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Design of Virtual Reality Systems for Education: A Cognitive Approach

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One of the main problems with virtual reality as a learning tool is that there are hardly any theories or models upon which to found and justify the application development. This paper presents a model that defends the metaphorical design of educational virtual reality systems. The goal is to build virtual worlds capable of embodying the knowledge to be taught: the metaphorical structuring of abstract concepts looks for bodily forms of expression in order to make knowledge accessible to students. The description of a case study aimed at learning scientific categorization serves to explain and implement the process of metaphorical projection. Our proposals are based on Lakoff and Johnson's theory of cognition, which defends the conception of the embodied mind, according to which most of our knowledge relies on basic metaphors derived from our bodily experience.

Keywords: virtual reality for education; metaphor; visualization of knowledge; design of virtual reality systems.

Introduction

There has been a spectacular growth in the development of virtual reality systems and particularly special-purpose applications for education over recent years. Youngblut's work (1998) includes and describes over seventy educational applications, all created in the 1994–1998 period. Other noteworthy examples of the interest raised by this technology in the teaching field are: the appearance of electronic journals accessible via internet and specialized in this issue (like '*Virtual Reality in Schools*'), monographic journal issues (like '*Presence*', volume 8, issue 3, June 1999) or the growing number of university and private research centers involved in creating virtual worlds for education.

The prototypes and applications developed so far are aimed at different sorts of users (children, university students, adults, pupils with cognitive or physical impairments, etc.) and cover a wide variety of didactic contents (science, the arts, physical/motor or cognitive skills, etc.) and pedagogical targets (improved learning, instruction, training, rehabilitation, development of real life skills).

However, although virtual reality is a very versatile technology, it should not be used indiscriminately in any educational program. Studying the right and applicable use of virtual reality is a challenge, an outstanding task. What educational situations, what disciplines or subjects and what sorts of students require this technology? Compared with other technologies, are virtual reality systems capable of improving the quality of student learning? When is virtual reality irreplaceable and why? What theories or models underlie the applications that are developed?

These questions remain unanswered, as almost all the efforts carried out in this field have focused on implementing special-purpose systems or limited-scope prototypes. The theoretical questions related to the design of models, methodologies and evaluation have hardly ever been addressed and studied in depth. Our research is principally motivated by the non-existence of a theoretical foundation in this field.

This paper analyses the design of virtual reality systems as learning tools and proposes a metaphor-based generic architecture. In the next section, we present our model of educational virtual reality systems. The third section explains the central component of the model, the metaphorical projection, by means of a case study that examines the learning of taxonomic classifications. In the fourth section, we justify our proposals from the perspective of the main findings of modern cognitive science. Finally, we summarize the main contributions of our model and propose a brief research agenda.

A Generic Model of Virtual Reality Systems for Education

In this section, we will describe the architecture of a model of virtual worlds for learning. This model should be a useful reference framework for designing and implementing any pedagogical program that calls for the use of virtual reality as an educational technology.

The central aim is to output a universal model. Universality chiefly has two meanings. Firstly, the possibility of applying the proposed model to any learning program, irrespective of its complexity and its initial independence of external factors (like the subjects or didactic contents to be taught, the physical or cognitive characteristics of students, and the underlying pedagogical methods or learning theories). Secondly, metaphor is the core of our model, and one of the main advantages of metaphors is their potential universality. Metaphors should be used in virtual environments as multi-sensory representations that can be experienced and interpreted by all students, irrespective of their language, thereby facilitating teamwork and interaction between participants.

Figure 1 shows the model proposed in this paper, identifying the essential components of the architecture of any educational virtual reality system: modules, resources, processes and participants. We will then describe each component, explaining its main features and functionalities

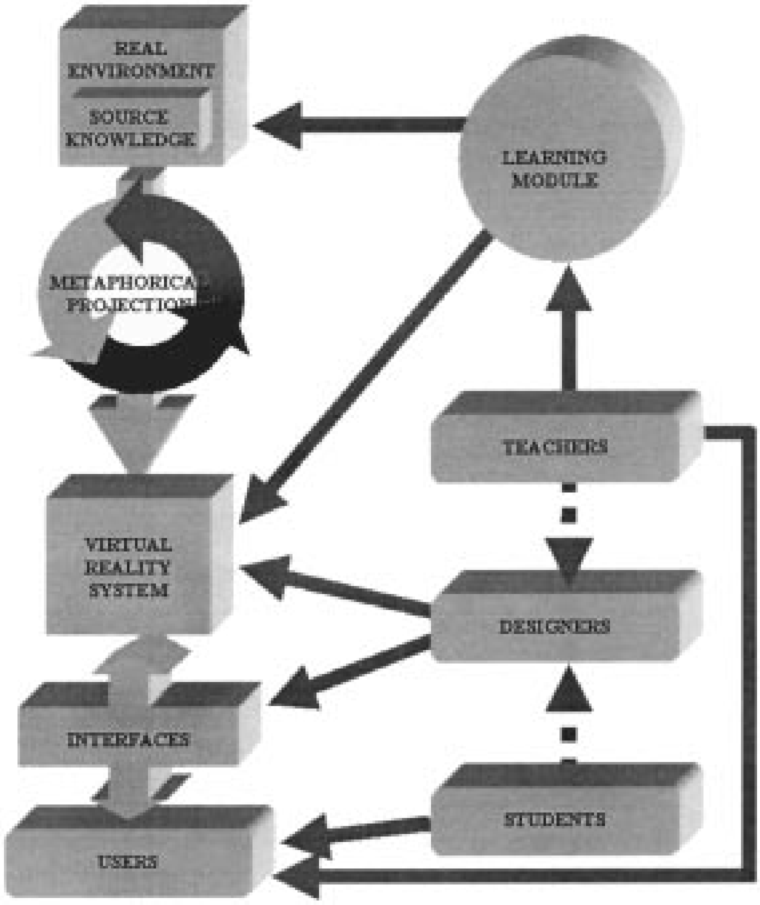

Figure 1. Model of virtual reality systems for education.

Real environment and source knowledge

Source knowledge represents all the concepts, didactic materials, skills and/or information related to the subject to be learnt by the student. The *real environment* can be defined as the setting in which teaching takes place. This setting must be taken into account when selecting and studying the source knowledge. The educational environment can sometimes play a fundamental role and determine the forms of learning. Examples of real environments are: a chemistry laboratory; an aircraft cabin, the airport and its facilities for a trainee pilot; the street, the district and the town for town planners or architects; the landscape, geology of the land and historical data for archaeologists; or the school classroom for a student taking a geography, drawing or mathematics lesson.

One of the key questions before designing a virtual reality learning system is to properly select the source knowledge. Obviously, it makes no sense to teach all educational contents using this technology, either because they can be directly learnt using traditional techniques or because other educational technologies are more effective and cheaper.

This paper defends that abstract knowledge is best suited for a virtual learning environment. Abstract knowledge means mainly complex concepts, that is, notions, theories, models, rules, processes and scientific laws that have the following characteristics:

- They do not have a clear correspondence in the real world. They are sometimes abstract, theoretical or generic entities, of which there are no references or specific examples in the real world.
- The knowledge concerned is ‘invisible’, having no profiles or physical observations and cannot, therefore, be experienced in practice or perceived by the human senses.
- Generally, they are ideal, abstract objects and cognitive processes that are difficult to visualize or imagine, concepts that are complicated to represent graphically or explain verbally.

The teaching and learning of this sort of knowledge raises enormous difficulties in traditional education. Selecting abstract contents, like source knowledge, will help to better identify what unique features virtual reality has as a pedagogical tool.

Another problem that arises is how to represent and teach abstract scientific concepts in a virtual environment. In an artificial world, primarily based on physical or sensory experience, scientific cognition will certainly call for new and original forms of symbolization and representation.

Metaphorical projection

Metaphor is the bridge between real and virtual environments. Virtual reality always provides a metaphorical parallel to our real world. Our model takes advantage of the fundamental role of metaphor to design, structure and build meaningful virtual reality systems. The learning of source knowledge can be made easier by its metaphorical embodiment in artificial worlds, where students can visualize, experience and interpret this knowledge directly.

The key component of our model is *metaphorical projection,* which can be defined as a mapping between the source knowledge of the real world and the virtual world. The main goal of this process of metaphorical transfer is to build a system or network of metaphors capable of defining the structure of the virtual world and organizing how to learn, navigate and interact with this. So, metaphorical projection takes place on four different, albeit interdependent planes: the structural plane, the learning plane, the navigation plane and the interaction plane.

The structural plane is composed of the metaphors that create the isomorphism between the source knowledge and the virtual world. These metaphors establish the organizational principles of the virtual scenario, determining its form and its structure. The aim is to base and structure the source knowledge in a familiar domain or situation that is already understood by students. The isomorphism or structural similarity will help them to discover the central features of the source knowledge domain.

The learning plane metaphors serve to design the pedagogical approach and strategies: the activities open to students in the virtual world, the role of student and teacher, the representation or symbolization of the didactic contents in the virtual scenario, etc. The most important components of the metaphorical projection are the structural and learning planes, which largely determine the selection of the metaphors in the other two planes.

The navigation plane describes how users browse and move around in the virtual world (walking, driving, flying, using a transportation tool, etc.). The metaphors of this plane also define the scale (or reference framework in which users move), as well as the students' viewpoint.

The metaphors of the interaction plane establish how pupils can interact with the virtual scenario, how they manipulate the objects they come across and how they communicate with other possible participants.

These four planes make up what should be a systematic and consistent set or network of metaphors. The metaphorical projection is an indispensable tool for conceiving the preliminary design of the two primary facets of the virtual world. Firstly, the design of the architecture of the virtual scenario: the structural and learning planes define both the configuration of the elements that constitute the structure of the virtual world, such as their symbolic meaning (the embodiment or metaphorical representation of the contents of learning in this physical space). Secondly, the design of how the student can 'inhabit' or use the environment: the navigation and interaction plane describe the different forms in which the user can move around and interact with objects and other virtual world participants (or how the user can interpret the meaning of the scenario).

In the next section, we present a case study that should give a better understanding of what metaphorical projection is and how it is carried out.

Virtual reality system

A *virtual reality system* is a computer application capable of generating a 3D environment in which the user is an active participant and interacts with the artificial world using a range of multisensory interfaces[1]. According to Bricken (1991), Byrne (1996), Zeltzer (1992) and Winn (1997), the main features offered by virtual worlds are as follows:

- Presence: users immersed in a virtual reality system get the feeling that they are actually there in the real place. Students are carried off to an environment of pure information that they can see, listen to and touch. In artificial worlds where presence is high, the sensation of immersion is so strong that the interface disappears and users lose all notion of interacting with a machine.
- Navigation: students can be either immobile observers or travelers in the virtual environment, moving around in different ways, e.g., walking, flying, speaking (giving

verbal orders to move), using a vehicle, touching an object or pointing in any direction within the environment, etc.

- Scale: the scale of the virtual environments can be altered, changing the relative size of users in respect of the virtual world and allowing students to become the same size as the biggest thing (a star) or the smallest object (an atom).
- Viewpoint: this is the possibility of users changing perspective at will. For example, students could pass on their viewpoint to a given artificial world object or process, or even to the viewpoint of another participant. Students can also be a floating viewpoint, flying or moving at any speed in any direction.
- User-environment interaction: users can make use of a range of ways of manipulating and modifying virtual worlds. Students could move the virtual objects by hand, eye movement or voice. Also, they have the ability to create and alter the environment.
- Autonomy: a virtual environment is autonomous and dynamic when it is capable of pursuing its own goals, executing actions and evolving, irrespective of user interactions.
- Co-operative learning: distributed and networked environments provide for collective participation, offering several users the possibility of sharing virtual spaces at the same time. Accordingly, the real-time interaction between different students leads to genuine co-operative learning.

Learning module

The *learning module* has the following functions:

- Select and clearly determine the source knowledge, that is, the didactic contents that are to be taught. The possible influence of the real environment on learning also needs to be examined.
- Establish the student profile: age, level of background knowledge, whether or not they have any physical or cognitive impairment involving special educational needs, their previous experience with virtual reality systems, as well as any other characteristic possibly influencing learning.
- Choose a given pedagogical program or learning theory, such as cognitivism, constructivism, the neo-Deweyist paradigm, the theories of Vygotsky or Piaget, etc., as a guide for the learning process. These are the functions of any learning module to be applied in a real environment. The following function, however, is specific to education in virtual worlds:
- Implement a preliminary design of the virtual world by means of a metaphorical projection, creating a meaningful isomorphism between the knowledge of the real environment and the virtual world for students. This preliminary design will serve to establish how the didactic material should be presented and structured, as well as to define the role of students and teachers in the virtual world.

Those in charge of the learning module are teachers and educators with elementary knowledge of the rudiments of virtual reality technology, as well as the architecture of this model.

Designers, students, teachers

The term *designers* refers to a wide-ranging group of professionals responsible for carrying out the final virtual reality system design and implementation:

- Designers and analysts, responsible for designing high-level virtual world hardware/ software. It is their mission, firstly, to assure that the different planes of the metaphorical projection are consistent and systematic and, secondly, to check that it is possible to implement the model as it has been designed.
- Mechanical, electrical, optical and sound engineers to design and construct the multi-sensory interfaces and devices of the virtual reality system.
- Graphic designers to create the 3D models of the virtual scenario and animations.
- Computer programmers to write the software to control the complex simulations.

Users are students and teachers, inhabiting and experiencing the virtual environment through different interfaces or input/output devices, such as head-mounted displays, gloves, body suits, trackers, 3D sound systems, etc., which provide the sense of immersion through visual, haptic, kinaesthetic and auditory feedback.

Both teachers and students could get to participate in design work (this possibility is indicated by the dashed lines in Figure 1). Teachers with advanced knowledge of virtual reality technology can make a direct contribution to the final system design and implementation. If the final system implemented is a pre-developed world, then students would have the possibility of configuring some features of the artificial world at will, redesigning the virtual scenario, modifying its structure, creating or deleting certain objects, etc.

The Metaphorical Projection: A Brief Case Study

Although we do not have the space here to discuss a full design of a virtual reality system here, the study presented below will serve as a preliminary approach and will be useful for gaining a better understanding of the process of metaphorical transfer.

The source knowledge we have chosen is as an example of scientific categorization: zoological taxonomies. Categorization is a very complex cognitive process, which, however, is part of all of our everyday activities. Classification is a mental process that human beings have performed since time immemorial and has led us to know how to recognize food, dangerous animals, social group, building materials and hunting equipment, etc.

A scientific example of categorization is taxonomic classification, where students are required to bring other cognitive skills into play. A classification is not only an index of data collection, it also has a heuristic function, on the basis of which to make predictions and generalizations; that is, a good scientific classification must provide a basis for explanation and inference. For all these reasons, the source knowledge we have selected are the zoological hierarchies conceived by Carolus Linnaeus, which define species in ascendent series of increasingly broader categories (e.g., species, genus, family, order, class, division) up to a single group that encompasses all organisms (the kingdom). Each category of the classification is defined by given unique, mainly physical, characteristics.

Below, we explain how the metaphorical transfer is carried out in each plane on the basis of this example.

Metaphorical projection: structural plane

Table 1 shows the metaphorical projection that we conceived for the structural plane. A correspondence is established in the table between the real and virtual environments at different levels of representation: preliminary approach, general structure, taxonomic relationship and taxonomic units.

According to the first level, the preliminary approach, the scientific taxonomy can be represented by a 3D scenario, a scenario that is familiar or known to students: spatial

Table 1. Metaphorical projection: structural plane

REAL ENVIRONMENT	*Levels*	*VIRTUAL ENVIRONMENT*
	Preliminary approach	
Scientific taxonomy	⟶	3D scenario
		a) Spatial: city, house, labyrinth . . .
		b) Natural: tree, island, planet . . .
		c) Geometric: cube, pyramid . . .
		d) Others: book, box, net . . .
	General structure	
Taxonomic architecture	⟶	Pyramidal network
Hierarchy:	⟶	Tree:
a) Kingdom		a) Starting root
b) Species		b) Terminal leaf
Taxonomic units	⟶	Rooms-cubes
	Taxonomic relationships	
Relationships between successive units	⟶	Corridors or channels between cubes
Relationships between same level units	⟶	Planes (colour, sound, shape . . .)
	Taxonomic units: features	
Basic features	⟶	Centrally positioned objects
Secondary features	⟶	Peripherally positioned objects
Other additional information	⟶	Available instruments

(house or building, block or district, town, labyrinth, etc.), natural (tree, mountain, island, planet, constellation, planetary system, etc.), geometric (sphere, cube, pyramid, etc.), or other (network, book, box, model, Meccano, etc.). The alternative that best symbolizes the hierarchical structure of the classifications, the scenario that can create a clearer and more intuitive structural isomorphism with the taxonomies, has to be selected from all these possibilities.

The next level of representation, called general structure, establishes the metaphorical transfers that explain the structural features of the scenario. Neither of the above-mentioned scenarios is, in our opinion, capable of reflecting all the features of the taxonomic domain on its own, which is why we preferred to build an ideal environment, a mixture of several scenarios: a structure that can be a house, tree, pyramid and network all at the same time.

The taxonomic architecture is represented as a pyramid-shaped 3D network of elements (see Figure 2). The first or top taxonomic category (the kingdom) would be at the apex of the pyramid and the lower categories (represented by species) at the bottom. The biological hierarchy of living beings is viewed as an inverted tree, whose leaves are organized and arranged at different depth levels: each level symbolizes a category or taxonomic rank (division, class, order, etc.). The leaves of the tree are cubes: spaces or rooms that represent the taxonomic units or taxa.

This structure also determines the taxonomic relationships. The relationships between units of successive levels (termed parent-child or ascendent-descendant relationships) are indicated in the virtual scenario by the corridors or channels between the cubes. The relationships between units of the same level (sibling relationships) can be symbolized by means of certain features, for example, the cubes belonging to one level could have a distinctive color or a given size or a distinguishing mark concerning shape (cut edges), an associated sound, etc.

The structural isomorphism between the source taxonomy and the virtual environment is clear: the hierarchical classifications of living organisms correspond with a tree network of cubes, a pyramidal building composed of different levels of rooms/cubes that can be browsed or explored by the user. So, the scale originally chosen for this virtual environment is the human dimension.

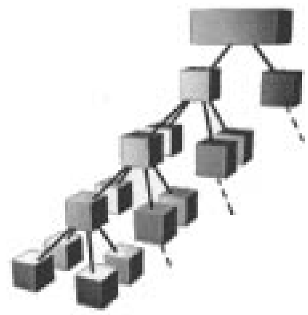

Figure 2. Pyramid-shaped 3D network.

If the cubes are rooms that represent the taxonomic units or taxa, then the objects located inside a room will symbolize the characteristics defining a taxon. The objects located centrally or in a prominent place in the room represent the most elementary or distinctive characteristics, whereas the objects situated at the edges symbolize the secondary properties.

Figure 3 shows the inside of a cube. The cubes are designed as rooms or spaces that can be explored. Each room contains objects that could be handled by students. For example, the 3D geometric figures (sphere, cube, cone) placed in the middle of the table are object-metaphors that represent the main distinguishing features of the cube or taxonomic unit[2]. The cylindrical column located in the far left-hand corner would indicate the ascendants and/or descendants of the current cube. The cupboard situated on the near left-hand side could contain different instruments for examining and gathering more information about the objects. The window on the right-hand wall is a screen on which 2D or 3D images about other cube-related features or characteristics could be projected.

Metaphorical projection: learning plane

Table 2 shows the metaphorical projection in the learning plane. The projection was realized on the basis of the pedagogical theory of constructivism[3].

Constructivism is a learning theory describing the process of knowledge construction. By definition, knowledge construction is an active process: students must become actively engaged in their learning experience, rather than act as passive recipients of information. This process can involve both cognitive and physical constructions of meaning, through the development of mental models or schemas, as well as physical or virtual representations of knowledge (Osberg, 1997). One of the key issues of constructivism is the need to develop a sense of depth about a concept. The constructivist environment is based on inquiry, which leads to deep understanding of the concept (in our case it is the concept of 'classification').

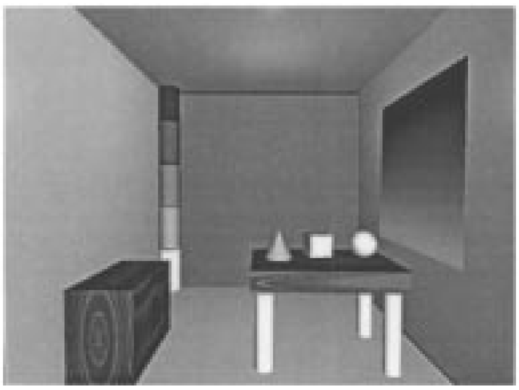

Figure 3. Inside of a cube.

Table 2. Metaphorical projection: learning plane

REAL ENVIRONMENT	*Levels*	*VIRTUAL ENVIRONMENT*
	Generic approach	
Learning	⟶	Game
Learning process	⟶	Travel, exploration, search
	Goals and tasks	
Learn to distinguish and differentiate the taxonomic conceptual domain	⟶	Explore the scenario taking different paths, interpreting its metaphoric sense
Learn to class the taxonomic units	⟶	Search for, find and take a given path in the network
Know how to describe a taxonomic unit	⟶	Recognize and interpret the inside of a room-cube
	Participants	
Students	⟶	Travellers, explorers
Professors	⟶	Collaborators, guides

As Table 2 shows, learning is viewed as a game played by the student, who should explore the scenario and complete a series of tasks. The student will be obliged to learn new knowledge or develop cognitive skills to achieve these tasks.

For example, the goal of the first task-learning of the taxonomic conceptual domain is to distinguish the main key concepts of any classification: hierarchy, class, category, set, element, membership, properties, inheritance, classificational criteria, etc. Students should be able to discover the metaphorical meaning of the virtual world by exploring the scenario, interpreting each of its elements and correctly relating these elements to the key concepts.

Table 2 is an overview that serves merely as a preliminary approach. The metaphorical projection would have to be completed in order to fully design the learning plane, adding all the information required. This involves exactly specifying the elements of the network that make up the virtual scenario (that is, defining all the didactic contents that are going to be taught), establishing each and every one of the possible routes (and their pedagogical meaning), describing the role of the teacher and other students (are lone trips possible or are only group expeditions permitted?), the instruments that can be used by students/-travelers to get their bearings within the virtual world or interpret its meaning (maps, indexes or waymarkers, magnifying glasses, microscopes or other viewing instruments), the exact description of the content of each cube/room and of the activities that can be performed in its inside, etc.

We should not overlook the possibly huge influence of the pedagogical approach or learning theory on the metaphorical projection. In this case, constructivism led us to suggest ‘travel’ or ‘exploration’ as the key metaphor. However, if we had chosen a more traditional pedagogical approach – according to which the teacher gives the lesson and all the students do is to listen, the metaphorical projection would be completely different. This would call for another key metaphor, such as ‘museum’ or ‘tourist’: the teachers would play the leading role as guides (explaining the scenario to students/tourists) and the students would merely listen and ask questions about what they do not understand. Although the scenario would be structured similarly, the students and teachers would perform completely different tasks and activities in this case.

Metaphorical projection: interaction and navigation planes

These two planes are secondary to the above. The full design of the structural and learning planes necessarily guides and determines the forms of navigation and interaction with the virtual world.

So, the selection of the best suited metaphors of interaction and navigation for our example will depend on the final design of the virtual reality system and also on other external factors (Bowman and Hodges, 1999), such as the characteristics of the tasks or possible movements (e.g., degrees of freedom in handling objects), environmental characteristics (e.g., density of objects in the scenario), user characteristics (e.g., arm length) and system and interface characteristics (e.g., stereo vs. mono viewing).

The techniques of navigation have to provide the means of selecting the desired direction and destination of the trip (students must be able to specify what direction they want to move in and where they want to get to); selection of the speed and acceleration of movement; and the means by which students decide to start, continue and stop moving. We can advance some possibilities of navigation for our example: realistic forms of moving around the scenario (e.g., walking), unrealistic or fantastic forms (e.g., flying or moving around like a ghost capable of passing through all physical objects) or a combination of both, depending on the distance, type of movements or routes to be taken in any situation. There are two possible user viewpoints: egocentric, when users are within the scenario, inside a room-cube (or when they move directly from one to another) and exocentric, if users have the possibility of exiting, moving outside of the scenario and looking at the cube network from a distance. Thus, the full hierarchy could be visualized as if it were a 3D map (and thus either identify the paths already taken in the network or select other routes).

The interaction with objects encompasses two basic tasks: the selection of the objects and how they can be manipulated (hold, move, release, throw, etc.). With regard to the interaction with objects for our scenario, the best thing would be direct manipulation. However, there are other options: move objects with eyes, gestures, verbal orders or menus. Where pedagogically necessary or relevant, some objects could be permitted to have magical features or students could be given the possibility of directly altering the environment.

Research in the field of human-computer interaction in recent years has focused on the metaphors of navigation and interaction. The papers by Bowman and Hodges (1999), Hand (1997), and Poupyrev and Ichikawa (1999) examine the latest interaction techniques developed for manipulating objects, navigation and control of the application in 3D virtual environments and propose methods of empirical evaluation of these techniques. Several authors, e.g. Stanney (1995), defend the need to create new visual, auditory and haptic metaphors for immersive virtual worlds[4].

Extending the initial design: a new metaphorical projection

Our preliminary design of the virtual environment for learning taxonomies is a very generic proposal and should be considered only as a starting point with many possible extensions, changes and improvements.

The network of cubes described above is a 'naked' skeleton and may be too abstract for younger students. It should be more made more visually appealing, engaging and familiar for children. For example, we could imagine and design other scenarios (a building, a tree, a mountain, a mine, etc.), albeit retaining the underlying network structure. Different sounds, colors and shapes could be added and used to distinguish ranks, categories or taxonomic units.

Depending on the age and background knowledge of the students, we could add many other elements or objects to better describe the classification and its characteristics: a 3D window map (to locate and visualize the habitat of the species), a clock of evolution (to measure the evolutionary changes in the species' history), a microscope (to view invisible features, like genetic properties) and so on.

Once students have learned the basics of classification, they are ready to act as taxonomists: they could design, build and modify their own classifications. For example:

- Re-build old classifications according to new criteria, such as shape, color, use of animals for human consumption (edible or not), habits or other structural information (morphology, anatomy, reproductive and vegetative structure).
- Group and classify species that no longer exist or animals that are extinct (dinosaurs, mammoths, dodos, etc.).
- Classify fantastic animals from literature or mythology (centaur, unicorn, etc.) or imaginary animals invented by the students themselves.

For students to be able to build new classifications, the metaphorical structure of the virtual environment must change slightly: from the initial scenario or spatial network to a manipulable puzzle. Although the skeleton remains the same, the scale or viewpoint is now more reduced: the cube network is converted into a 3D puzzle. Cubes are boxes, whose content, position and order in the network can be modified directly by the user, as if it were Meccano. Thus, students could re-build the structure and create new classifications.

A Cognitive Approach

This section addresses the foundation and justification of our ideas from the viewpoint of cognitive science. Firstly, we will defend the epistemological value and educational worth of metaphors. Secondly, we propose a new and original use of virtual reality as a technology for visualizing cognition. Finally, we will describe how the experientialist theories of cognition reinforce and justify our purpose of building metaphor-based educational environments.

Metaphor as a cognitive tool

Contemporary studies on metaphor have dropped aesthetic or rhetorical questions to focus on the reflection of their cognitive function. Almost all researchers now accept the idea of metaphor playing a structural role in organizing our conceptual system.

According to Radman (1997), metaphors cannot be dealt with exclusively as verbal instruments, since they are also instruments of thought. Metaphors are capable of transmitting new cognitive contents and serve as a cognitive key that can be applied universally across the boundaries of semantic areas, scientific disciplines and the domain of life experience.

Today's researchers consider metaphors as cross-domain mappings (Holyoak and Thagard, 1995; Lakoff, 1994). Metaphor can be used to see something through someone else's eyes and, therefore, structure and understand one domain in terms of another. According to Anderson (1983), all human learning is analogy based.

Metaphors are extremely valuable tools for improving learning: if we want to discover something new, we first have to be able to imagine this. Metaphors also have a heuristic value, as they are a means for our imagination to build clear ideas rather than vague concepts. Analogies and metaphors have the power to alter our conceptual systems and change the form in which students see the world.

Mayer (1993) explains how the metaphor that he refers to as instructive can make descriptions and scientific concepts easier to understand for students. Instructive metaphors can be used to associate and relate one domain with another and, at the same time, illustrate the problem-solving keys.

Virtual reality as visualization of cognition

Ever since it appeared on the scene, the aim of virtual reality technology has been to build synthetic worlds capable of simulating, representing or recreating the different faces and sides of reality. The virtual environments developed to date can be classed according to the type of visualization they use:

a) Visualization of things, objects, activities, scenarios or persons in virtual environments aiming at imitating reality; for example, buildings or architectural spaces for virtual walkthroughs, flight simulators, systems of telepresence for long-distance face-to-face communications, etc.
b) Visualization of information: text and documents, data and information bases; for example, virtual environments as information spaces, in which users can explore, retrieve, organize and browse a collection of references to information sources, located on the Web or elsewhere.
c) Visualization of knowledge is concerned with exploring information in such a way as to gain an understanding and insight into the data. It can be used to understand and solve scientific problems, look for regularities or connections, find hidden patterns in data and create new models. Scientific visualization in virtual environments is the art of

making the unseen visible: torsion forces inside a body, heat conduction, flows, plasmas, earthquake mechanisms, botanical structures or complex molecular models.

Our work aims to go one step further: to design and develop virtual worlds that provide visualization of cognition. This term, visualization of cognition, means the externalization of mental representations embodied in artificial environments.

We are interested in how to map mental contents into sensorial representations and experiences in a virtual world. Mental representations are the internal system of information used in cognitive activities (perception, language, reasoning, problem solving, etc.). These representations cannot be observed directly. However, we believe that their metaphorical embodiment in virtual environments could help users with cognitive disabilities (learning, categorizing or language problems) to experience representations through the senses and thus better understand them. Such environments could be fully explored, allowing users to (re)build their own cognitive model and enhance learning by means of the sensory interaction with the virtual model.

The embodied mind: a theory of the cognition as basis of our model

Throughout different publications (Lakoff and Johnson, 1980; Lakoff, 1987; Johnson, 1987; Lakoff and Johnson, 1999), Lakoff and Johnson have developed an experientialist theory of cognition known as the embodied mind or the embodiment hypothesis. These authors defend that the mind is inherently embodied and that abstract concepts are largely metaphorical. We took this as the underlying theory for our proposals[5].

The mind is embodied because both concepts and reason derive from and use the sensorimotor system. The mind cannot be conceived separately from the body. Thought requires a body in the sense that the real structure of our thoughts comes from the nature of the body. Most of our concepts are based on common bodily experiences. Lakoff and Johnson claim that categories, concepts and experience are inseparable. The categories that we form are part of our experience. They are structures that divide aspects of our experience into classes. For example, when we conceptualize categories, they are often conceived as a spatial metaphor, as if they were containers with an inside, outside and boundaries organized in complex hierarchies (note the similarity of this metaphor with the structure used in our case study).

Furthermore, abstract concepts are mostly metaphorical: most concepts heavily rely on basic metaphors based on bodily experience. Conceptual metaphors are mappings across conceptual domains that shape our thought, experience and language. Our learning and our understanding are structured in terms of concepts framed by our bodies.

Conclusions and Future Research Areas

The main contribution of this paper is to propose a model of virtual reality systems for education. This model aims to be universal, as it offers a framework – an independent architecture of external factors – that can be used in different scenarios.

The central component of the model is the metaphorical projection, which provides the guidelines for the entire virtual world design. The goal of metaphorical design is to create a semantic space[6]. All its elements are configured symbolically to make sense of an artificial environment that students can visualize and experience with their senses. The virtual environment thus becomes the physical representation of the knowledge to be taught. Students must perceive, assimilate and make sense of the stimuli from this environment. It is a question of interpreting or reading and not just sensing or experiencing the environment. This is the characteristic, which, in our opinion, distinguishes virtual reality as an educational technology: the possibility of creating symbolic spaces capable of embodying knowledge.

Lakoff and Johnson's experientialist theory defends that human beings' rationality cannot be dissociated from their bodily being. Our body and physical experience determine how we learn and reason. Our rationality is embodied: thought appears to be ineffable if it is not explained in bodily or physical terms. This theory justifies our interest in building metaphorical virtual worlds, where knowledge and learning are represented in an environment that must be interpreted through senses and bodily activity.

The model that we present here is only a preliminary approach and should be added to, verified and corrected by future research. Below, we propose a brief research agenda with some of the possible research areas:

- Design and implement a full prototype, a virtual reality system capable of demonstrating the pedagogical potential and possibilities of our model.
- Investigate evaluation techniques. How can the metaphorical design of a virtual reality system be evaluated? How can we find out whether the chosen metaphors are best suited for improving learning?
- Check whether other developed systems fit the model we propose. This experiment, implementation of a design *a posteriori*, would serve to verify and measure the universality or applicability of our model in implemented systems.
- Develop a full methodology for building educational virtual reality systems based on metaphorical design.
- Investigate whether learning with immersive virtual reality systems is qualitatively different from other forms of learning, like personal experiences (result of our everyday interaction with the world) or formal schooling. Does virtual reality herald a new educational paradigm, a new form of learning, or is it merely an educational aid for students?

Although, according to the current state of research, these questions cannot be answered in full, the solution of these problems is a scientific challenge of enormous interest and merits all our effort.

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Notes

1 Our model only considers fully immersive systems where students experience presence in virtual worlds through multisensory devices. We do not discuss here non-immersive systems that run on a desktop computer presenting 2D environments with which users can interact only by means of the mouse and the keyboard.

2 The object-metaphors can symbolise concepts, information or properties related directly to the underlying scientific taxonomy. The object-metaphors provide visual, sound and haptic clues and can be linked or united with other symbols, images, videos, animations, maps, sounds, texts (or voice) to rule any misinterpretation of their meaning. In any case, the teacher can always offer guidance and additional information.

3 Constructivism has been the most commonly used learning theory in virtual environments for education. The main pedagogical benefits offered by this theory in the design and use of virtual reality tools have been studied and described by different researchers (Youngblut, 1998), (Osberg, 1997), (Winn, 1997).

4 Some new metaphors have been designed for user interfaces in virtual reality systems and several specific techniques have been implemented in prototypes and commercial applications. For example, Fairchild, Hai *et al.* (1993) proposed the 'Flying hand', 'Floating guide' and 'Lean-based' metaphors. Ware and Osborne (1990) implemented 'Eyeball in hand', 'Environment in hand' and 'Flying vehicle control'.

5 Lund and Waterworth (1998) previously proposed the use of Lakoff and Johnson's theories as a basis for what they call 'experiential interface design', which tries to reflect embodiment at the human-computer interface. They illustrated their ideas with SchemaSpace and Personal Spaces (Waterworth, 1997), two virtual environments for visualizing information.

6 There are many examples of symbolic spaces in different cultures and times. We can give three significant examples: (i) Australian aborigines view their country as an immense musical score: wherever they go, they can sing immemorial songs that (re)create the landscape and grant territorial rights. The holy song is also a map and a means of guidance and communication between far-off tribes (Chatwin, 1997); (ii) Yates (1984) described what were known as 'palaces of memory', mnemonic systems created in Ancient Greece. If you want to remember something, you imagine a space (a house with rooms, a theatre, etc.) that you use as an artificial memory in which you order all the things you want to memorize. All you have to do to recall everything that you memorized is to go for an imaginary walk through the scenario in the right order; and (iii) the religious building was something more than a meeting place for believers in the Late Middle Ages in Europe. Gothic churches and cathedrals also symbolized and were a material reproduction of heaven, a heavenly city. But what is absolutely new is the emergence of a technology, virtual reality, which can be used to build fictitious virtual worlds (with unique characteristics, even unparalleled in the real world), where it is possible to experience sensorially a physical space and also a metaphorical space (a semantic space that embodies, represents a meaning).

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