Effects of Time in Virtual Reality Learning Environments Linked with Materials Science and Engineering

J. Extremera[1], D. Vergara[2(✉)], M. P. Rubio[1], L. P. Dávila[3], and F. De la Prieta[1]

[1] University of Salamanca, Salamanca, Spain
{jamil.extremera,mprc,fer}@usal.es
[2] Catholic University of Ávila, Ávila, Spain
diego.vergara@ucavila.es
[3] University of California at Merced, Merced, CA, USA
ldavila@ucmerced.edu

Abstract. The increasing presence of virtual reality learning environments (VRLEs) in university classrooms makes it necessary to study what factors influence the effectiveness of this type of teaching tool. In particular, when planning to use a VRLE in class to support the classes, a careful design of the application to achieve a high level of efficiency at the formative level must be carried out. This article discusses key aspects that need to be taken into account during the design of a VRLE that have been determined to be increasingly important for students to achieve a higher level of meaningful learning (and, thanks to it, the knowledge acquired through the use of the VRLE will last in their memory for a longer time) and also feel a greater motivation to use it to: (i) adapt both the level of interactivity as well as the way the VRLE conducts the student through the virtual experiment; and (ii) maintain a look and a handling mode of the VRLE similar to other virtual environments that exist at the present time (e.g. video games). The study carried out and described in this article highlights the effectiveness of using in certain cases a step-by-step guidance protocol to improve long-term learning of concepts under study. In addition, the importance of using modern development tools to achieve a high level of motivation among students is emphasized.

Keywords: Virtual reality learning environments · Materials science and engineering · Meaningful learning

1 Introduction

The exponential improvement experienced by computer processors in the 21st century is easily observable in all areas of life, having been accompanied by the continuous evolution of all types of hardware (such as memory units, sensors or display devices, to name a few examples). Furthermore, this technological evolution has been followed by the development of many research works that have resulted in new realities hardly imaginable by the general public a few decades ago, such as multi-agent systems [1–3],

P. Vittorini et al. (Eds.): MIS4TEL 2020, AISC 1241, pp. 1–9, 2020.
https://doi.org/10.1007/978-3-030-52538-5_1

multi-core processing [4] or advanced image processing [5]. In this context, virtual reality has also experienced a great development and expansion in a multitude of fields, including university education through virtual reality learning environments (VRLEs), which are being used in a large number of disciplines. In the particular case of materials science and engineering (MSE), VRLEs that can be found are focused on helping students to learn about the realization of different tests of materials such as: tensile [6, 7], compression [8], impact [9, 10], hardness [9, 10], and non-destructive [11, 12].

The advantages of using VRLEs to support MSE teaching have been reported in different studies [6, 13, 14], including those describing that: (i) the problem of classroom congestion during training classes is minimized; (ii) experiments whose conduct in a real laboratory would be impossible due to their high price or hazard can be simulated; (iii) detailed visualization of the elements involved in experiments that are often difficult or impossible to see in a real laboratory can be discerned in a VRLE; and (iv) encouragement of students to learn the study subject is a key benefit.

The design of a VRLE plays a decisive role in the effectiveness that it will have by improving the teaching-learning process for which it will be used [15–17]. Vergara et al. [15] reported that there is a direct relationship between the design of a virtual teaching tool and the motivation that it generates on the user to continue using it. An important parameter for measuring the effectiveness of a VRLE is the level of meaningful learning that students achieve through its use. Meaningful learning is a concept that refers to the idea that an acquired knowledge is fully understood by an individual, who can connect it with another knowledge previously acquired. The authors of this article have found that not all VRLEs, despite being attractive and motivating, achieve the same degree of meaningful learning. Thus, this article compares different VRLEs designs applied to MSE to elucidate which parameters should be considered to achieve a high level of meaningful learning, being remarkable the use of a guidance protocol to help students to conduct the virtual experiments. The results and conclusions obtained in this study can be taken into account in the creation of VRLEs dedicated to the teaching of various university courses in the sciences and engineering fields.

2 Design Considerations of VRLEs

2.1 Design of Guidance Protocol

The process of creating VRLEs has been described in previous work [18] and consists of the following steps: (i) determine the level of realism necessary to achieve the objectives of the VRLE; (ii) establish the level of interactivity; (iii) choose the software and hardware that best suits the development and use needs of the VRLE; (iv) develop the VRLE, which in turn consists of 3D modeling and interactivity programming; and (v) test the application with a pilot group of users and apply the feedback obtained to modify the VRLE.

However, the authors have found that the process described above does not ensure in all cases that students reach an adequate level of meaningful learning. To solve this problem, the authors propose to apply a step-by-step guidance protocol on those VRLE that seeks to train students in conducting experiments in real laboratories. This step-by-step protocol occurs as VRLEs:

- Offer a sufficient level of interactivity to carry out the virtual experiment in a motivating and effective way at the formative level. This means that a very low level of interactivity does not allow the user to interact with the VRLE enough to retain knowledge or keep him motivated. On the other hand, a too high level of interactivity can result in the user losing the thread of the experiment, negatively impacting on motivation.
- Direct the user what is the next action that shall be taken, as well as provide information about how to do it.
- Prevent the user from taking unnecessary actions to perform the experiment or actions that may ruin it.

The use of a step-by-step guidance protocol like the one described above allows students to focus on understanding each stage of the experiment without having to invest a large amount of time in learning how to use the VRLE [19]. Figure 1 shows the process of creating a VRLE when a step-by-step guidance protocol is incorporated. In this process (Fig. 1) it can be observed that the level of interactivity that the authors suggest to use depends on the objective of the VRLE, that is: (i) when the objective of the VRLE is to help to understand a theoretical concept, the level of interactivity should be within a range from a step-by-step guidance system (therefore, restricted interactivity) to an open world (plenty of freedom of action); or (ii) when the VRLE is used to teach a laboratory experiment, a step-by-step guidance system should be implemented.

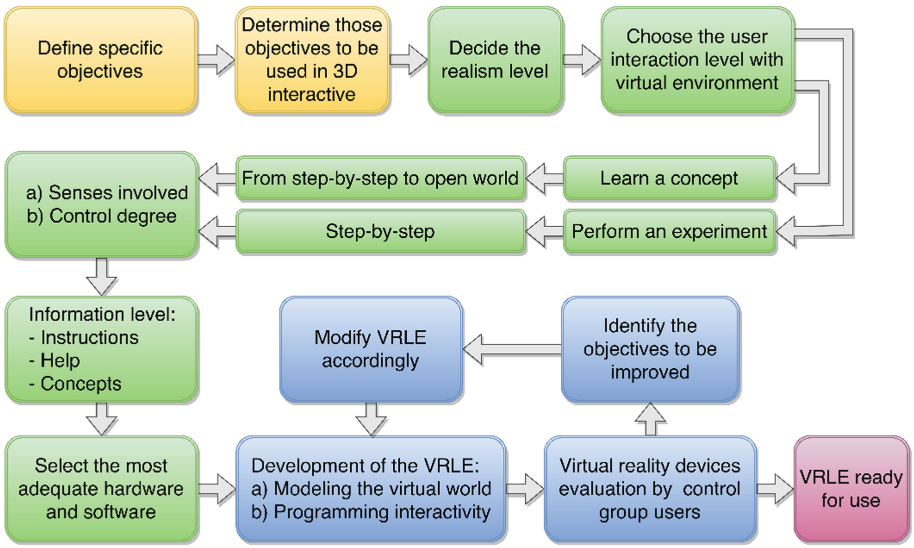

Fig. 1. VRLE creation process considering the implementation of a step-by-step guidance.

2.2 Obsolescence Effects on Students' Motivation

As noted above, the fourth stage of the process of creating a VRLE consists of two different activities [16, 20]: 3D modeling and interactivity programming. The 3D modeling gathers the activities related to the conceptualization and creation of the 3D elements that form the virtual environment, i.e.: laboratory, instruments, machines, lighting, etc. The virtual environment will then be visualized by the user, either on a computer monitor, on a head-mounted display (HMD) or another type of system as cave automatic virtual environment (CAVE) [21, 22]. There are different programs to carry out the modeling tasks, highlighting among them 3DS Max, Maya, Blender or Cinema 4D. On the other hand, the programming of interactivity consists in providing the 3D environment with the possibility to be manipulated by users, so they can interact with it: grabbing objects, using machines, moving around the scene, etc. This activity is carried out by using specific programs known as game engines, which are tools that were originally developed to program video games. Different game engines can be used to program the interactivity of a VRLE, such as Unreal Engine 4, Unity or CryEngine. Note that this type of VRLE do not incorporate a machine back-end to follow the user activity.

Over the last few years, the authors have developed different VRLEs applied to the MSE using different technologies [6, 8, 11, 15, 23–26]. Figure 2a shows the VRLEs created approximately 6 years ago, using development tools of that time. These applications are currently perceived by students as less motivating as they offer an "outdated" look: unrealistic materials and lighting, interactivity restricted to keyboard and mouse, or impossibility to easily adapt the applications to immersive virtual reality. On the other hand, Fig. 2b shows newly created VRLEs using current development tools. The new VRLEs (Fig. 2b) offer an aspect and interactivity in line with the possibilities offered by modern virtual reality technology: realistic-looking environments, lighting based on physical equations, different possibilities of interaction or the possibility of easily adapting applications to be used with immersive virtual reality, among others.

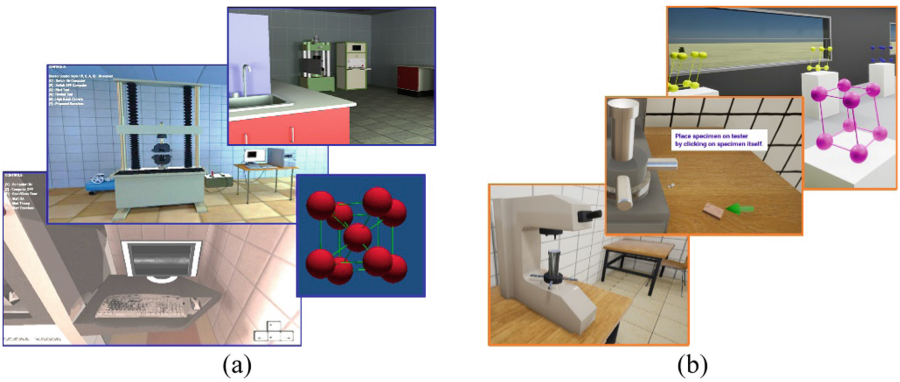

Fig. 2. Virtual reality learning environments: (a) created 6 years ago with former development tools and others (b) created recently with current development tools.

3 Meaningful Learning Analysis

During the conduct of an experiment in a real MSE laboratory, it is common that a single equipment is being utilized by a large group of students. It is expected that this circumstance will negatively affect the teaching-learning process of the experiment [8], and for this reason, the use of a VRLE is preferred. Consequently, the authors used VRLEs as shown in Fig. 2a, but found that one year after using them, there was a large number of students who did not remember how to perform the experiments that they simulated with VRLEs. Thus, the analysis of the data obtained in this study is intended to elucidate the main factors that explain this fact.

3.1 Methodology

This study was carried out at the Catholic University of Ávila (Spain), during the courses between 2015 and 2020, participating every year approximately 20 MSE students of the degree in mechanical engineering. The methodology used is summarized in the following steps:

- The instructor teaches the theory about the operation of the simulated machine in the VRLE to perform the virtual experiment.
- The use of a VRLE in the classroom should be under the supervision of the teacher. Also, students can continue using the VRLE without restrictions out of school hours.
- Resolution of exercises in groups of 2–3 students, either in VRLE itself or on paper.
- One year after the previous three steps have been completed, students answer to technical questionnaires to assess the level of knowledge retained.

During the years 2015 to 2018, VRLEs designed without a step-by-step guidance protocol were evaluated; these VRLEs were used a year earlier (i.e. these VRLEs were used in class between 2014 and 2017). Moreover, in 2019 and 2020 VRLEs designed according to Fig. 1 (including a step-by-step guidance protocol) were evaluated and developed with current development tools (Fig. 2b); those latter VRLEs were used subsequently in 2018 and 2019.

3.2 Results

As described above, students were surveyed one year after using VRLEs to assess the degree of knowledge they still retained. Figure 3 shows the data obtained from the surveys filled out by the 120 students who participated in the study (approximately 20 students per course). The resulting bar graph (Fig. 3) shows the average of the questionnaire questions answered correctly each course (accuracy rate), indicating the level of knowledge that students remember about the MSE content they learned a year earlier with the help of VRLEs. Furthermore, Fig. 3 shows that, between 2015 and 2018, were evaluated VRLEs designed without a step-by-step guidance protocol (i.e. developed several years ago) while in 2019 and 2020 were evaluated VRLEs designed according to the scheme of Fig. 1 (i.e. developed more recently, which include a step-by-step guidance protocol).

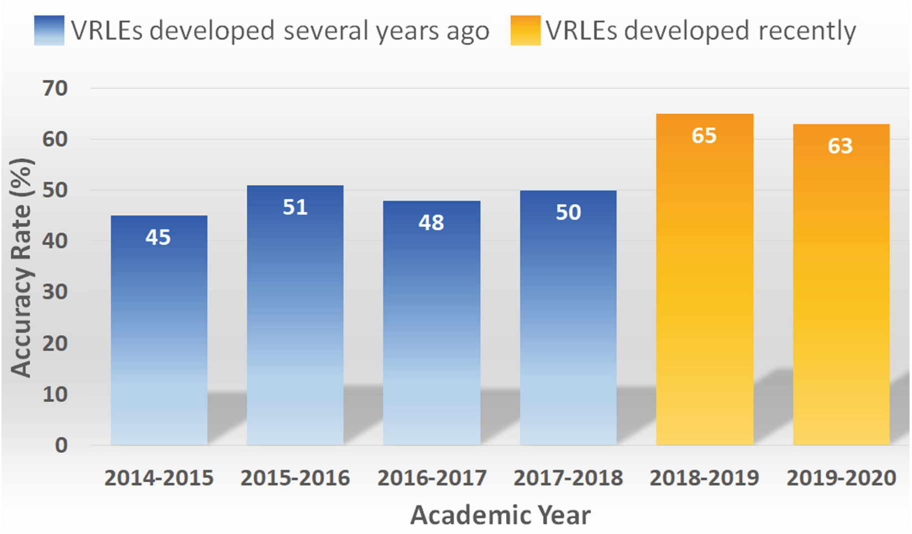

Fig. 3. Accuracy rate of questionnaires answered by students who used the VRLEs a year earlier as a support to learn fundamental concepts in MSE.

4 Discussion

The continuous evolution of information and communications technology (ICT) brings with it an accelerated virtual reality technology improving. This rapid evolution implies that VRLEs, although at the time of their creation are well-valued by students after a few years are perceived as obsolete and less motivating. The experience of the authors indicates that students welcome updates such as those described in this article, which indicates that regular updates of VRLEs using modern development tools favors that these teaching applications can maintain motivation among students (thus achieving that VRLEs do not lose their effectiveness at the formative level over time). However, as discussed below, periodic updates to VRLEs do not ensure by themselves alone a significant improvement in meaningful learning.

It is impossible to achieve that a group of students remember 100% of the content learned a year ago. As noted in Fig. 3, the percentage of knowledge retained varies little from course to course between 2015 and 2018. However, in 2019 and 2020 the success rate increased by approximately 30% compared to the period 2015–2018. Considering that the contents taught in the MSE subject and questionnaires used to evaluate the retained knowledge were almost identical every year, this improvement in the level of retained knowledge (30% higher than previous years) can be due to two factors: the use of updated development tools or the implementation of a step-by-step guidance protocol. The technical improvement of VRLEs when they are updated helps students to be motivated to use them and focus on the concepts being taught, which favors some improvement of meaningful learning.

However, based on the experience of the authors and previous studies [6, 8, 11, 12, 15, 27, 28], students' motivation to use this type of teaching resources is usually high. Consequently, updating VRLEs with current development tools cannot be the only factor that explains the increase of 30% in the number of questions correctly answered in the surveys of 2019 and 2020. In fact, in the authors' opinion, the key factor that explains the improvement in meaningful learning lies in the implementation of the step-by-step guidance protocol (Fig. 1). This is in line with previous studies [29] in which the effectiveness of step-by-step guidance protocols has been tested in teaching tools based on the audio-visual use of e-books for MSE teaching.

Nevertheless, further research works should be conducted to measure the level of influence on the meaningful learning of both factors considered in the present paper: the use of recent development tools and the implementation of a guidance protocol. In particular, new studies could be based on fixing one of the factors and varying the other one, considering the same questionnaires described in the present paper to assess the level of meaningful learning. These future research works should: (i) evaluate both a group of VRLEs with guidance and another similar group of VRLEs without guidance protocol–both groups of VRLEs should be developed with the same development tools–; and (ii) compare the evaluation of a group of VRLEs developed with modern tools and another similar group of VRLEs developed with older tools–both groups of VRLE should lack a guidance protocol–.

5 Conclusions

The design of a VRLE is directly related to its effectiveness as an educational tool. Periodic updates of a VRLE by using current development tools lead to a modern aspect of this type of application, that helps maintain the motivation of students to use it. Besides, updating a step-by-step protocol in those VRLEs dedicated to simulate laboratory experiments allows students to achieve a higher level of meaningful learning, thereby retaining the acquired knowledge for a longer time.

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