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Virtual Reality Simulation-Based Learning

Aprendizaje basado en simulación con realidad virtual

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ABSTRACT

The use of virtual reality (VR) and augmented reality (AR) to improve learning is a topical issue in Higher Education. This paper aims to assess the impact of virtual reality simulation (VR-SBL) on student learning and satisfaction. To this end, two cases are presented that have been carried out at Universidad Europea de Madrid (UEM): the first consists of training experience to provide first aid in the event of a traffic emergency through the use of immersive virtual reality technology, where a comparison has been made between how students learn with this new methodology concerning the traditional master class. The second case is the simulation of accidents in a laboratory using virtual reality desktop technology, where a comparison has been made between how students learn with this methodology for simulation of such accidents in the real laboratory. In both cases, a quasi-experimental design with an experimental group and a control group has been used. Also, a pretest-posttest design has been applied, consisting of a knowledge test before the experience (pretest) and a knowledge questionnaire after the experience (posttest). To measure satisfaction with the activity and the adequacy of the tools used, a user experience questionnaire was administered. In conclusion, student satisfaction was high in both cases. Besides, in the first case, the experimental group using immersive virtual reality had a significantly better academic performance. As for the second case, no significant differences were found in terms of learning. Therefore, the level of learning in both groups (virtual reality simulation and real scenario simulation) was the same.

Palabras clave:
Realidad virtual
RV
Simulación
Realidad virtual de escritorio
Aprendizaje basado en simulación
Quasi-experimental
Educación médica
Laboratorios virtuales

RESUMEN

El uso de realidad virtual (VR) y realidad aumentada (AR) para la mejora del aprendizaje es un tema de actualidad en la Educación Superior. El objetivo de este trabajo es evaluar el impacto de la simulación con realidad virtual (del inglés, VR-SBL) en el aprendizaje y satisfacción del estudiante. Para ello, se presentan dos casos llevados a cabo en la Universidad Europea de Madrid (UEM): el primero consiste en una experiencia de formación en primeros auxilios ante una emergencia de tráfico mediante el uso de tecnología de realidad virtual inmersiva, donde se ha comparado cómo aprenden los estudiantes con esta nueva metodología respecto a la clase magistral tradicional. El segundo caso consiste en la simulación de accidentes en un laboratorio mediante el uso de tecnología de realidad virtual de escritorio, donde se ha comparado cómo aprenden los estudiantes con esta metodología respecto a una simulación de dichos accidentes en el laboratorio real. En

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ambos casos se ha utilizado un diseño cuasi-experimental con un grupo experimental y un grupo de control. Además, se ha aplicado un diseño pretest-postest, que consiste en la realización de un test de conocimientos previo a la experiencia (pretest) y un cuestionario de conocimientos posterior a la misma (postest). Para medir la satisfacción con la actividad y la adecuación de las herramientas empleadas se ha utilizado un cuestionario de experiencia de usuario. Como conclusión, la satisfacción de los estudiantes en los dos casos denota una valoración alta. Además, en el primer caso, el grupo experimental que utiliza la realidad virtual inmersiva mejora significativamente el rendimiento académico. En cuanto al segundo caso, no se han encontrado diferencias significativas en cuanto al aprendizaje, por lo tanto, el nivel de aprendizaje en ambos grupos (simulación con realidad virtual y simulación en escenario real) es el mismo.

1. Introduction

It is common practice to use technology such as mobile devices or computers in the classroom as a didactic tool. Today, virtual reality (hereinafter referred to as VR) is a trending topic in education, as demonstrated by the Horizon Report 2016 (Johnson, Adams, Cummins, Estrada, Freeman, & Hall, 2016), which indicates that virtual and augmented reality will be important technologies in higher education in the coming years. VR allows for simulations and representations of reality through immersive technology (Moreno & Ramírez, 2015). Yet what is virtual reality? The Oxford Dictionary (Oxford University Press, 2018) defines virtual reality as *"The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors."* Although virtual reality can be executed on a PC and viewed on a monitor (Desktop VR), the use of devices such as glasses or head-mounted displays (HMD) make the experience much more immersive, as the user can be completely removed from the surrounding environment and completely transferred to a much more controlled, virtual learning environment.

In the last four years, there has been a boost to this technology with the emergence of new virtual reality devices on the market that are increasingly accessible to the public. With the appearance of Google Cardboard (Google, 2019), immersive virtual reality is available to any user with a smartphone and the minimum investment to acquire or manufacture cardboard glasses that are compatible with Google's. The best virtual reality headsets for smartphones are the Samsung Gear VR, which requires a S6 or higher Samsung Galaxy mobile device (Samsung, 2019) and Daydream View (Google, 2019) for Android users. Lately, high-end standalone virtual reality headsets are coming to the market at an affordable price. They can be used without additional mobile devices, without wires and without a PC. This range of products includes Oculus Go (Facebook, 2019), the recently launched Oculus Quest (Facebook, 2019) which lets users walk around a large space, or the Lenovo Mirage Solo (Lenovo, 2019) with Daydream technology (Google, 2019). The high-performance VR market is also growing; PC-tethered VR headsets (those that require a connection to a PC) offer the highest quality for immersive virtual reality applications. The most popular PC-tethered VR headsets include the HTC VIVE PRO (HTC, 2019) and Oculus Rift S (Facebook, 2019). Sony has also launched its Sony Playstation VR device (Playstation, 2019), compatible with Playstation 4 Plus, which allows users to enjoy a professional-quality virtual reality experience at home. In addition, there are mixed reality devices, such as Microsoft Hololens 2 (Microsoft, 2019a) and Magic Leap One (Magic Leap, 2019), that have the ability to project virtual objects onto the real world in the form of holograms and allow for interaction with virtual objects. With the emergence of Windows Mixed Reality (Microsoft, 2019b), an extension of Windows 10 that establishes a unified mixed reality environment, many other manufacturers such as Lenovo, HP, Samsung, ASUS, Acer and Dell are also launching their own mixed-reality devices based on the Microsoft Windows environment. However, there are other forms of VR where immersion occurs (Robertson, Czerwinski, & van Dantzich, 1997). Desktop VR or Nonimmersive VR is the use of animated interactive 3D graphics to build virtual worlds with desktop displays and without head tracking, the 3D environment that can be directly manipulated using a keyboard and a mouse (Robertson et al., 1997; Robertson, Card, & Mackinlay, 1993), or other external peripheral devices.

Recent studies (Curcio, Dipace, & Norlund, 2016; Fernández, 2017a) present a review of virtual and augmented reality as well as mixed reality case studies, their applications in formal education and their impact on education. Curcio, Dipace and Norlund (2016) emphasize that successful use of virtual reality technology in student learning is directly related to the design of a good theoretical framework. Along these lines, Fernández (2017a) concludes that the focus should be on establishing clear, specific learning objectives, and that the ultimate goal of virtual reality activities should be improving students' acquisition of knowledge and skills. Regarding the applicability of this technology, Carrillo and Cortés (2016, p.281) point out that virtual reality can take on different scopes in the academic world: "*it can be applied in the teaching of basic and applied sciences, in very* *diverse areas and activities at any educational level and its application is already prolific in higher education, in the fields of medicine, dentistry, various engineering degrees, architecture, etc.*"

1.1. Simulation-based learning (SBL)

Simulation-based educational (SBE) methods are recognized as an established component of medical training for medical students and doctors (Palés & Gomar, 2010; Lateef, 2010; Becker & Hermosura, 2019). According to Vázquez and Guillamet (2009), simulation-based training consists of replacing reality with a simulated scenario in which students and professionals can train in order to acquire communication, psychomotor or teamwork skills (Okuda et al., 2009). This type of training is always linked to a feedback session in which participants and teachers analyze the activity carried out. This session must be accompanied by a phase of reflective critical thinking in order to gain a deeper understanding of both the basic and clinical sciences involved in the process being taught. Therefore, SBE engages learners in lifelike experiences with varying fidelity designed to mimic real clinical encounters (McGaghie, Issenberg, Cohen, Barsuk & Wayne, 2011).

Simulation technologies encompass diverse products including computer-based VR simulators (Cook et al., 2011), which allow learners to experience open-ended, evolving situations with many interacting variables. Gredler (2004) defines the main characteristics of VR simulation as follows: an adequate model of the complex real-world situation with which the student interacts; a defined role for each participant with responsibilities and constraints; a data-rich environment that permits students to execute a range of strategies; and feedback for participant actions in the form of changes in the problem or situation. The results of the study conducted by Cook et al. (2011) conclude that technology-enhanced simulation training in healthcare education is consistently associated with large effects on the outcomes of knowledge, skills and behaviors. In addition, McGrath et al. (2017) indicated that virtual reality (VR) simulation applications increase learner motivation, improve contextualization of learning, and develop superior technical abilities. Such applications also provide convenience and flexibility and increase the ability to scale and distribute simulations widely with lower costs.

The purpose of this work is to assess, through two cases carried out at Universidad Europea de Madrid (UEM), the impact of virtual reality simulation (VR-SBL) on student learning and satisfaction. The first case tackles first aid in a traffic emergency with an immersive VR application, and the second one deals with the simulation of accidents in a lab and uses a desktop VR application.

2. Two cases of virtual reality implementation at Universidad Europea de Madrid

Case 1: First aid in a traffic emergency with immersive virtual reality

This activity involves the application of virtual reality to higher education, specifically in the Laboratory Techniques course in the first year of the Advanced Career and Technical Education program called Advanced Diploma in Pathological Anatomy and Cytology Diagnosis, offered at Universidad Europea de Madrid (Jiménez, Mariscal, Heredia, & Castilla, 2018).

This activity arises from the need to change the way first aid is taught at university level. The most common methodology is classical or traditional, where the teacher is a mere transmitter of information, and organizes the content and asks questions. The students in this scenario take on a passive role. Role-playing is a technique that is gaining relevance in first aid classrooms (Quinn, 2000): students play the role of victims and those who care for them, simulating a real situation. The use of pedagogical styles that require the active participation of students is more likely to succeed in most degree program courses. Another very common technique is the combination of an explanation by the teacher and the use of first aid mannequins to simulate reality (Fernández, 2017b).

This activity was carried out in two groups: a control group, in which the students received a master class, and an experimental group, which followed a methodology based on virtual reality.

Regarding the experimental group, RCSI Medical Training Sim application (Royal College of Surgeons in Ireland, 2018) (see figure 1) is the selected system to support the training process.

Figure 1. Screenshot of the RCSI Medical Training Sim application. Source: Facebook (2018).

This selected application allows health personnel to be trained in case of emergency. In this case, the learning objective was to train students in the process to be followed for a patient who has recently arrived at the hospital after suffering a car accident. To carry out the comparison of both groups, the content of the master class was designed to be similar to that offered by the application.

This activity has the following intended learning outcomes for both groups:

- Analyze the site where the accident occurs and establish priorities for action.
- Assess the condition of the victims and apply the appropriate procedures for the restoration of ventilation and circulation without causing greater damage to the victim.
- Apply cardiopulmonary resuscitation (CPR) techniques; apply the most appropriate procedures in case of trauma, injuries, hemorrhages and wounds caused by the traffic accident.
- Apply the most appropriate procedures to immobilize and transfer the injured person.
- Value the importance of self-control in stressful situations and the importance of not increasing the risk for the injured person and the people providing assistance.

The RCSI Medical Training Sim app was selected for this experience because it includes an alternative fully educational and didactic mode that perfectly ties in with the learning outcomes and the level of knowledge of the students participating in the activity, allowing students to learn from this experience in an immersive environment. This application provides a safe and realistic training platform to rehearse and simulate commonly encountered intense life or death scenarios without consequences. The app was created and validated by the Royal College of Surgeons in Ireland in conjunction with Immersive VR Education (Royal College of Surgeons in Ireland, 2018).

This application is currently released onto the Samsung Gear VR- Oculus platform (Facebook, 2019) and is available free of charge. Students used Samsung Galaxy S8 Smartphone devices with Samsung Gear VR headset (version SM-R325) and headphones; this ensured that students were more isolated, avoiding potential interruptions. One professor and two assistants were present throughout the session, intervening if necessary, to assist students in the face of possible technical difficulties (see figure 2).

Figure 2. UEM student enjoying a VR experience through RCSI Medical Training Sim.

Case 2. Simulation of accidents in a lab with a desktop VR application

The activity for the second case was another virtual simulation experience in the university context, specifically in the Introduction to Lab Work course, which is part of the first year of the bachelor's degree in Pharmacy at Universidad Europea de Madrid. In this course, the future pharmacist comes into contact with laboratory work, learning everything they need to know to effectively perform their work. This activity teaches students to identify the material and equipment they are going to handle, what is the safest way to work, how to handle the different reagents and manage waste, carry out bibliographic searches of interest, as well as prepare documentation according to regulations. This course is the basis of the knowledge that students need to effectively take the experimental subjects that they will study during the degree.

With the traditional methodology, students acquire theoretical knowledge in the classroom, through the teacher's explanations and the use of videos that allow them to understand certain experimental procedures more effectively. In addition, several practical sessions are held in the laboratory, during which the students are taught the most common basic safety rules and procedures. Through this traditional method, students are taught how to work safely and how to proceed in the event of an accident. However, in this situation the student does not face a real accident or dangerous scenario in which they can simulate and act on their decisions.

In order to meet this training need, the "UE Risk Simulator" application was created at UEM, with the aim of students learning how to deal with different accidents that may arise in the laboratory and what would be the most effective way to resolve them. The UE Risk Simulator was designed by Professor Moreno and developed by Universidad Europea's XR Lab and its technological partner company Stratesys. The "UE Risk Simulator" is a desktop VR system for Windows, supported by Cosmic platform (Cosmic, 2019). Cosmic is a simulator that makes it possible to bring risky professional situations into the classroom. Students can resolve real-life challenges in a safe environment. The Mentor-Teacher can monitor student performance in real time (see figure 3) and analyze the results of the activity.

Figure 3. Screenshot of the Student Performance Monitor in UE Risk Simulator.

Students access Cosmic platform through a PC and a web browser. Once in Cosmic, students must select the course and proposed challenge. UE Risk Simulator application runs on Windows and the selected simulation starts. The simulator is based on Unity game engine. Students use only the PC mouse to enjoy the training activity. Users can move around, manage third person camera view, interact with active objects in the simulation scenario and select required safety equipment from the inventory to complete the steps that need to be followed during a laboratory emergency (see figures 4 and 5).

Figure 4. Screenshot of the UE Risk Simulator.

Figure 5. UEM students enjoying UE Risk Simulator in classroom.

This activity has the following intended learning outcomes for both groups:

- Knowledge of basic laboratory operations. Safety rules and precautions.
- Knowledge of how waste disposal is carried out.
- Knowledge of a laboratory's main utensils and basic equipment.

In this case, students are trained to handle a chemical spill in a laboratory. Students must learn to select the right PPE (Personal Protective Equipment) such as gloves, glasses, safety chocks or masks. After the training is successfully completed, students should be able to manage collective protection equipment (markers and chemical neutralizers); safety procedures; labelling and information in the SDS (safety data sheets).

3. Methodology

The procedure used in this study is framed within the quasi-experimental designs that according to Hedrick et al. (1993, p. 58) "have the same purpose as experimental studies: to prove the existence of a causal relationship between two or more variables. When randomization is impossible, quasi-experiments (similar to experiments) allow the impacts of the treatment or program to be estimated, depending on whether an appropriate basis for comparison has been established." These designs are characterized by the use of two groups, one experimental and the other control, whose difference lies in the performance of the activity with or without virtual reality. Table 1 summarizes the main characteristics of each case.

Concept	Case 1	Case 2
Program of study	First year of the Advanced Career and Technical Education program called "Advanced Diploma in Pathological Anatomy and Cytology Diagnosis" at Universidad Europea de Madrid	First year of the bachelor's degree in Pharmacy at Universidad Europea de Madrid
Course	General Laboratory Techniques	Introduction to Lab Work
Experimental group	Students using the "RCSI Medical Training Sim" application	Students using the "UE Risk Simulator" application
Control group	Students receiving a traditional master class	Students performing real simulation in the laboratory

Table 1. Characteristics of cases 1 and 2.

3.1. Objectives and hypotheses

The objective of this research is to assess the impact of virtual reality simulation through applications such as RCSI Medical Training Sim and UE Risk Simulator and how they positively influence learning and student satisfaction. To this end, the following null contrast hypotheses were used in the two case studies:

- Hypothesis 1. There are no statistically significant differences in pretest performance between the experimental group and the control group.
- Hypothesis 2. There are no statistically significant differences in posttest performance between the experimental group and the control group.
- Hypothesis 3. There are no statistically significant differences in pretest-posttest performance in the experimental group.
- Hypothesis 4. There are no statistically significant differences in pretest-posttest performance in the control group.

3.2. Participants

Figure 6 shows the detail of the students in the sample for case 1. As can be seen, the total number of participants is 18 students distributed homogeneously between the two groups. However, the number of students in the experimental group is slightly higher than in the control group. In case 2, represented in figure 7, the sample is composed of a total of 63 students divided into the two groups: 49 students in the experimental group and 14 students in the control group.

Figure 6. Sample for case 1 by group.

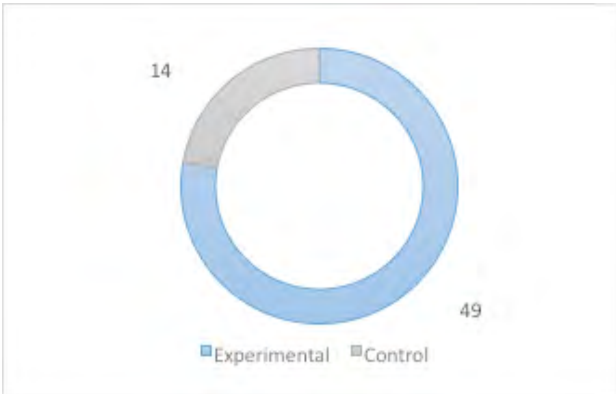

Figure 7. Sample for case 2 by group.

3.3. Instruments

Information was collected through a knowledge questionnaire that was administered before (pretest) and after each activity (posttest).

In case 1, the grading scale is from 1 to 10. It is important to note that the grades obtained in the pretest and posttest are not comparable, since the posttest is a questionnaire that assesses advanced knowledge of the subject, while the pretest assesses basic knowledge. In case 2, the pretest and posttest grading scale is from 1 to 3 (poor – OK – good).

In order to measure satisfaction with the activity and the suitability of the tools used, a Likert-type user experience questionnaire was used, in which the students in the group rated from 1 to 5 (no – very high/excellent satisfaction) their degree of satisfaction with the following aspects: methodology used; learning acquired during the activity; application of knowledge; duration of the activity; ease of use of the application; ease of navigation through the scenario; ease of finding interactive points; and degree of overall satisfaction.

3.4. Data analysis

The research carried out is of a quantitative nature. To this end, data analysis was structured around two non-parametric tests: the Mann-Whitney U test for comparing the relationship between the performance variable in the pretest and in the posttest depending on the group, and the Wilcoxon W test for determining whether there are differences in performance before (pretest) and after (posttest) using the virtual application in the experimental group and after the master class or the actual simulation in the control group. The statistical software SPSS version 21.0 was used to carry out these hypothesis comparisons.

4. Results and Discussion

4.1. Group performance (experimental and control)

Average performance on the pretest and posttest by group is summarized in figure 8. In this case, the grading scale is from 1 to 10 and the results indicate that the group of students who used the virtual application (experimental group) performed better on average than the group of students who received a master class (control group). It should be remembered that the grades obtained on the pretest and posttest are not comparable, since the posttest is a questionnaire that assesses advanced knowledge of the subject, while the pretest assesses basic knowledge.

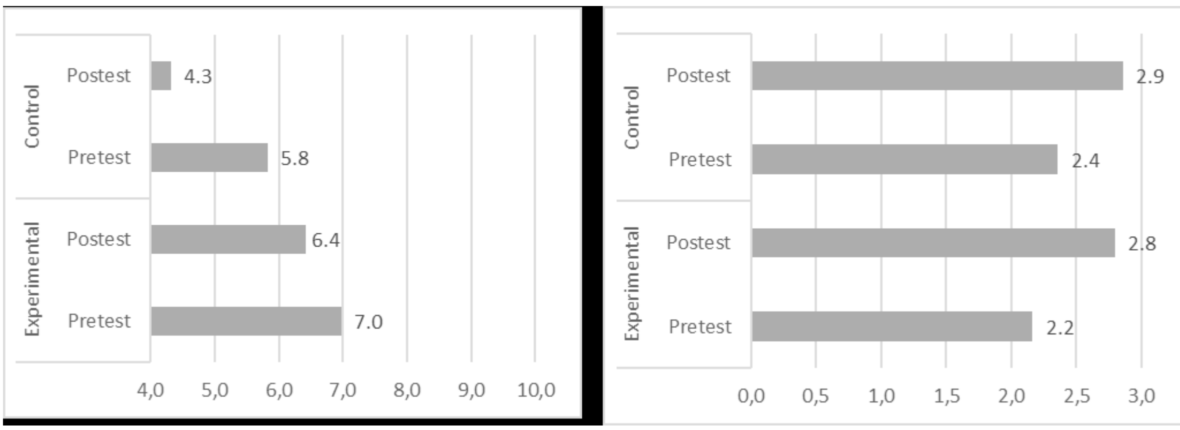

Figure 8. Average performance on the pretest and posttest by group.

In case 2 (graph on the right), the grading scale is from 1 to 3 (poor – OK – good) and the results show that the group of students who used the virtual application (experimental group) and those who used the real simulation (control group) performed similarly well on the posttest.

To determine whether these results are significant, the Mann-Whitney U test was carried out. The results corresponding to the pretest (see table 2) indicate that in case 1 the average rank for the pretest is higher in the experimental group, while in case 2, the averages in the pretest are very similar in both groups; however, it is slightly higher in the control group.

	Mean rank		**Contrast test statistic**[a]			
	Experimental	Control	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-talled)
Case 1	11.9	6.5	16	52	-2.147	0.032
Case 2	31.15	34.96	301.5	1526.5	-0.749	0.454
a. Grouping Variable: Group						

Table 2. Contrast statistics pretest.

Regarding the contrast statistic, also presented in table 2, it can be observed in case 1 how the probability associated with the Mann-Whitney U statistic [$p_{pretest}$(0.032)] is less than α=0.05. This result leads us to reject the null hypothesis and determine that there is a relationship between performance on the pretest and the group the student belongs to, with the experimental group obtaining better results. In case 2 the result is different: the probability associated with the Mann-Whitney U statistic [$p_{pretest}$(0.454)] is higher than α=0.05. This result leads us to accept the null hypothesis and determine that there are no statistically significant differences in the pretest scores between the experimental group and the control group.

The results for the posttest (see table 3) show in case 1 that the average rank is higher in the experimental group, while in case 2 it is the control group that obtains the best performance.

The results of the contrast statistic in case 1 show a probability associated with the Mann-Whitney statistic U [$_{pposttest}$ (0.014)] lower than α=0.05, which leads us to reject the null hypothesis and conclude that there are statistically significant differences in the posttest between the groups. That is to say, after using the virtual reality application, performance is significantly higher than that achieved after the master class.

Regarding case 2, the results of the contrast statistic show that the probability associated with the Mann-Whitney U statistic [$_{pposttest}$ (0.815)] is higher than α=0.05. For this reason, the null hypothesis is accepted and it is concluded that the differences that exist in the posttest between the experimental and control groups are not statistically significant, showing that the same learning results are achieved through both a real simulation of a laboratory accident and the virtual application.

	Mean rank		**Contrast test statistic**[a]			
	Experimental	Control	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-talled)
Case 1	8.64	3.5	2.5	17.5	-2.462	0.014
Case 2	31.82	32.64	334.0	1559.0	-0.234	0.815
a. Grouping Variable: Group						

Table 3. Contrast statistic posttest.

4.2. Performance as a function of the test (pretest and posttest)

The non-parametric Wilcoxon W test was used to assess performance according to the test. The results for the experimental group are shown in table 4. In case 1, the results indicate that the probability associated with the Wilcoxon W statistic [$pcase1_{.exp}$ (0.070)] is higher than α=0.05, which leads us to accept the null hypothesis. Therefore, after using the virtual application there are no statistically significant differences in performance. This result is due to the fact that the posttest has a higher level of complexity than the pretest.

In case 2, the experimental group performs better after using virtual simulation, and the probability associated with the Wilcoxon W statistic [$p_{case2.exp}$ (0.000)] is lower than α=0.05. Thus, there are statistically significant differences such that performance is significantly improved after using virtual simulation.

Ranks		N	Mean Rank	Sum of Ranks	Z	Asymp. Sig. (2-talled)
Case 1	Negative Ranks	5[a]	3.80	19.00	-1.802[b]	0.070
	Positive Ranks	1[b]	2.00	2.00		
	Ties	1[c]				
	Total	7				
Case 2	Negative Ranks	0[a]	0.00	0.00	-5.231[b]	0.000
	Positive Ranks	29[b]	15.00	435.00		
	Ties	20[c]				
	Total	49				
a. Posttest < Pretest b. Posttest > Pretest c. Posttest = Pretest						

Table 4. Pretest-posttest contrast statistic differences in the experimental group.

The results for the control group, i.e. the group that does not use the virtual application, can be seen in table 5. The results for case 1 indicate that the probability associated with the Wilcoxon W statistic [pcase1 (0.10)] is higher than α=0.05, and therefore the null hypothesis is accepted and we can conclude that after the master class there are no statistically significant differences in student performance.

In case 2, the results indicate that the probability associated with the Wilcoxon W statistic [pcase2 (0.008)] is lower than α=0.05, which leads us to reject the null hypothesis and determine that after the real simulation there are statistically significant differences in student performance.

Ranks		N	Mean Rank	Sum of Ranks	Z	Asymp. Sig. (2-talled)
Case 1	Negative Ranks	4[a]	3.375	13.5	-1.625[b]	0.10
	Positive Ranks	1[b]	1.5	1.5		
	Ties	0[c]				
	Total	5				
Case 2	Negative Ranks	0[a]	0.00	0.00	-2.646[b]	0.008
	Positive Ranks	7[b]	4.00	28.00		
	Ties	7[c]				
	Total	14				
a. Posttest < Pretest b. Posttest > Pretest c. Posttest = Pretest						

Table 5. Pretest-posttest contrast statistic differences in the control group.

4.3. Satisfaction results

In terms of satisfaction with the learning resources used in the two cases, the results show a high level of satisfaction. Figure 9 shows the main results for case 1. After using the RCSI Medical Training Sim application, the results are quite adequate; in all cases, the average is above 4 and in most cases above 4.5 on a scale with a maximum value of 5. The only scores below 4.5 are for items related to the application of your knowledge (4.3) and the length of the session (4.4). The highest rated items correspond to the pedagogical and navigation items; in particular, the methodology used is rated as excellent by 70% of students. Fifty percent also indicate that the learning acquired is excellent. When it comes to navigation and ease of use of the application, 70% of students also say they are *excellent*.

To summarize, the overall degree of satisfaction shown by the students after using the application is *very high/excellent* for 60% of the students and *high* for 40%, with no students indicating that their degree of satisfaction is *medium, low* or *very* low.

	Null	Low	Medium	High	Very high / Excellent	Mean
Methodology used	0%	0%	0%	30%	70%	4.7
Knowledge aquired	0%	0%	0%	50%	50%	4.5
Knowledge application	0%	0%	10%	50%	40%	4.3
Length of the session	0%	0%	20%	20%	60%	4.4
App user friendliness	0%	0%	20%	10%	70%	4.5
Was navigation through the app adequate?	0%	0%	10%	20%	70%	4.6
Did you have any difficulty finding the interactive points?	0%	0%	10%	20%	70%	4.6
Global satisfaction	0%	0%	0%	40%	60%	4.6

Figure 9. Case 1 Satisfaction Results.

In case 2 (see figure 10), all the questions have an average higher than 3 points out of 5, with the exception of the item on ease of navigation (2.7 points). In particular, aspects such as methodology, learning acquired and the application of knowledge are rated highly (in these cases, the average is over 4 points). Also relevant is the overall satisfaction obtained: more than 50% of students show a high level of satisfaction (average of 4 points out of 5).

	Null	Low	Medium	High	Very high / Excellent	Mean
Methodology used	0%	2%	12%	53%	33%	4.2
Knowledge aquired	0%	0%	8%	35%	57%	4.5
Knowledge application	0%	0%	8%	37%	55%	4.5
Length of the session	0%	12%	43%	27%	18%	3.5
App user friendliness	6%	37%	24%	10%	22%	3.1
Was navigation through the app adequate?	16%	39%	14%	16%	14%	2.7
Did you have any difficulty finding the interactive points?	2%	33%	27%	16%	22%	3.2
Global satisfaction	0%	2%	22%	51%	24%	4.0

Figure 10. Case 2 Satisfaction Results.

5. Conclusions and Discussion

From the methodological point of view, the key to success for this type of application lies in having a good instructional design for the activity, which establishes clear, specific learning outcomes, as the studies by Curcio, Dipace & Norlund (2016) and Fernández (2017a) conclude.

The main conclusions for each of the cases are set out below.

Case 1

The main conclusions from the research carried out in the first case are that students who perform the activity with virtual reality (experimental group) perform better on average in the pretest and posttest than the group of students who receive a master class (control group). These results are similar to those presented in Curcio, Dipace and Norlund (2016) and Fernández (2017a).

The user experience survey allows us to conclude that the degree of satisfaction after using the application is very high, as is the case with students' motivation when using methodologies of a technological nature, since they feel like they are part of the learning process.

Huang et al. (2019), Candiago and Kawamoto (2016), Curcio, Dipace and Norlund (2016), Dalgarno and Lee (2010), and De Freitas (2006) indicate that student motivation improves in three-dimensional and virtual reality environments. However, we must keep in mind that the sample used in this study is not significant and is limited to the study of a specific application (RCSI Medical Training Sim), so these results cannot be generalized.

This study presents some limitations, since a statistically significant relationship is identified in the previous performance between the experimental group and the control group, with the experimental group performing better. As in the study presented by Yang, Chen and Jeng (2010), this may be due to students' motivation and their level of involvement, as they knew that they would be carrying out an activity with virtual reality. Moreover, for most students it was their first or second experience with virtual reality. Another relevant aspect that should be taken into account is language, as two students had difficulty because their level of English was lower than that required to use the application.

When the groups are analyzed separately and the pretest and posttest results are compared, it can be concluded that after using the virtual application there are no statistically significant differences in performance. This result is due to the fact that the posttest has a higher level of complexity than the pretest, which only assesses basic knowledge, and so the two tests are not comparable.

Case 2

In light of the results presented, it can be concluded that the group of students who used the real simulation (control group) performed better than the group who learned by means of virtual simulation (experimental group). However, the difference between the two groups is minimal and not statistically significant, which allows us to conclude that virtual simulation is as effective for learning as simulation in a real scenario. However, it is important to note that performance improves significantly in the experimental group after using the virtual application. With both methodologies, real and virtual simulation, it has been demonstrated that the student learns significantly more than from the master classes.

The results obtained are very pertinent: using virtual methodologies, we can attain the same degree of learning as achieved through a real simulation. This conclusion cannot be generalized and is limited to the study and the application described in case 2.

The possibility of replacing a real simulation with a virtual one offers numerous advantages. On the one hand, it allows us to carry out any type of exercise regardless of the risk that it might pose for the students, such as responding to a fire or how to handle a radiological hazard (Nakai & Suzuki, 2015; Candiago & Kawamoto, 2016). On the other hand, it allows those students who study online to learn the same way from home, avoiding the need to travel to the learning center while ensuring that they acquire this knowledge correctly. It also allows us to optimize resources and teaching spaces, since all students could learn at the same time without having to use laboratory material (McGrath et al., 2017). Individual students have the opportunity to think and act on an accident, they can make their own decisions, make mistakes and repeat the exercise as many times as they want until they resolve it correctly (Palés & Gomar, 2010; Corvetto et al. 2013; Zamora, De los Santos, Sierra, & Luna, 2015), turning mistakes into an opportunity for learning (Kapp, 2012). In addition, the program allows students to view the solution step by step once they finish the exercise in case they have any questions, so that each student can learn at their own pace.

As we are aware of the limited sample size used in this study, it will be expanded in future work. Thus, generalizations can be made about whether this methodology could replace some real simulations while obtaining the same learning results and satisfactorily improving learning with respect to a previous master class, without needing to use many resources and ensuring student safety.

6. Conflict of interest

There is no conflict of interest declared for any of the authors of this manuscript.

7. Ethics approval and consent to participate

Students signed an informed consent form to participate in the study (Annex 1).

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9. References

Becker L. R., & Hermosura B. A. (2019) Simulation Education Theory. In S. Deering, T. Auguste, & D. Goffman (Eds.) *Comprehensive Healthcare Simulation: Obstetrics and Gynecology. Comprehensive Healthcare Simulation* (pp. 11-24). Cham: Springer. doi: https://doi.org/10.1007/978-3-319-98995-2_2

Candiago, A., & Kawamoto, L. T. (2016). Development and Validation of a Serious Game for Chemistry Laboratories. *Spaces, 37*(11), E-1.

Carrillo, J. L., & Cortés, J. A. (2016). Secuencias didácticas con realidad virtual: En el área de geometría en educación básica. *F@ro: revista teórica del Departamento de Ciencias de la Comunicación*, *1*(23), 2.

Cook, D. A., Hatala, R., Brydges, R., Zendejas, B., Szostek, J. H., Wang, A. T., . . . Hamstra, S. J. (2011). Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *Journal of the American Medical Association, 306*(9), 978-988. doi:https://doi.org/10.1001/jama.2011.1234

Corvetto, M., Bravo, M. P., Montaña, R., Utili, F., Escudero, E., Boza, C., . . . Dagnino, J. (2013). Simulation in medical education: a synopsis. *Revista médica de Chile*, *141*(1), 70-79. doi:https://doi.org/10.4067/S0034-98872013000100010

Curcio, I. D. D., Dipace, A., & Norlund, A. (2016). Virtual realities and education. *Research on Education and Media*, 8(2), 60-68. doi:https://doi.org/10.1515/rem-2016-0019GS

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10-32. doi:https://doi.org/10.1111/j.1467-8535.2009.01038.x

De Freitas, S. (2006). Learning in immersive worlds: A review of game-based learning. *Joint Information Systems Committee.* Retrieved from: https://bit.ly/3aCB8GP

Facebook Technologies, LLC. (2018). RCSI Medical Training Sim. Retrieved from: https://ocul.us/2Y6byr6

Facebook Technologies, LLC. (2019). Oculus. Retrieved from: https://www.oculus.com

Fernández, M. (2017a). Augmented Virtual Reality: How to Improve Education Systems. *Higher Learning Research Communications*, *7*(1), 1-15. doi:https://doi.org/10.18870/hlrc.v7i1.373

Fernández, R. (2017b). Calidad de la enseñanza a través de los juegos de rol en el espacio europeo de educación superior. *Revista Electrónica sobre Educación Media y Superior*, 4(7).

Google (2019). Daydream. https://vr.google.com/daydream

Gredler, M. E. (2004). Games and Simulations and Their Relationships to Learning. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (pp. 571-581). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers. doi:https://doi.org/10.4324/9781410609519

Hedrick, T. E., Bickman, L., & Rog, D. J. (1993). *Applied research design. A practical guide*. Applied Social Research Methods Series*.* Newbury Park, CA: Sage. doi:https://doi.org/10.4135/9781412983457

HTC Corporation. (2019). HTC VIVE: Discover Virtual Reality Beyond Imagination. Retrieved from: https://www.vive.com/eu

Huang, Y. C., Backman, S. J., Backman, K. F., McGuire, F. A., & Moore, D. (2019). An investigation of motivation and experience in virtual learning environments: A self-determination theory. *Education and Information Technologies*, *24*(1), 591-611. doi:https://doi.org/10.1007/s10639-018-9784-5

Jiménez, E., Mariscal, G., Heredia, M., & Castilla, G. (2018). Virtual reality versus master class: a comparative study. In *Proceedings of the Sixth International Conference on Technological Ecosystems for Enhancing Multiculturality* (pp. 568-573). New York, USA: ACM. doi:https://doi.org/10.1145/3284179.3284276

Johnson, L., Adams, S., Cummins, M., Estrada, V., Freeman, A., & Hall, C. (2016). NMC Horizon Report: 2016 Higher Education Edition. Retrieved from: https://bit.ly/3bz0gQ6

Kapp, K. M. (2012). *The Gamification of learning and instruction*. *Games Based Methods and Strategies for training and education*. San Francisco: Pfeiffer/ASTD Press.

Lateef F. (2010). Simulation-based learning: Just like the real thing. *Journal of emergencies, trauma, and shock*, *3*(4), 348-52. doi:https://doi.org/10.4103/0974-2700.70743

Lenovo (2019). Realidad virtual y aumentada: Página principal Lenovo España. Retrieved from: https://www.lenovo.com/es/es/arvr

Magic Leap, Inc. (2019). Magic Leap Home. Retrieved from: https://bit.ly/2KA0CKE

McGaghie, W. C., Issenberg, B., Cohen, E. R., Barsuk, J. H., & Wayne, D. B. (2011). Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. *Academic Medicine*, *86*(6), 706-711. doi:https://doi.org/10.1097/ACM.0b013e318217e119

McGrath, J.L., Taekman, J.M., Dev, P., Danforth, D.R., Mohan, D., Kman, N., . . . Bond, W. F. (2017). Using virtual reality simulation environments to assess competence for emergency medicine learners. *Academic Emergency Medicine*, *25*(2), 186-195. doi:https://doi.org/10.1111/acem.13308

Microsoft. (2019a). Mixed Reality Technology for Business. Retrieved from: https://bit.ly/2VZxpOi

Microsoft. (2019b). Windows Mixed Reality. Retrieved from: https://bit.ly/2yL00ik

Moreno, N. M., & Ramírez, M. B. (2015). Uso didáctico de la realidad virtual en los Grados de Educación Infantil y Educación Primaria. In A. Matas, J. J. Leiva, N. M. Moreno Martínez, N. M., A. H. Martín, & E. López (Eds.), *I Seminario Internacional de Innovación docente e Investigación Educativa*, Universidad de Málaga.

Nakai, A., & Suzuki, K. (2015). Development and research activities of advanced system safety laboratory for safety education/culture. In *Perspectives on Process Safety from Around the World 2015-Topical Conference at the 2015 AIChE Spring Meeting and 11th Global Congress on Process Safety.*

Okuda, Y., Bryson, E. O., DeMaria, S., Jacobson, L., Quinones, J., Shen, B., & Levine, A. I. (2009). The utility of simulation in medical education: what is the evidence? *Mount Sinai Journal of Medicine: A Journal of Translational and Personalized Medicine*, *76*(4), 330-343. Oxford University Press (2018). doi:https://doi.org/10.1002/msj.20127

Palés, J. L., & Gomar, C. (2010). The use of simulations in Medical Education. *Theory of Education: Education and Culture in the Information Society*, *11*(2), 147-169.

Playstation. (2019). PlayStation VR: El dispositivo de juego de RV para PS4. Retrieved from: https://bit.ly/2VZxyRQ

Quinn, F. M. (2000). *The Principles and Practice of Nurse Education*. London, UK: Nelson Thornes.

Robertson, G., Card, S., & Mackinlay, J. (1993). Three views of virtual reality: Nonimmersive virtual reality. *IEEE Computer*, *26*(2), 81. doi:https://doi.org/10.1109/2.192002

Robertson, G., Czerwinski, M., & van Dantzich, M. (1997). Immersion in desktop virtual reality. In *Proceedings of the 10th annual ACM symposium on User interface software and technology* (p.11-19). New York, USA: ACM. doi:https://doi.org/10.1145/263407.263409

Royal College of Surgeons in Ireland – RCSI. (2018). VR-mSurgery. Retrieved from: https://bit.ly/3aDKcvc

Samsung Electronics Co., Ltd. (2019). Samsung Gear VR with Controller. Retrieved from: https://bit.ly/2Kvx1lv

Sangrà, A. (2001). La calidad en las experiencias virtuales de educación superior. Retrieved from: https://bit.ly/3cLcbKU

Stratesys. (2019). COSMIC. Retrieved from: https://bit.ly/2YgPjPB

Vázquez, G., & Guillamet, A. (2009). Training based on simulation as an essential innovation in medical training. *Educación Médica*, *12*(3), 149-145. doi:https://doi.org/10.33588/fem.123.524

Yang, J. C., Chen, C. H., & Jeng, M. C. (2010). Integrating video-capture virtual reality technology into a physically interactive learning environment for English learning. *Computers & Education*, *55*(3), 1346-1356. doi:https://doi.org/10.1016/j.compedu.2010.06.005

Zamora, F. G., De los Santos, M., Sierra, G., & Luna, E. (2015). Quality in basic cardiopulmonary resuscitation skills associated with undergraduate simulation fidelity. *Research in Medical Education*, *4*(13), 22-27.