffolon 2019) (Mahdi et al. 2019) (Mahdi 2021).

In this paper, we will examine how scenario design can be integrated into VRLEs for the creation and use of dynamic and engaging learning experiences by the teachers themselves, without the need for help from a pedagogical assistant or computer engineer. To achieve this, we develop according to an agile approach a tool called the VR-PEAS editor (Virtual Reality PEdAgogical Scenarisation tool), which provides a solution to support and help teacher-designers to design, adapt and reuse their VR-oriented educational scenarios. This tool enables the designer to generate a VRLE and to play the scenario produced.

This paper is organised as follows. In the next section, a selected literature review of VR-oriented pedagogical design is presented. The section concludes by noting the lack of a model that covers the pedagogical needs of teachers independently of the application area, and which includes the modelling of pedagogical structuring and the consideration of the specificities of the VR environment. Our research proposal for a VR-oriented pedagogical scenario model and the VR-PEAS scenario editor are described in Section 3. The architectural and technical choices that were made are explained in Section 4. In Section 5, we report on an case study evaluation conducted with teachers, and we draw conclusions in Section 6, where some findings, assessments and perspectives for future work from this study are given. Our aim is to contribute to the elaboration of powerful abstraction and to enable models and processes to be run on computers in the TEL domain (Tchounikine et al., 2009).

2 Scientific Background

In this section, we carry out a literature review of pedagogical activities in VRLE and VR-oriented authoring tools. Bringing these topics together allows us to analyse both the strengths and shortcomings of our VRLE learning design proposal.

2.1 VR-oriented educational activities

As mentioned earlier, instructional design involves specifying and modelling the progress of pedagogical situations. In the context of VR, a pedagogical scenario allows teacher-designers to structure the learning context and to organise it in the VRLE and over time. VRLEs are subject to several uncertainties that the scenarisation system cannot control, for example the freedom of action of the learner, the autonomy of virtual characters, and the evolution of the states of VR objects, making it impossible to predict every outcome in the virtual environment, and the learning design system must

therefore be resilient to guarantee the smooth unfolding of the educational objectives. This involves taking into account uncertainties and regenerating the learning scenario in real time.

Chen et al. (2004) propose a theoretical framework that identifies four principles for designing VR-oriented pedagogical scenarios: (i) the conceptual principle that guides the learner towards the information that must be taken into account; (ii) the principle of metacognition, which guides the learner's thinking process during learning; (iii) the procedure, which indicates how to use the information available in the virtual environment; and (iv) the strategic principle that allows the learner to analyse the learning task or the problem to be solved. This research work provides a basis for identifying the different elements that should be taken into account when designing a VRLE (e.g. the type of learning targeted, pedagogical scripting, support systems, and the pedagogy to be implemented). However, it does not take into account the process of learning design of VRLEs by the teachers.

In the approach of Carpentier and Lourdeaux (2014), the virtual environment is populated by autonomous virtual characters and the user is free to act. The design of a pedagogical scenario is realised in two steps: the dynamic objectives are determined based on the user's activity, and a pedagogical scenario is then generated and implemented through adjustments to the simulation.

Marion et al. (2009; Marion 2010) define a VR-oriented pedagogical activity as a task to be carried out by the learner in the virtual environment and described by the teacher (the 'what'). To this description, the teacher can add pedagogical information with the aim of instrumenting this task based on a specific pedagogical objective (the 'how'). An educational objective is then accomplished by carrying out a series of steps, called learning activities, which include a series of virtual actions.

From a study of these research works, we found that existing scenario models cannot be easily adapted by the teacher to a specific pedagogical situation. A pedagogical model is planned from the earliest stages of the design of a VLRE, and all possible situations must have been considered beforehand. This constraint can not be adapted to the practices of the teacher-designer (Goodyear, 2015; Hernández-Leo et al., 2017).

2.2 *VR-oriented authoring tools*

In this section, we analyse a selection of VR-oriented authoring tools (also called scenario editors) in order to identify common aspects that can help a teacher to design a pedagogical scenario and to generate a VRLE. An authoring tool is computer software whose primary purpose is to enable, encourage, and assist people without programming skills in designing, editing, configuring, and running virtual content. It allows for the integration of the content of an educational situation designed by educational engineers or teachers (objects, instrumented educational activities, etc.). In the following, we review some examples of VR authoring tools (Marion, 2010; Oubahssi & Piau-Toffolon, 2019; Cormier et al., 2011; Gerbaud et al., 2008; Lourdeaux, 2001).

Proposed by Marion (2010), the Poseidon scenario editor aims to facilitate the creation of VR-oriented pedagogical scenarios. Functionalities have been designed for creating and modifying the components of a Poseidon scenario (learning environments, pedagogical organisation and pedagogical activities). This tool is based on an explicit business model that describes both the characteristics of the virtual environment (entities, activities, etc.) and the concepts involved in learning, and ensures a link between them. The approach is based on meta-modelling to ensure the genericity of modelling, regardless of the nature or field of the VRLE, and relies on an abstract

representation of virtual environments with the MASCARET model (Buche et al., 2004).

The ARVAD project (a virtual learning environment for the acquisition of orientation skills) (Oubahssi & Piau-Toffolon, 2019) focuses on the design and operationalisation of learning situations in a VR environment. Its objective is to facilitate learning through digital means, and to provide trainers of Local Units for School Inclusion (LUSI) classes with an educational toolkit that allows them to create and adapt or modify VR scenarios and assess the learners' progress. LUSI classes welcome pupils with cognitive or mental learning disabilities. As a follow-up to this project, an authoring tool called EditovLAN (*Editor of Virtual environment to Acquire orientatioN skills*) was developed to allow teachers of LUSI classes to develop exercises based on plans or a labyrinth and visual indices (to help with navigation and displacement). The teacher can also gradually increase the levels of difficulty using more complex plans and courses, reduced visual indices, etc. The editor interfaces are simple and ergonomic, with drag and drop mechanisms at the main interface. However, this tool only makes it possible to model scenarios related to the activities undertaken in LUSI classes.

Another tool called VirTeaSy, proposed by Cormier et al. (2011), allows for the design of virtual teaching situations dedicated to implantology, and makes it possible to generate learning/teaching situations for students on surgical or dental courses to train on the placement of implants. Using the VirTeaSy tool, the teacher first builds the virtual environment, and then identifies the 3D objects that constitute it (such as a dental tool, a tooth, a chair, etc.) and their interactions. VirTeaSy makes it possible to modulate the virtual environment according to the elements of the conceptual structure of the situation, such as the density, shape and thickness of the bone, the location of the

implant site, and the adjacent anatomical structures. In addition, functions, aids, and the dental instruments available for the learning activities can be defined. The VirTeaSy project provides an effective solution to the well-known difficulties in practical training in implantology, but it cannot be used in other contexts.

Gerbaud et al. (2008) developed the Giat Virtual Training (GVT) platform, which aims to simplify the development of virtual environments for training sessions and can help in applying procedures within a specific learning domain. It is based on two main models: a model of behavioural objects and interactions, called STORM (Mollet et al., 2006), and a scenario model called LORA (Mollet et al., 2006). The description of a virtual environment for learning with GVT is organised around two aspects: a description of the VR objects and their interactions, and a description of the procedure to be realised. The generation of scenarios describing the progress of these activities in a well-defined order is a complicated task in GVT, and to achieve this, Mollet et al. (2006) used the LORA language. GVT is reusable thanks to its generic STORM model. A distinction is made between the activity scenario, which describes the procedures to be realised in the virtual environment, and the pedagogical scenario, which promotes the reusability of existing scenarios. One limitation of GVT is that it can only be applied to learning procedures in the design of specific industrial context, and can rarely be applied in other contexts.

Proposed by Lourdeaux (2001), the FIACRE project was designed to be used in the industrial context of high-speed train operation. A prototype training simulator using VR design techniques was created. Although train drivers use this simulator, FIACRE is not a driving simulator but a learning system for the control and manipulation of switchblades on high-speed railway lines. The trainer identifies the components of the virtual environment for the learner. FIACRE describes the activity characteristics to be

offered to learners, depending on the cognitive and behavioural components that the trainer seeks to reproduce in the virtual environment. This allows the trainer to specify which behavioural interfaces can be used and how, for each activity. FIACRE uses an intelligent pedagogical agent called HAL (Help Agent for Learning) to assist trainers and offer the appropriate assistance for learners. However, FIACRE can only be used in the industrial context in which the project took place.

2.3 Findings and discussion

Our review of the state of the art has focused mainly on the various works on the design of learning environments, and we note that many issues, both theoretical and methodological, remain to be explored. We identified (as illustrated in Table 1) a lack of a model that covers the pedagogical needs of teachers, aim The solutions proposed are too often rigid, making it difficult to design reusable and adaptable scenarios. Our aim is to provide a methodology that ensures best practices for the integration of Virtual Reality in an educational context. This literature review helped us to propose a process of design and production of virtual Reality learning environments based on pedagogical aspects and taking into account technological aspects.

Approachs	Supporting and helping teachers to design, adapt and reuse VR-based pedagogical scenarios.						
	Propose a model scenario				Propose a design process	Propose a editor	Teaching oriented
	Adaptable	Generic	Operationalisable	Reusable			
Chen et al. 2004)	Yes	Partial	No	Yes	No	No	Yes
Carpentier & Lourdeaux, 2014)	Partial	Partial	Yes	Yes	Yes	Humans platform	Partial
(Marion, 2010) (Marion et al. 2009)	No	Partial	Yes	Yes	Yes	Poseidon	Yes
(Oubahssi et al. 2019)	No	No	Yes	Yes	Yes	ARVAD & EditoVLAN	Yes
(Cormier et al. 2011)	Yes	No	Yes	Yes	Partial	VirTeaSy	No
(Gerbaud et al. 2008)	No	Partial	Yes	Yes	Non	(GVT) platform	No
(Lourdeaux, 2001)	No	Non	Yes	Yes	Non	FIACRE	No
(Buche et al. 2004).	Yes	No	No	Yes	Yes	MASCARET	No

Table1. Analysis of the VR-oriented models and tools

3 A VR-oriented Pedagogical Scenario Model

The literature review presented above allowed us to define a list of characteristics that seem to be useful and interesting in terms of answering our research questions in relation to the teachers' learning design activity. These characteristics are as follows:

- Abstract modelling of virtual actions to ensure genericity;
- Modelling of pedagogical resources (VR-oriented pedagogical objects) and their relationships with the actions realised in the virtual environment;
- A flexible structure to help teachers to adapt or create new pedagogical situations without reinventing the VRLE design process for each new environment;
- A reusable structure that is modifiable, with configurable components, allowing it to be adapted to different contexts for the realisation of a scenario without the need to modify its description.

To validate our choices, we considered four examples of educational situations, as follows:

- Virtual animal experimentation, where the objective is to sensitise students to protocols and various actions related to animal experimentation.
- Realisation of a volumetric assay, where the objective is to control the steps necessary to determine the concentration of an unknown solution by volumetric assay.

- An investigation using ion recognition tests in solution, where the objective is for the student to identify the presence of ions in a solution using test products (reagents).
- Relativity of movement, where the objective is to understand that the nature of the movement depends on the chosen frame of reference.

The analysis and design of these different pedagogical situations made it possible to obtain a clearer vision of the essential elements for the modelling of a domain-free VR-oriented pedagogical scenario. It also allowed us to identify the pedagogical concepts necessary to express a VR-oriented pedagogical scenario, such as the activities and actions used in a virtual environment, the pedagogical objects necessary for their realisation, and the animations associated with these objects.

Following prior research (Fuchs et al., 2002; Fuchs et al., 2011; Richir et al., 2015; Schlemminger et al., 2013), we consider that activities can be grouped into four basic behaviours called virtual behavioural primitives (VBPs). This concept has been described in detail by Mine (1995) and Fuchs et al. (2011). There are four types of action in a VBP: (i) techniques for observing the virtual world; (ii) techniques for moving within the virtual world; (iii) techniques for acting within the virtual world, and (iv) techniques for communicating either with others or with the environment. To achieve our research goals, we refine the VBPs into sub-categories, each representing a group of specific VR actions. We also associate some of the most frequently recommended VR devices with each category. For example, for the category '*acting within the virtual world*', we identify two subcategories, '*selecting*' and '*manipulating*', and three devices that can be used (VR gloves, a VR controller, or a VR headset). Unlike training simulators, a VRLE mainly consists of virtual devices; this offers the advantage that the user can detach from realism when this can improve learning.

The results of our analysis have led us to the design of a VR-oriented pedagogical scenario model (Figure 1) to reflect the concepts that are most relevant and necessary for the description of an action and hence of an activity in a virtual environment. Our proposal is based on a detailed description of activities (use of the VBP concept) in which the learner interacts with a device, in order to take into account the specificities of the conduct of these activities in a virtual environment. Our model is organised based on four levels: the *User*, *Scenario*, *Business pedagogical concepts* and *Technical levels*.

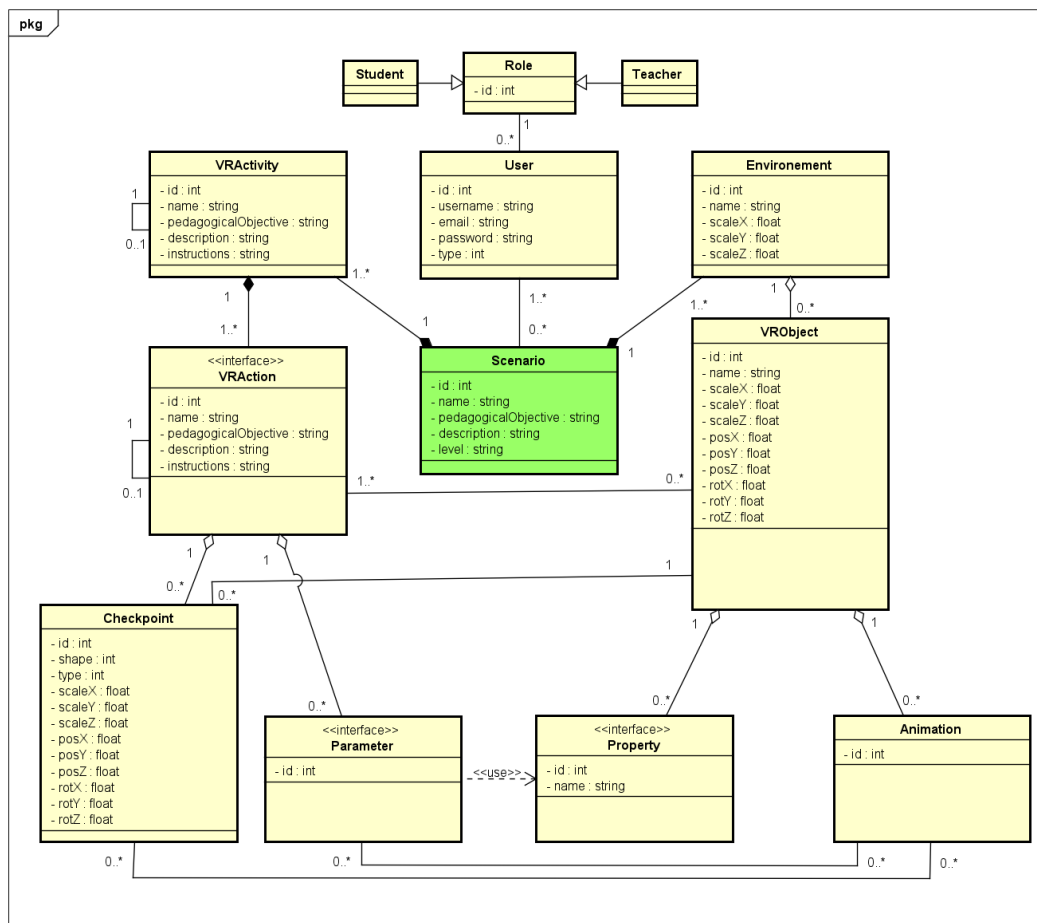


Figure 1. The proposed VR-oriented pedagogical activity model

User level: The *User* class includes any person involved in the design process. Each *User* has a role, and may be a learner or a teacher. The teacher participates as a designer (in the phase of formalisation and preparation of the environment), and also as

a facilitator (during the learning phase) while the learner participates in the learning phase of the VRLE.

Scenario level: The principal entity of our model is the *Scenario class*. A scenario can be created by the teacher and played by the learner. Each scenario is characterised by a name, a description, and a specific level, and responds to a specific educational objective. It is composed of one or more VR educational activities, represented by the *VRActivity* class, and one or more environments, represented by the *Environment class*.

Business pedagogical concepts level: The *VRActivity* entity has a reflexive association, where a lambda pedagogical activity may have a beta parent action. The beta will be activated only when the lambda is validated. Activities that do not have a parent activity can be performed at any time. Educational activities are made up of a set of VR actions, represented by the *VRAction* entity. Each *VRAction* is characterised by a pedagogical objective for the learner, a description that details the virtual action, and the steps that must be followed by the learner in order to realise the action correctly. We note that some virtual actions must be realised in a predefined order. The reflexive association of the *VRAction class* indicates that a virtual action *Action2* may have a parent action *Action1*, meaning that *Action2* will only be triggered when *Action1* is validated. Similarly, *Action3* will only be triggered when *Action2* and *Action1* are validated. If *Action1* does not have a parent action, it does not depend on the trigger conditions, and can be executed at any time during the educational activity. To further describe these virtual actions, we use reference shapes called checkpoints, a technical concept used and developed in several prior research works (Djadja et al., 2019; Gil et al., 2014; Mahdi, 2021; Oubahssi & Mahdi, 2021). Four types of checkpoints have been identified that correspond to the state of the action, as follows: (i) *StartCheckpoint*

identifies the start of the action start; (ii) *ProgressCheckpoint* represents the progress of the action; (iii) *EndCheckpoint* identifies the end of the action; and (iv) *FailCheckpoint* reflects an unsuccessful action realised by the learner. These checkpoints can be cubic or spherical, depending on the teacher's needs. To represent these checkpoints, we use a non-instantiable class structure interface. In addition to checkpoints, VR actions have parameters with specific values; for example, in the activity entitled “*anaesthesia of the animal via intraperitoneal injection*”, we define the parameter associated with the action of *injecting a liquid* as the volume of the contents of the *syringe object*. Depending on the values assigned to the parameters, the properties associated with each VR object may change; for example, this virtual object will have the property of a container.

Technical level: This level groups the objects and concepts needed to realise VR actions, as well as the animations produced in the VRLE. For example, a learning environment (represented by the entity Environment) contains VR objects (*VRObject*) that may be necessary for the learner's interaction or understanding of the learning concept. The *VRObject* class allows us to describe two types of objects: technical and pedagogical VR objects. We use the term raw object to indicate a technical VR object, which is also referred to as a 3D object or graphic object. A raw object is an entity used to acquire knowledge, whereas a pedagogical object is a teaching resource or learning object (IEEE, 2002) and is represented as a reusable educational entity that can be aggregated, stored, searched for and reused in different learning environments (Wiley, 2002).

VR objects aggregate entities that support the progress of VR actions. Each VR object can have one or more *Property* characteristics and one or more *Animation* behaviours. Properties are used to store values associated with these objects. Some technical

properties are common to all objects (especially those that govern the position, shape, or colour of objects), while others are properties specific to the object or learning domain; for example, a hydrochloric acid solution (as a pedagogical object) has properties such as concentration, volume and vaporisation temperature. These pedagogical objects and their properties allow for the creation of VR actions and the triggering of their animations. The parameters of the action and the checkpoints can be set by the teacher in order to flesh out the description of the pedagogical actions. The *Animation* class enables the dynamic behaviour of raw objects. Animations define the values of the object's properties based on the actions exerted on the object or on the environment in which it is used. For example, a cube (representing a raw object) must have the technical properties of weight and position: if it is dropped, it falls and deforms. We can associate it with educational properties such as gravitation for use in an educational context as a physics course.

To achieve this, we associate a model in JSON format (Figure 2) with each VR object, and predefine the animations that should be developed. Each animation has an identifier, a name, a description, and a set of compatible actions: for example, the animation corresponding to the “*cut action*” shows the skin opening. The defined objects (including their contours and trajectories) are flagged with checkpoints to trigger the corresponding animation when the learner achieves or misses the respective checkpoint (Figure 3). We define a list of animators for each animation. The animator depends on a specific object, a trigger variable, an animation type, and a Boolean condition that stops the animation when the learner passes the checkpoint. In other words, a checkpoint includes the rules that describe the dynamic behaviour of raw objects. These rules define the animation associated with an object, based on the actions performed on it or on the environment.

```

1 {
2   "defaultscaleFactorX": 1.0,
3   "defaultscaleFactorY": 1.0,
4   "defaultscaleFactorZ": 1.0,
5   "TriggerName" : "ScissorsAnimator",
6   "Animations": [
7     { "LocalId" : "1", "Name": "Open and close the scissors", "Description": "description", "CompatibleActions": "1",
8       "Animators" : [
9         {"AssociatedObject": "ScissorsAnimator", "ActivatorName": "Play", "StopAnimationsOnExit": true, "Type": 1}
10      ]
11    }
12  ],
13  "Properties":{
14    {"PropertyType":3,"Name":"Observable"}
15  }
16 }

```

Figure 2. Extract from the JSON file describing the properties of a VR-oriented pedagogical object

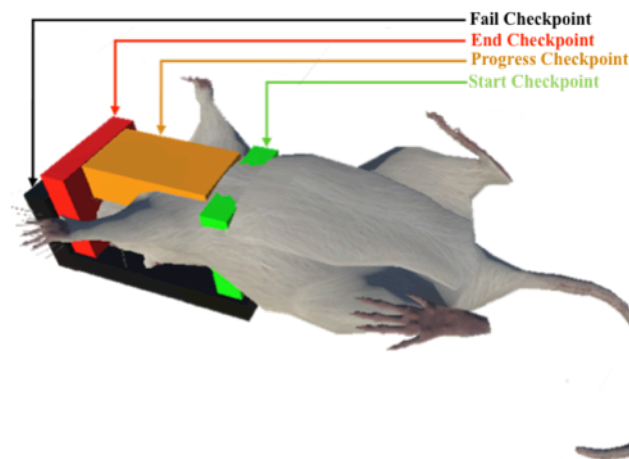


Figure 3. Virtual pedagogical object showing an example of the use of checkpoints
To summarize, our proposed model of VR-oriented pedagogical scenario is organized into 4 levels :

1. User level: used to define and manage the users involved in the design process, this level is independent of the learning domain.
2. Scenario level: used to define the learning scenario, its pedagogical actions and to associate virtual actions to it, it is also independent of the learning domain.
3. Pedagogical business concepts level: this level is specific to the domain, because each domain has its own business concepts. This level makes it possible to associate virtual actions with domain activities. For example, in the chemistry

domain, the actions "*Fill the burette and pour water*" can be linked to the activity "*Choose the reagents needed to carry out the test*".

4. Technical level: Allows the use of technical or educational objects specific to the domain, as well as the virtual animations associated with each object. For example, in the chemistry domain, the teacher can use the objects (H₂O, burette, beaker) and the animation simulating the filling of the beaker.

In order to use VR-Peas in a new domain, it is necessary to develop virtual objects and animations specific to that domain. The prospects of this research are to define mechanisms to automate the addition of objects and their animations in the VR-Peas editor.

4 VR-PEAS: Architecture and Elements

In this research, one of our objectives is to offer teachers an easy-to-use visual modelling tool to create or adapt an existing scenario, based on the scenario model presented in the previous section. In particular, we consider the question of the description of the VR-oriented learning activities and their organisation. This visual modelling tool must be able to provide an overall view of the entire scenario to be implemented, and should allow teachers to automatically deploy the pedagogical scenarios that they have designed with the editor tool. We have developed a tool called VR-PEAS that allows trainers to create and edit VR-oriented pedagogical scenarios, in order to help teachers to design operational VRLEs.

4.1 Architecture of VR-PEAS

We observed that in an interactive context, the pedagogical scenario no longer consists solely of scenario modelling, but also involves the establishment of the mechanisms necessary for the realisation of this scenario. Figure 4 shows the overall architecture of our editor, and its different modules are discussed in the following sections.

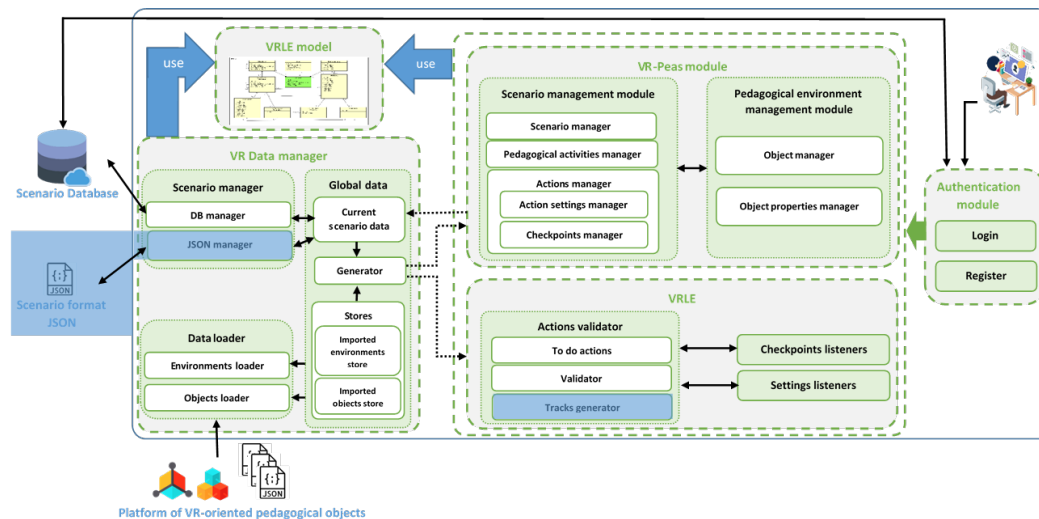


Figure 4. Architecture of VR-PEAS

Authentication module: The authentication module allows the teacher to create an account and to be authenticated. The teacher must enter a login and password. These authentication data are exchanged with the scenario database in order to save new user accounts or to recover accounts that already exist in the database. We apply access management policies by defining different access profiles, so that each person can only access the data they actually need.

VR-PEAS module: This module is dedicated to the scenarisation of educational situations by the teacher-designer. It is based on two sub-modules, which represent the core of our contribution: the *Scenario management module* and the *Pedagogical environment management module*.

Scenario management module: This allows teachers to manage their own scenarios (creation, reuse and modification). As soon as a scenario is created, the module offers the teacher the option of choosing a new learning environment or editing an existing one. The environment preparation is ensured by a module for managing teaching/learning environments. Teachers may adapt this environment by adding specific teaching objects. The scenario management module includes a *pedagogical activities manager* that allows teachers to define their activities and indicates the

progression of the scenario. The actions associated with each pedagogical activity are managed in a sub-module called the *actions manager*. In this latter module, the pedagogical objects associated with the actions must be selected. Depending on the action pattern, the *actions manager sub-module* includes a checkpoint manager for creation, manipulation and movement as well as an *action parameter manager* to define the necessary educational parameters.

Pedagogical environment management module: The learning environment management module is necessary to help the teacher to prepare the chosen environment, and makes it possible to instantiate the pedagogical objects loaded in the *VR data manager*. It also makes it possible to display and use pedagogical objects via the *educational object manager*. This module is equipped with a pedagogical *properties manager*, which allows each object to be assigned suitable pedagogical properties.

VRLE model module: This is used to implement the scenario model described in the previous section. The *VR-PEAS* module and the *VR data manager* use this module to structure the models of VR-oriented educational scenarios.

VR data manager module: This ensures the connection to the database, where the scenario data is stored via the *Scenario manager*. The latter includes two modules, called *DB manager* and *JSON manager*. The first module is used to exchange scenario data with the database, and the second is responsible for loading and unloading data from a scenario provided in JSON format. The sub-module entitled *Data loader* is composed of a *VR environment loader*, which is responsible for the loading of virtual environments, and a *VR objects loader*, which loads VR-oriented educational objects. The current scenario data retrieved in the *Scenario manager* are stored in a sub-module called Global data.

VRLE module: This allows for playing of the scenario. It is used by the teacher to test the execution of the scenario via the generated VRLE, and is also accessible to learners during the learning phase. The **VRLE module** makes it possible to control the actions of the learner thanks to a sub-module called the *Actions validator*. The latter includes the list of actions to be performed and generates the learning traces.

4.2 **Functionalities of VR-PEAS**

As illustrated in Figure 5, the main functionalities of VR-PEAS are:

- Graphic manipulation functionalities in the user interface, in particular:
 - Drag-and-drop of pedagogical objects from the inventory of objects to add or remove elements from the environment;
 - Reorganisation by modifying the position of objects in the user interface and defining the desired alignments and rotations;
 - Resizing of objects to adapt their size as needed via the graphic manipulation palette. We note that the manipulation of an entity (object, checkpoint, etc.) of the environment in order to associate a particular configuration with it can be realised either directly from the editor or in the immersive mode (with a VR headset and controllers);
- Functionalities for navigation of the environment and adjustment of visualisation. Our editor offers different views (immersive and non-immersive) according to the needs of the teacher;
- Notifications about the learner's mission, to let them know at all times what they are expected to do;
- Management of the sequence of VR actions associated with a pedagogical activity and the sequence of pedagogical activities within the virtual

environment, via a checkbox that allows the designer to specify whether the current action (or activity) must be preceded by another action (or activity);

- Functionalities for reloading an existing scenario or a partially designed scenario by importing various components created beforehand, such as virtual environments, pedagogical activities and VR actions. The objective is to promote the reuse of existing components, both to speed up the design and to capitalise on the use of components that already have been proved in other VRLEs;
- A VLRE trigger functionality that is used to generate the target VLRE and test the pedagogical scenario;
- A backup functionality that allows the scenario to be saved at any time during modelling.

The teacher can prepare the virtual environment and model a scenario by identifying the educational objects and the parameters necessary for carrying out the VR actions, via the environment preparation interface. This interface is provided with an inventory of VR-oriented pedagogical objects related to the educational situation. Teachers then proceed to the creation and configuration of instrumented educational activities via the modelling interface. This interface is equipped with the activity management palette, as illustrated in Figure 5. The overall features of VR-PEAS can be previewed on the demo video available from the link given below.¹

¹<https://lium-cloud.univ-lemans.fr/index.php/s/SX8agkGB2CLYxML>



Figure 5. VR-PEAS: Scenario modelling interface

4.3 Scenario operationalisation service in VR-PEAS

Our editor offers the teacher not only the means to design a pedagogical scenario but also to operationalise and generate their own VRLE. With this dual function, a teacher can automatically deploy the scenario that has been designed and also allow learners to play the scenario and perform the various instrumented activities. Once the scenario has been designed, all its data are exported via an operationalisation service to the scenario database. The operationalisation service is then responsible for importing the current scenario and its various components. It also makes it possible to load virtual environments and pedagogical objects in the *Global data* module (Figure 4) before proceeding to their instantiation. Using the data associated with the current scenario, the operationalisation service instantiates the 3D environment and the pedagogical scenario objects in the VRLE. We note that the teacher may modify the scenario, save it and deploy it again. Figure 6 illustrates the service for operationalising VR-oriented pedagogical scenarios.

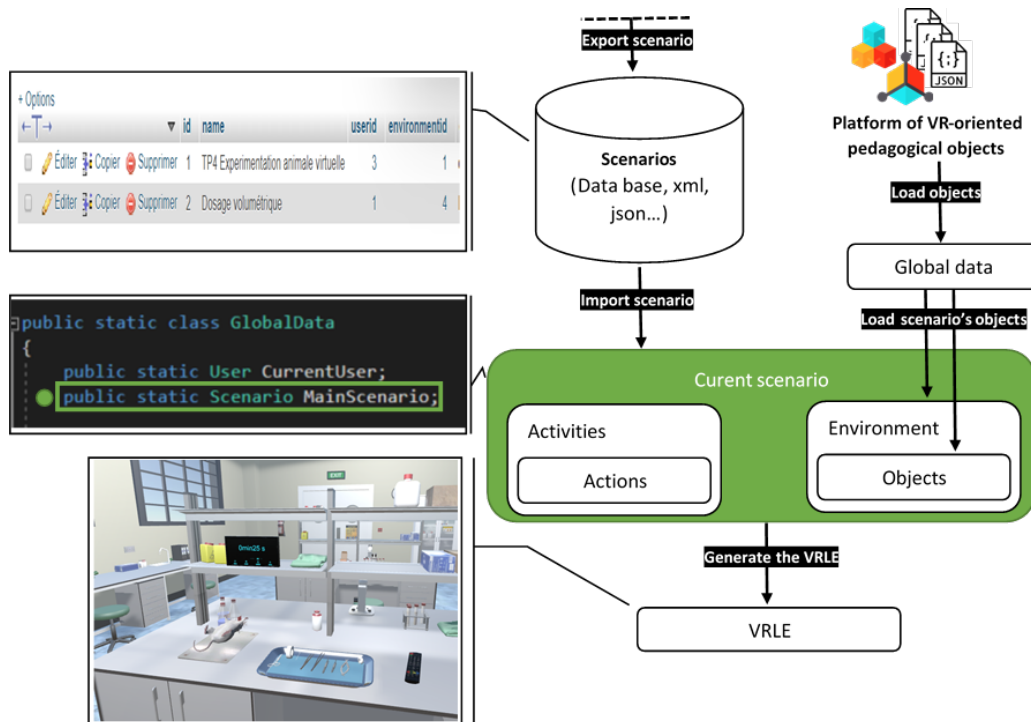


Figure 6. Operationalisation service in VR-PEAS

5 Evaluation of VR-PEAS

To validate our technical contributions, we considered a case study that involved four different pedagogical situations (described in Section 3) in order to compare and illuminate different aspects of our research problem. In this evaluation phase involving four participants, a qualitative technique based on questionnaires was used, and the development process of this research work was based on an agile approach. One of the fundamental aspects of agile methods is the implementation of iterative and incremental development and evaluation processes, carried out in a collaborative spirit. In each iteration, all of the functions (planning, analysis, design, unit testing and acceptance testing) are carried out, and at the end of the iteration, a working product is demonstrated to representative users (in our case, teachers).

This approach is consistent with our research methodology and teachers are engaged in an iterative and participatory design process where development and evaluation phases are intertwined (Figure7). We organised the development process with four teachers involved in 3 domains of expertise (2 in chemistry, 1 in physics, 1 in biology). During the first iteration, a pre-evaluation phase was proposed where the researchers' team presented the objective and concept ideas of the research work and they were asked to propose a pedagogical scenario limited to five activities to get started. Then after each development process iteration, we organised an evaluation session with the four teachers, in order to identify their suggestions for improvement and the new functionalities to be realised. We organised an average of six iterations. The number of iterations depended on the teachers and their domains of expertise. For example, with the biology teacher we validated two VR actions at each iteration.

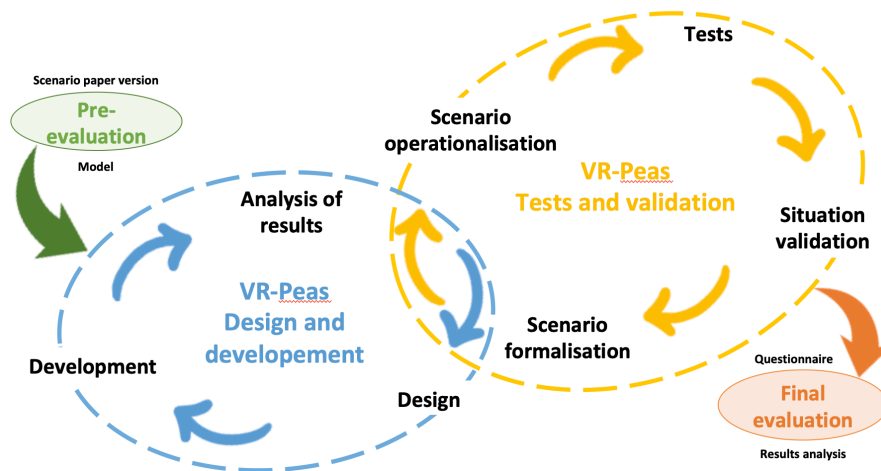


Figure 7. Intertwined development and evaluation process

It should be noted that these teachers had no previous experience in pedagogical authoring tools or the creation of VRLEs. At the end of each iteration, we aimed to test our theoretical proposals (the scenario model) on a larger scale and also to carry out an intermediate validation of the VR-PEAS prototype. In the last iteration, we carried out a

final validation of the entire scenario with the teachers via a questionnaire. This approach allowed the teachers to obtain regular updates on the development process and the functionalities implemented in the editor, and also allowed us as researchers to improve our scenario model and to evaluate the ability of the VR-PEAS tool to help teachers (considered to be novices in the development of pedagogical scenarios) to express and model VR-oriented pedagogical scenarios.

At the methodological level, we defined evaluation criteria based on the definitions of utility and usability given by Tricot et al. (2003). Utility refers to the objectives that an artefact makes it possible to achieve in specific situations when used by a given user (Tricot et al., 2003), whereas usability refers to the possibility of using a device at the level of its interface, its navigation, and its coherence with the objective. To evaluate the usability, we applied the System Usability Scale (SUS) model (Bangor et al., 2009; Lewis et al., 2018). In our case, we consider that VR-PEAS is:

- Useful if it allows a trainer to design a VR-oriented pedagogical scenario. We use this criteria to validate whether our scenario model, and in particular the representation of its pedagogical structuring (design of activities and pedagogical actions), makes it possible to produce a VRLE which responds to the initial needs of the teacher;
- Usable by teachers if it is easy to use (allows simple and easy navigation), that is, if it provides a scenario creation interface with functionalities that facilitate its use. Validation is therefore a question of exploring the satisfaction of the teachers with the realisation of the tasks;
- Useful if it can be applied in different contexts. In addition to the evaluation of usability and usefulness perceived by teachers, we aim to check that it allows us

to create VR-oriented pedagogical scenarios that can be used in different educational contexts.

Our evaluation phase took place in three steps. We started by validating our pedagogical scenarios model with the teachers, in order to get their feedback. We then carried out intermediate tests, in which the teachers were asked to design and deploy the educational activities for their scenarios. One of the primary purposes of this evaluation phase was to allow the teachers to interact with the tool (the editor) in order to improve the development iteration in progress. Discussions with teachers were also held to provide them with VR objects adapted to their needs. A test phase was applied to validate the different activities that had been designed and to validate the entire scenario in the last iterations. Finally, we sought to validate the usefulness and usability of the tool via a questionnaire submitted to each teacher participating in the final evaluation. This led into an analysis phase in which we interpreted the feedback collected from the teachers via the questionnaire.

In the last step, we analysed the results obtained during the evaluation of VR-PEAS. The questionnaire consisted of two types of questions: (i) closed questions concerning the usefulness and usability of VR-PEAS, where each teacher was asked for scores on a scale of one to five (from strongly disagree to totally agree); and (ii) open questions, whose objective was to let users express themselves freely and to present their feelings and suggestions for improvement. The results showed general satisfaction with the VRLE generated over the iterations. The usefulness of VR-PEAS was also considered satisfactory, since the teachers were able to design and generate good-quality teaching scenarios. This also supported our proposed scenario model. Although our results are not statistically representative, the results confirmed the usability of our editor and its usefulness in different contexts. Using VR-PEAS, the teachers were able

to design a variety of activities, and were able to provide clear and detailed specifications.

Three teachers felt more comfortable with the tool and gave better marks than the fourth, who did not have time to really get used to the immersive mode and exploit the full potential of VR. However, despite the new concepts that the teacher-designers had to assimilate, this teacher still managed to understand the functionalities of our scenario tool, which validates its intuitiveness. The others quickly transcribed their scenarios and used the VR-PEAS functionalities more appropriately, with less practice time than the fourth teacher. Finally, although the results of the evaluations validate our objectives, the VR-PEAS tool in its current version has certain shortcomings, particularly related to its ergonomics. Another point raised by the teacher-designers was the need to review the captions used for the elements of the palette, as they may cause some uncertainty among teachers who do not have strong pedagogical skills.

6 Conclusion

In this research work, we addressed the issue of designing and deploying VR-oriented educational scenarios. To provide practical and theoretical solutions, we reviewed various models in the literature and existing tools to assist teachers in the design and deployment of a VRLE. We identified a lack of a model that covers the pedagogical needs of teachers, including the modelling of pedagogical structuring and the specificities of the VR environment. A VR-oriented pedagogical scenario model was designed based on our findings from the literature, and designs for four different pedagogical situations were considered in order to establish the information necessary for the description of a pedagogical activity in a virtual environment. The objective was to provide scenarios that could meet the needs of the teachers and that could be designed by them. We organised our approach around two central elements of the VR-

oriented pedagogical scenario: the VR action, which acts as a link between the use of a virtual environment and the pedagogical activity (Mellet d'Huart, 2002), and the VR-oriented educational object necessary for its realisation. To ensure that the scenarios created in this process were sufficiently generic and reusable, we focused on the concept of design patterns. This approach allowed for adaptability to the complexity and context-dependence of the scenario (Mor et al., 2006). To enable the design and operationalisation of pedagogical scenarios in a VR environment, we developed a VR-oriented pedagogical scenario editor called VR-PEAS that reified the design and production process of a VRLE. The tool was designed to be easy to handle by teachers who are not expert in VRLE design, and is rich in functionalities to enable various scenario contexts to be handled. In order to validate our theoretical and technical contributions, we proposed a development approach based on an agile mode, with iterative test and evaluation phases that took place in three steps: a pre-evaluation stage, intermediate evaluations in parallel with the development phase of VR-PEAS, and a final evaluation of the tool based on empirical evaluative case studies and using a qualitative method with the administration of a questionnaire. This allowed us to assess the usefulness and usability of the VR-PEAS tool. The results from the various evaluations and our analysis of the answers from the teacher-designers to the questionnaires revealed that each teacher successfully designed a VRLE that aligned with the pre-defined scenario. Although we did not obtain statistically significant results, we saw positive trends in the responses regarding usefulness. Using the VR-PEAS editor, teachers were able to design pedagogical scenarios that involved complex and varied activities. In addition, the teachers seemed to develop skills in the use of VR-PEAS, as they were able to apply their learning to subsequent designs. This research opens up many possibilities for future development, such as improving VR-PEAS,

creating a platform of VR-oriented pedagogical objects, tracking analysis, exploring collaborative learning, and larger-scale experimentation involving learners. Our development approach was exploratory implementing development and evaluation phases iteratively as we intended to elicit basic concepts to design VR oriented training scenario. Further development should be improved in regard to the proposal of Vix et al (2023) of a method for developing VR training applications.

Availability of data and material

VR-Peas tool is available on the link: <https://lium-cloud.univ-lemans.fr/index.php/s/qxjtwrcbe6n8dkx>

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