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Theoretical Bases for Using Virtual Reality in Education

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Abstract

This article elaborates on how the technical capabilities of virtual reality support the constructivist learning principles. It introduces VRID, a model for instructional design and development that offers explicit guidance on how to produce an educational virtual environment. The define phase of VRID consists of three main tasks: forming a participatory team, analyzing the appropriateness of employing virtual reality technology to tackle a known learning problem, and performing a feasibility study. The design phase of VRID comprises the macro-strategy that provides guidance on the selection, sequencing, and organization of the subject-matter topics that are to be presented, and the micro-strategy that provides strategies for effective presentation of the learning contents. The development phase includes all the necessary tasks to implement the outcome of the design phase. Among the tasks for this development phase include determining the developmental platform, developing the various components of the educational virtual environment, performing specialist evaluation as well as conducting one-to-one learner evaluation. Conducting a small group evaluation and performing an effectiveness evaluation study are the two important tasks of the evaluation phase.

Introduction

Virtual reality technology offers various capabilities that are able to provide promising support for education. Some of these capabilities include the ability to allow the learners to visualize and interact with the three-dimensional virtual representation, experience the virtual environment in real-time, visualize abstract concepts, articulate their understanding of phenomena by constructing or manipulating the virtual environments, visualize the dynamic relationships between several variables in a virtual environment system, obtain an infinite number of viewpoints of a virtual environment, allow individuals to interact with each other in collaborative virtual environment, as well as visit and interact with events that are unavailable or unfeasible due to distance, time, cost, or safety factors. With such capabilities, in which some are unique to this particular technology, virtual reality offers many educational benefits that if appropriately implemented will bring a positive impact to its application to education.

A high-fidelity virtual reality system, such as the immersive system, tracks a learner's movement and maps it onto the virtual setting. The learner interacts and experiences the three-dimensional virtual environment that provides visual, auditory, haptic and/or kinesthetic feedback in real-time. Such rich experience and the fact that the learner is technically immersed make possible the creation of unique and impressive learning systems. Nevertheless, the need for costly and cumbersome head-mounted displays, gloves, and tracking systems, as well as high-end computer systems has somehow restricted virtual reality's ubiquitous use in education.

A non-immersive virtual reality system, or sometimes known as a desktop virtual reality system, provides an alternative, although not entirely, to the immersive set up. Such a system uses the affordable personal computer to generate the three-dimensional virtual environment and display it on a computer monitor, which is a perspective display. In perspective displays, three-dimensional information is projected onto a two-dimensional surface (display screen), and thus requires the viewer to imagine the three-dimensional representation from a two-dimensional projection (Neale, 1997). However, the viewer may utilize stereo glasses to obtain a stereoscopic view of the virtual environment. Human interaction with the generated virtual worlds can be performed via input devices, such as mouse, keyboard, 3D mouse, joystick or game-controller. As this type of virtual reality system is relatively low cost, it makes this technology feasible to be widely utilized for educational purposes. Nonetheless, it is unable to provide the kind of immersion and experience as the ones offered by the immersive system.

Connecting individual virtual reality systems to the network allows learners, either at a different or the same geographical location, to interact and experience the same virtual environment. These learners work together in the shared environment and the results of any action taken by a learner will be observable by all other learners, which may then affect their subsequent behavior in the virtual environment. Hence, such a networked virtual environment allows mimic to real-world type of collaboration, which if properly designed, will without doubt benefit collaborative and active learning.

Theoretical foundations of virtual reality learning

Virtual reality technology demonstrates various unique capabilities that depict brilliant technical accomplishments. This technology continues to advance rapidly and to provide even more capabilities, which may eventually make possible the creation of new learning experiences and opportunities. Indeed, among educators, the introduction of virtual reality technology in education brings about excitement and high expectation of its capabilities. Nevertheless, it is important to note that this technology is merely a tool. Tools by themselves do not teach. They have to be carefully and effectively implemented to assist in the learning process. To date, the theoretical foundations of using virtual reality in education are not widely addressed. Indeed, studies to gain more insights into such theoretical foundations are indispensable to enable effective, efficient, and appropriate utilization of the technology for education purposes.

How does virtual reality support constructivist learning?

The constructivist philosophy holds that knowledge is constructed through an individual's interaction with the environment. Constructivism is not a new theory. The core ideas of this theory have existed for over a century, with Jean Piaget and John Dewey as among the first few to develop a clear idea of it. As opposed to behaviorism that holds to knowledge reproduction, constructivism as a learning theory emphasizes the combination of inputs from the senses, existing knowledge, and new information to develop new meaning and understanding through active, authentic, cooperative and reflective learning activities.

Jonassen, Hernandez-Serrano, and Choi (2000) and Greening (1998) list virtual reality as one of the technologies that can support constructive learning. Virtual reality provides a controlled environment in which learners can navigate, and manipulate the virtual objects found within, and more important, the effects of such interaction can be observed in real time. Virtual reality is therefore very well suited for providing exploratory learning environments which enable learners to learn through experimentation. Generally, constructivists believe that learners can learn better when they are actively involved in constructing knowledge in a learning-by-doing situation. Winn (1993) highlights that the characteristics of virtual reality and the axioms of constructivist learning theory are entirely compatible, and asserted that constructivist theory provides a valid and reliable basis for a theory of virtual reality learning.

Bricken (1990), Chen and Teh (2000), Neale, Brown, Cobb, and Wilson (1999), and Winn (1993) are among others who further point out how the various capabilities of this technology can support constructivism. The following section elaborates how virtual reality technology can support this learning theory, founded primarily on the constructivist learning principles as proposed by Jonassen (1997).

Problem

According to Jonassen (1997), it is crucial to provide problems to the learners in constructivist learning environments as they learn through their attempt to solve the problems. Constructivism also holds to the principle that learning is contextual. As stated by Hein (1991), learning cannot be separated from our lives. Thus, a constructivist learning environment needs to provide adequate description and/or depiction of the contextual factors that surround a problem so that the learner can understand it. Constructivism also stresses the importance of presenting an authentic problem; a problem that is similar to the one that exists in the real world. Jonassen (1997) also points out the necessity for presenting such an authentic problem in an appealing and interesting way. The understanding of the problem context, and the authenticity as well as the attractiveness of the problem, may help the learner to value its importance and relevancy, which may eventually lead to higher motivation and engagement in finding the solution for the problem.

Virtual reality in this regard could present a three-dimensional representation of a problem in the form of visual, auditory, tactile and/or kinesthetic. It allows the simulation of real environments that mimics the real world environments or artificial environments which simulate aspects of the real world that are inaccessible through direct experience. Such problem representation is definitely more appealing, interesting and engaging compared to other representation methods, such as in narrative, text, or picture form, as it stimulates most of the senses that a human uses when dealing with real-world environments.

The contextual factors that surround the problem may be depicted in the virtual environment itself. Nevertheless, most current virtual reality systems also allow other representation methods to be incorporated into them. Hence, problem context can also be explained using text, narration and/or picture. In addition, the complexity of the represented problem can also be adjusted to scaffold the learning process. Alessi (1988) suggests how the level of fidelity affects learning. For example, simplifying the complexity of a simulated problem, which also means reducing its fidelity, will produce better learning for a novice learner than a very high fidelity simulation (Alessi, 1988). Reduced fidelity in such representation directs the learner's attention to elements of primary importance (Salis & Pantelidis, 1997).

Manipulation of virtual representation

Jonassen (1997) states that constructivist learning is not the passive acceptance of knowledge but requires a learner to manipulate something such as constructing a product, manipulating parameters or making decisions. To engage the learner in meaningful learning, learning must be an active process in which the learner uses sensory input and constructs meaning out of it. Jonassen (1997) asserts that an engaging problem manipulation space should provide a realistic physical simulation of the real-world task where the learner can directly manipulate or explore the objects or activities in the problem space, and receive feedback as a result of their manipulation through changes in the physical appearance of the objects or in the representations of their actions. Sometimes, it is also necessary to create a problem manipulation space that allows the learner to articulate his or her solutions to problems.

A virtual environment provides a problem manipulation space that allows the learner to freely explore and manipulate the virtual objects within the environment. Unlike many other educational tools, a virtual environment is designed without a specified sequence. Its focus shifts from the design of prescribed interactions with the learning environment to the design of environments that permit the student to experience any kind of interaction the system is capable of. This complies with the learner-centered approach where the learner can keep control over what he or she wants to explore or manipulate. In other words, the learner can choose to navigate through the simulated environment or interact with the objects of his or her interest for further observation. In doing so, the learner may make mistakes and wrong predictions and these experiences are the conditions for modifying existent knowledge and thus constructing new knowledge (Dijkstra, 1990).

A virtual environment allows the learner to control and interact directly with objects within the virtual world. Such control and interaction, together with free exploration, provide a greater sense of empowerment. Bricken (1990), Chen and Teh (1998), Johnson et al. (1998) and Pantelidis (1996) are among those who assert the potential of virtual reality to produce a strong positive emotional reaction. The learner feels free and empowered. Moreover, it also offers flexibility for repetition and self pacing. All these factors contribute to motivation, which is a key component to learning. This once again complies with another principle of constructivist learning environment that specifies the need to grant learners with responsibility for the learning process to create understanding (Jonassen, 1991).

Navigation through the virtual environment

Learners can also learn from the process of visiting or exploring the virtual environment. A learner who navigates through a virtual environment can gain valuable virtual experience, thus enabling discovery or experiential learning. A textual description, for instance, requires reading skills, a picture can be recognized immediately but is not interactive, but a physical space allows the user to explore and walk through it. More important, it has natural semantics that provide meaning to the user without any explanation. This virtual experience supports the constructivist point of view that emphasizes understanding is tracked by experience.

An obvious advantage of virtual reality is that this technology allows a learner to experience environments, which cannot be experienced in real world due to cost and/ or risk factors. In other words, it allows the learner to assess things that are unreachable or unrealizable in the physical world. If the constructivists' interpretations are valid, creating a virtual world that allows the learner to explore and interact with the information will enable the learner to learn much more about the knowledge domain than other methods that passively present the information to him or her (Byrne, 1996).

Multiple perspectives

A unique feature of virtual reality technology is that it allows a learner to obtain an infinite or unlimited number of viewpoints of the three-dimensional environment. The learner is able to view things from all three dimensions, as well as both inside and outside. This definitely includes physically impossible viewpoints. As pointed out by Duffy and Jonassen (1991), there are many ways to structure the world, and there are many meanings or perspectives for any event or concept. Such a feature complements the constructivist theory of learning because it enables the learner to have multiple perspectives of the world and thus encourages diverse ways of thinking.

Related situations and rich information

Constructivists believe that one needs knowledge to learn. It is impossible to assimilate new knowledge without having some structure developed from previous knowledge to build on (Hein, 1991). Therefore, it is important that constructivist learning environments provide access to a set of related experiences or knowledge that a learner can refer to. Rich sources of information are also essential in constructivist learning environments to assist the learner to build the internal representation of their thought processes and subsequently direct the manipulation of the problem space (Jonassen, 1997).

Indeed, a virtual environment in itself naturally contains information needed by the learners. The development of virtual reality on the web, specifically in the non-immersive system, allows other relevant information from the World Wide Web, the huge information bank, to be linked to the virtual environment. This provides access to various related multimedia resources available on the web that could assist the learner to construct his or her knowledge.

Cognitive tools

Jonassen (1997) also stresses the importance of providing cognitive tools, which are tools to assist the mental processes, in constructivist learning environments. A virtual environment can serve as an excellent visualization tool, as it enables the learners to visualize the three-dimensional representations of a problem or simulated environment and present abstract information in a more cognitively accessible format. Thus, it helps to reduce the learner's cognitive load in constructing mental images and performing visualizing activities. Conversely, if the learner is presented only with the two-dimensional representations of an object or problem that is three-dimensional in nature, he or she will be demanded to mentally reconstruct the three-dimensional shape from the two-dimensional sections. This task will entail the knowledge of isometric, parallel and perspective projection, elevations, materials, dimensioning and so on.

A virtual environment can also be used to make the abstract more concrete and visible by providing symbols not available in the non-symbolic real world. Focus can be given on salient aspects of a situation, so learners do not get lost in complexity. In other words, the virtual environment is a cognitive tool that is capable of making imperceptible things perceptible as well as the contrary. Virtual environments also allow the learner to visualize and understand complex structures that would otherwise remain hidden. In a virtual environment, a learner can get infinitely close to an object to see the details or far from it to obtain an overall view of the environment. Such variation in the level of details can significantly aid the learning process because objects and processes could be studied in detail, in isolation, in close-up or at a distance.

As learners study phenomena in a constructivist learning environment, it is important that they articulate their understanding of the phenomena (Jonassen, 1997). According to this learning theory, learning is not instantaneous. For significant learning, learners need to re-examine ideas, contemplate on them, and test them out. A virtual environment supports this principle of learning because it can always be customized to allow the learners to construct a new environment from within the existing virtual environment. This means this technology could serve as a design tool to allow the learners to articulate their understanding of a phenomenon. The virtual environments can also always be configured to allow repetitive testing of ideas, and even preprogrammed to automatically correct any error done by the learner while constructing the environment.

As mentioned earlier, it is important to provide an authentic representation in a constructivist learning environment. Authentic representation, which is often complex, may contain elements that are related and mutually dependent. Virtual environments can be used to simulate the dynamic relationships of these elements where the learner can interactively control the values of the parameters or variables of a simulation, test the simulation model, and observe the effect on the virtual environment. This allows the process of discovering the cause and effect relationships. This discovery process allows the learner to reevaluate what they know and to change their understanding based on what they have directly learned/observed from the environment (Osberg, 1997). In addition, virtual reality could also create a more realistic simulation because of its physically based modeling functionality. In general, physically based modeling is modeling that incorporates physical characteristics into objects, allowing numerical simulation of their behavior.

Collaboration

Constructivists believe in the collaborative nature of learning. Learning occurs when a group of learners work together to solve problems (Jonassen, 1997). In other words, learning is a social activity where teamwork and mutual exploration is important. Hence, according to Jonassen (1997), constructivist learning environments should provide access to information and cognitive tools to assist learners to collaboratively create meaning through their interactions with each other and with these tools.

This complies with the concept of distributed virtual environments where a group of learners, who may be either co-located or at a distance, share the same virtual environment or problem manipulation space. With this new development, all other learners could view ideas articulated by a learner in the virtual environment, and they collaboratively construct knowledge through conversations about what they are learning. The group of learners may collaborate through synchronous and/or asynchronous communication. Examples of synchronous communication include real-time text and/or audio chatting and desktop video conferencing, while written and/or auditory message, or even virtual action, could be left for someone who will later join the virtual environment; e-mail as well as newsgroups are classified as asynchronous communication since the conversations do not occur in real-time.

Table 1 provides a summary of the constructivist learning principles as indicated by Jonassen (1997) and how virtual reality technology can support them.

Table 1. How do the technical capabilities of virtual reality support the constructivist learning principles?

Constructivist Leaning Principles	Technical Capabilities of Virtual Reality
Interesting, appealing, and engaging problem representation, which describes the contextual factors that surround the problem	• Can present problem in a shared three-dimensional environment that simulates aspects of the real world
Multiple perspectives, themes, or interpretations of a problem to encourage diverse ways of thinking	• Can provide unlimited number of viewpoints of the three-dimensional environment • Can provide an independent controlled viewpoint for each learner • Can exclude secondary elements in the virtual environments that may divert the learner's attention from the elements of primary importance
Active learning – learner uses sensory input and constructs meaning out of it	• Can provide a problem manipulation space that allows free exploration and manipulation. Feedback/Interaction can be observed through visual, auditory, tactile, and/or kinaesthetic cues by other participating learners

(continued)

Table 1. ***(continue)***

Constructivist Leaning Principles	Technical Capabilities of Virtual Reality
Understanding is tracked by experience	• Can provide virtual experience instead of words or pictures. Virtual experience has natural semantics that provide meaning to the learner without any explanation
Instruction cannot be designed – learners construct their own knowledge	• Virtual environment is designed without a specified sequence – permits any kind of interaction the system is capable of
Rich sources of information	• Virtual environment in itself naturally contains needed information • Can also be complemented with other computer-supported collaborative learning tools to provide other relevant information (e.g., World Wide Web)
Cognitive tools – intellectual devices used to visualize, organize, automate, or supplant information processing	• Can act as visualization tool, modeling and design tool, dynamic modeling tool, and automation tool
Conversation and collaboration tools – access to shared information and knowledge building tools to help learners collaboratively construct socially shared knowledge	• Can provide a shared space for a group of learners, either co-located or at a distance, to collaboratively construct knowledge through synchronous and/or asynchronous communication • Can incorporate virtual bodies (embodiments) to improve the realism of the collaboration process.

Although virtual reality technology is able to support constructivist learning, constructivism should not be seen as a panacea that works for all kinds of educational virtual environments. It may be appropriate for certain learning situations, some types of learning, and some learners, but not all. Indeed, a perfect learning theory that is suited for all learning conditions is unavailable. Each educational philosophy, ranging from behaviorism, through cognitivism, to constructivism, has its own advantages as well as limitations. Hence, learning systems that are designed based on an eclectic approach that selectively combines behavioral, cognitive, and constructivist principles will be more appropriate to ensure learners obtain the desired learning outcomes.

VRID – Instructional design and development model for educational virtual environments

It is undeniable that many existing systems have demonstrated the benefits and values of implementing educational virtual environments. However, few studies focus on deriving the underlying theoretical framework that can guide the design of effective educational virtual environments. As pointed out by Reigeluth & Frick (1999), more instructional design theories (or models) are needed to provide guidance on the use of new information technology tools. Hence, the pertinent question would be how to design instruction to enable the effective utilization of the virtual reality capabilities to support the desired outcomes. What are the appropriate theories and/or models to guide the design and development of such learning environments, so that the resulted learning environments are compatible with human learning?

An instructional design theory/model comprises a set of practical procedures, which takes into account principles of human learning for the design of effective instruction that helps learners to best attain a given goal (Gagné & Briggs, 1974). While an instructional design theory/model prescribes instructional methods to optimize desired instructional outcomes (Reigeluth, 1999), an instructional development model (also known as instructional design process) relates to the process an instructional designer should use when planning and preparing an instruction (Reigeluth, 1999).

VRID is an instructional design and development model that offers explicit guidance on how to produce an educational virtual environment.

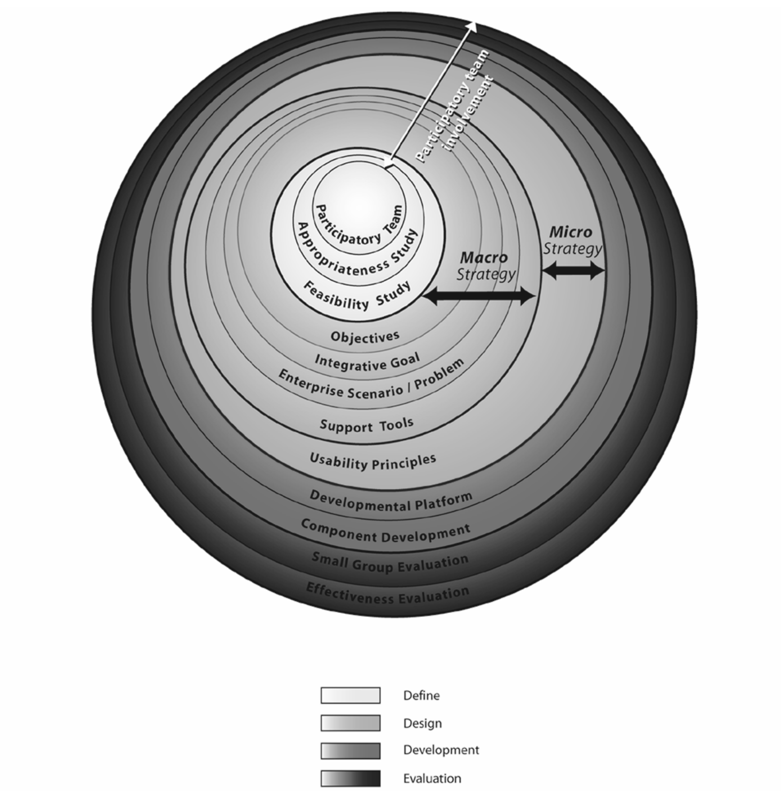

Figure 1. The VRID instructional design and development model.

Figure 1 depicts the VRID instructional design and development model. The smallest circle at the centre of the illustration marks the starting point of the instructional design and development process. A user of the model is expected to perform tasks specified in the innermost ring, the define phase, followed by the instructional steps of the design phase, and then the tasks pointed out for the development phase, and finally the evaluation phase in the outermost ring. Nevertheless, the involvement of participatory team members throughout all these phases provides continuous feedback that will most likely cause some tasks and/or phases to be attended to a few times and in any order. Consequently, the instructional design and development process does not occur linearly from the innermost ring to the outermost ring. Instead, the user needs to switch from one task or phase to another, although the starting point is the define phase in the innermost ring and the ultimate target is still the evaluation phase in the outermost ring.

The four phases of VRID

Define

The define phase of VRID consists of three main tasks: forming a participatory team, analyzing the appropriateness of employing virtual reality technology to tackle a known learning problem, and performing a feasibility study.

Participatory team. The first task is to form a participatory team whose members are to actively participate and collaborate in the design and development process. This participatory team is led by a manager who holds the key role in coordinating the collaborative work among the team members, who often consist of subject matter specialist(s), instructional design specialist(s), interface design specialist(s), technical specialist(s) and potential learners.

A subject matter specialist is a person who is knowledgeable about the subject and responsible for ensuring the appropriateness as well as the accuracy of the learning content. An instructional designer guides the design of the educational virtual environment, based on the macro-strategy as described in the design phase, while an interface design specialist focuses more on the micro-strategy to ensure the developed environment is usable. A technical specialist provides necessary skills and knowledge to develop the various elements of the educational virtual environments, which may include modeling of three-dimensional objects, assembling these objects into a virtual environment, writing programming codes to incorporate behavior to the objects, configuring the tracking systems and peripherals, and any other tasks to realize the intended environments. The involvement of potential learners is also crucial as it leads to the creation of educational virtual environments that take into account the learners' existing skills and knowledge, expectations, learning preferences, and motivation level, as well as other general characteristics such as age, gender, education level, reading ability and relevant work experience. Different members may be involved at different points during the design and development process, with the manager bearing the responsibility to ensure effective communication among them.

Appropriateness study. The involvement of subject matter expert(s) and possibly the instructional design expert(s) to analyze the appropriateness of employing virtual reality technology to tackle a known learning problem is important in the define phase. Although the virtual reality technology depicts various impressive technical capabilities, it should not be viewed as a solution that works for all kinds of learning problems. Learning problems that are appropriate for virtual reality implementation should possess characteristics that can be supported by the virtual reality technology.

Virtual reality can be suitable for learning problems that require three-dimensional representations, as this technology is inherently three-dimensional. Such three-dimensional representations mimic the real world representation, and hence are able to provide a more intuitive understanding to the learners. A virtual environment also can also be customized to allow a learner to construct a new environment from within the virtual environment. In other words, this technology allows a learner to articulate his or her understanding of a phenomenon and thus, will be well fitted to learning problems that require such conditions.

Virtual reality can also be appropriate when a simulation is to be used. This technology is capable of representing the dynamic relationships in a system by building simulations of those systems. In addition, virtual reality can be used to produce a more realistic simulation by incorporating physically based modelling in the environment. Another unique feature of virtual reality, which is unavailable in any other traditional instructional media, is the ability to provide an infinite or unlimited number of viewpoints of the three-dimensional environment to a learner. Thus, virtual reality is appropriate for learning problems that require the learner to take different views of the virtual environments to enable him or her to comprehend the learning problems from various perspectives.

Virtual reality is also appropriate for experiential learning. This technology allows the learner to control the navigation and interact directly with the objects within the virtual environment as well as to experience total immersion in the case of immersive systems, allowing him or her to not just view but also experience the environment. In another words, this technology suggests the potential for an entirely new form of experiential learning. Such control and interaction, together with free exploration, also provide a greater sense of empowerment, which makes a virtual environment very well suited for the learning problems that need to engage learners to learn through learner-centered activities.

Virtual reality may also be appropriate when learning problems require the use of a real object that is hazardous, unfeasible, inconvenient, and/or costly, as well as when the use of other methods can lead to misunderstanding of the concepts that are to be delivered. In short, learning problems that are best to be implemented using virtual reality technology should require the use of the unique attributes and capabilities offered by this technology.

Feasibility study. If a learning problem is found to be appropriate to be implemented using virtual reality technology, the next task is to evaluate the feasibility of such implementation. Technical feasibility assesses the availability of the necessary hardware set up, such as computers, virtual reality peripherals, and networks, as well as the necessary software that usually focuses on the operating system for the targeted learners. If the needed hardware and software are unavailable or the existing hardware and software are inadequate, then it is crucial to perform a financial feasibility study to determine whether adequate financial resources are available to realize the needed set up. Regarding the social aspect, the competence of the technical staff to maintain the technical setting, and the capability of the educators to manage and employ the virtual environments, as well as the readiness of the learners to use this method of learning, should also be assessed.

Design

The strategies involved in the design of learning activities can be divided into macro-strategy and micro-strategy (Reigeluth & Merrill, 1978). The design phase of VRID comprises both these strategies.

Macro-strategy. Reigeluth and Merrill (1978) relate macro-strategy to the selection, sequence, and organization of the subject-matter topics that are to be presented. The macro-strategy of VRID takes an eclectic approach that combines principles from different theories (Alessi & Trollip, 2001). With such an approach, the concept of integrative goals as proposed by Gagné and Merrill (1990) is combined with the model for designing constructivist learning environments as proposed by Jonassen (1999). The concept of integrative goals is behaviorist in nature and a number of cognitive principles, such as those related to attention, perception, motivation, locus of control, and active learning are inherent in the virtual environment itself. Nevertheless, the constructivist paradigm stands dominant in this macro-strategy as it is in accord with the new paradigm of instruction, and more important, as elaborated earlier, many characteristics of virtual reality are found to be compatible with the constructivist learning principles.

Constructivists believe that learning goals cannot be fully pre-specified apart from the actual learning context (Wilson, 1997). According to Wilson, in postmodern instructional design, goal analyses often cannot identify the content. Instead, rich learning experiences and interaction in which learners can grasp on their own the content missing between the gaps of analysis should be designed. Thus, for this macro-strategy, the concept of integrative goals (Gagné & Merrill, 1990) helps to determine integrative goals and its associated enterprise schemas. Based on the identified integrative goals and enterprise schemas, a rich and interactive educational virtual environment is then designed as guided by the constructivist learning environments design model (Jonassen, 1999) to enable learners to have a more complete understanding of the contents.

This macro-strategy suggests that the design process begins by following Gagné & Merrill's (1990) concept of integrative goals, which involves identifying the individual learning objectives and then the relationships among these objectives to derive the integrative goal. These objectives may fall into the category of verbal information, label, intellectual skill, or cognitive strategies. The next step involves designing instruction that allows the learner to acquire the capability of achieving this integrated outcome, which is known as the enterprise scenario.

This enterprise scenario is somewhat similar to the problem posed in a constructivist learning environment as proposed by Jonassen (1999). Jonassen (1999) asserts that a problem in a constructivist learning environment consists of three integrated components: the problem context, the problem representation, and the problem manipulation space. Basically, this step involves selecting the problem context, problem representation and problem manipulation space that help in achieving the integrated goal. The virtual environment represents the problem as well as provides a space for the learner to perform learning activities. The design process continues by providing various necessary supports that may assist the learner to actively construct their knowledge in the learning environment. These supports include related situations, information resources, cognitive tools, and/or collaboration tools.

Micro-strategy. Having completed the design at the macro level, focus is shifted to the micro-strategy. Micro-strategy basically relates to the strategies for effective presentation of the learning contents. It concerns primarily the usability of the learning environment design in which the burden on the learner's cognitive load for operating the learning environment is kept minimal. In an immersive system, usability issues such as those reported in Stanney, Mourant and Kennedy (1998) to ensure effective and easy navigation through virtual environments, intuitive and efficient interaction with virtual object and avatars, and minimum occurrence of motion sickness, discomfort, harm, or injury for learners of different characteristics have to be taken into account. As for a non-immersive system, the possible integration of multimedia messages with the virtual environments has made principles for the design of multimedia instructional messages, such as those derived from the cognitive theory of multimedia learning (Mayer, 2002) to be very much applicable. In addition, research studies, such as Chen and Wan (2008), aim to derive more design principles that are particularly related to the non-immersive virtual reality system.

Specialist evaluation. The involvement of specialists, particularly the instructional designer and the interface design specialist, may cause the macro as well as the micro structure of the learning environment to be revised accordingly. The subject matter specialist reviews the accuracy, significance, sequencing, currency and comprehensiveness of the content; the instructional designer evaluates the materials against the macro- and micro-strategy; while the interface design specialist examines the interface and judges its compliance with recognised usability principles.

Development

The development phase includes all the necessary tasks to implement the outcome of the design phase. Among the tasks for this development phase include determining the developmental platform, developing the various components of the educational virtual environment, performing specialist evaluation as well as conducting one-to-one learner evaluation.

Developmental platform. An important task of this phase is to determine the developmental platform, which includes both the hardware and the software components. Ideally, the selection of the developmental platform should be primarily based on the requirements of the learning problem to ensure optimum learning. For example, if immersion is crucial in conveying a concept, then an immersive system should be selected. Nevertheless, in real practice, various constraints such as financial availability to procure most appropriate hardware and/or software system, technical know-how with respect to the request to use the existing hardware and/or software systems, and/or time constraints may result in the selection of a less ideal developmental platform. In such cases, participatory team members should critically analyze the trade-off due to the constraints and then decide on the most appropriate developmental platform or otherwise temporarily terminate the project until crucial constraints are lifted.

Component development. Another important task of this phase is to develop the components of the educational virtual environment. These components may include the interface design, scenario design, and instructional design. Interface design focuses on the look and feel, interaction modalities, navigation, metaphor, help, and support. Scenario design relates to the three-dimensional virtual objects, and their relationships and behaviors, as well as how they are assembled to form the required virtual scenario, while the instructional design component emphasises the work to integrate the interface design with the scenario design, primarily based on the proposed macro strategy.

Specialist evaluation. Members of the participatory team are involved at different stages of the design and development process. Subject matter specialist(s), instructional design specialist(s), interface design specialist(s), and technical specialist(s) are often very much involved in the design and development of the various design components. Having these specialist(s) to continuously review the developed components creates opportunities for them to ponder upon the appropriateness as well as the accuracy of their earlier design. The specialist evaluation process involves choosing the components to be evaluated, preparing the evaluation questions, designing data collection tools, and managing the actual evaluation. This evaluation process often leads to redesigning and redevelopment of the components as unforeseen problems at the earlier design phase are usually uncovered during the actual development process. Such an evaluation, redesign, and redevelop cycle is iterated until the evaluated components are revised to a satisfactory level.

One-to-one learner evaluation. One-to-one learner evaluation involves individual typical learners reviewing a fully or partially developed educational virtual environment. In such evaluation, one learner is involved at a time and much interaction occurs between the learner and the evaluator. Often, a series of two to four evaluations is conducted, which also implies that this type of evaluation is performed iteratively. The evaluation cycle continues until few revision suggestions are received from learners.

This evaluation aims to gather feedback on the clarity, completeness and appropriateness of instruction, clarity of directions, adequacy of visual, aural, haptic and/or kinaesthetic quality, ease of navigation and interaction procedure, as well as any other matters that the learners perceive as unmotivating or impeding their learning process. Information can be collected through learner's comments, interviews, and observations. The steps involved in conducting this evaluation include preparing evaluation questions, designing data collection tools, preparing the learner for the evaluation session, managing the evaluation session, debriefing the evaluation session, reviewing the evaluation data, revising the educational virtual environment, and repeating the cycle until its final iteration.

Evaluation

The evaluation phase consists of two important tasks: conducting a small group evaluation and performing an effectiveness evaluation study.

Small group evaluation. A task of this evaluation phase, prior to the actual summative evaluation session, is to conduct a small group evaluation, commonly known as a pilot study. Unlike specialist evaluation and one-to-one evaluation, interaction between the person who conducts the evaluation and the learners is kept to a minimum in the small group evaluation. The instruction is administered in an environment similar to one used in the 'real world' and in a realistic manner. Small group evaluation involves a group of representative learners and focuses on learner performance data, which is usually obtained through a properly designed test, to confirm revisions made after previous specialist evaluation and one-to-one evaluation of the educational virtual environment. The learners' failure to achieve the required performance may provide clues to the specific problems of the educational virtual environment, and these problems should be fixed accordingly.

This small group evaluation also serves to provide feedback on the appropriateness of the actual evaluation procedure, such as the amount of time needed for the virtual reality learning session, the clarity of the instructions given to the learners, and the need and/or the way to provide navigation training to the learners prior to the learning session. In addition, it is also meant to check the reliability of the test that will be used to measure the learners' performance.

Effectiveness evaluation. While specialist evaluation and one-to-one learner evaluation focus on the revisions needed to improve the educational virtual environment during the design and development process, the evaluation phase that involves a bigger group of targeted learners helps to inform the learning effectiveness of the developed educational virtual environment.

An experimental evaluation study to derive and confirm the design principles of effective educational virtual environment, as well as a study that looks into the effect of situationalities, such as the effects of individual differences on these principles, are crucial. On the other hand, studies that compare the effectiveness of virtual reality-based methods with other methods for delivering a specific skill or knowledge, as well as meta-analysis studies that aim to identify trends in findings across these studies, should be kept minimal, as such studies may not be contributing much toward the effective use of this technology in education.

Distinct features of VRID

The following describes the three distinct features of VRID.

Instructional design and development model

VRID advises on both the instructional design of educational virtual environments as well as on the process of designing and developing them. It offers explicit guidance on the instructional actions to be taken in order to design educational virtual environments that can better help human learning. In addition, it also provides guidance on the process of designing and developing the environments.

Ongoing participatory team involvement

Communication and collaboration among participatory team members form a critical aspect of the model. This model suggests such communication and collaboration should occur during all the different phases, and the outcome of this process serves as an important feedback to improve the educational virtual environment.

Non-linear and dynamic

The instructional development component of VRID lays emphasis on an iterative and reflective process, which is similar to the concept of the Recursive, Reflective Design and Development (R2D2) model, a model put forward by Willis (1995) and later revised in Willis and Wright (2000). Such process leads to non-linearity in terms of the tasks taken. In other words, instead of accomplishing each task once and according to the phase-by-phase sequence, it follows a more creative and dynamic approach to design. The involvement of the participatory team in all the different phases provides the possibility to take up a task in any required order. Feedback from the instructional design experts at the design phase, for example, may point to the need to redefine the integrative goal at the define phase. Similarly, findings from the pilot evaluation study may point to the need to redesign the interface of the educational virtual environment. As a consequence of this non-linearity, some tasks may be addressed many times during the design and development process.

Conclusions and future fundamental research endeavors

This article explains constructivism as the underlying learning theory that fits well with the characteristics of virtual reality technology. Founded on this learning theory, VRID is suggested as an instructional design and development model to guide the design and development of educational virtual environments. Although the four phases of the model are described one after another in an ordered sequence, the model holds to the concept of non-linearity and flexibility in which reflections from the participatory team are crucial to determine the exact sequence of tasks being taken.

To date, the theoretical issues of using virtual reality in education are not widely addressed. Indeed, to enable effective and proper infusion of such technology into an education setting, more fundamental research, such as design-based research that aims to generate theories on virtual reality learning, should be further encouraged. In such research, various aspects of the designed learning environment are adjusted and tested in their naturalistic contexts (Barab & Squire, 2004) in the effort to derive a general theoretical framework. Research should also focus on identifying the advantages of virtual reality methods, devising innovative methods that employ the unique features of this technology, and figuring out the approaches to implement this technology that can help to improve the quality of education as well as to direct the proper use of virtual reality.

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