FEATURE ARTICLE

Using Virtual Reality in the Learning of Geomatic Engineering Education

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Emerging technologies can be effective in enhancing the teaching–learning process. In this article, virtual reality (VR) is used as a tool to support learning and skill acquisition in a subject of geomatics in an engineering degree. The developed tool is an immersive virtual environment that allows access to a first-person observation of the methodology to be followed in the field to carry out the proposed task. In order to validate this tool, a quasi-experiment was performed involving 170 students and several instruments to assess the knowledge acquisition of these students and their perceptions toward the learning experience. The obtained results indicate that the use of VR in the field of geomatics may be a promising means of conveying new knowledge and enhancing learning and competence acquisition in geomatics.

In the teaching–learning process, new knowledge, skills, behaviors, or values are acquired, and those already possessed by any individual are modified or reinforced. Students can adapt to the learning environment and learn more effectively.[1]

Geomatics or geospatial technology is a subject studied in different engineering degrees. It deals with the acquisition, storage, analysis, and exploitation of geospatial information. It operates mainly in the field of geodesy, cartography, topography, photogrammetry, remote sensing and geographic information systems together with different Computer Systems.[2] The growing interest in the field of spatial information, the complementarity, integration, and synergy between the disciplines and techniques that characterize it have recently led to the characterization of a new professional profile. The methodological changes for teaching this type of technologies are not yet consolidated and more experiences are needed to gradually provide solutions.[3]

Furthermore, in EDUCAUSE's 2019 Horizon Report, virtual reality (VR) is described as one of the prominent technologies that will be widely adopted in higher education in the 2020s.[4] The potential of immersive environments to enhance learning through different educational experiences has been highlighted in recent studies.[5] VR allows students to visit through virtual simulations spaces, that are not foreign to them afterward. Thus, students are placed at the center of a real 360-degree recorded environment that can be navigated simply by using, for example, head movements.[6]

Cave Automatic Virtual Environment (CAVE) systems allow users to experience virtual environments in specially constructed rooms using a structure of projections on different walls, floors, and ceilings[7] and have been used in various applications including flood scenarios,[8] BIM in construction[9] and automotive.[10]

VR can be easily available through mobile devices and low-cost VR devices such as cardboards, making it a useful tool for teachers at different stages of the teaching–learning process.[11] In fact, there has been recent research involving VR applications which have been used with a large number of students thanks precisely to this cardboard-based approach.[12]

VR headsets allow for a fully immersive experience where the learner can look in all directions, unlike a desktop which limits the view to a flat screen.[13,14] It also allows for motion tracking, many visors now offer head and body tracking, which allows for more realistic interaction with the virtual environment.[15] This gives users the feeling of being in the environment, not just observing it. It is an enhanced interactive experience through natural interaction.[16]

Radianti et al.[17] systematically reviewed the application of VR in higher education from a broad perspective. Moreover, prior works examined the use of VR as

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an educational tool to support field or laboratory work in sciences and engineering disciplines.[18] Specifically, studies such as Diaz et al.[19] used 360° VR resources in chemical engineering undergraduate laboratories. Kim et al.[20] propose a 360° video content development process adapted to the VR environment to improve educational effectiveness. Viitaharju[21] focused on first year chemical engineering students to study how the use of VR helps to properly understand the methodology and procedures to be performed. Verner[22] conducted a study on operational skills and integrative thinking with first year industrial engineering students in a robotic systems laboratory. Bhute et al.[23] performed a study on the adaptation of engineering education in the wake of the COVID-19 pandemic, arguing that teaching laboratories are essential in engineering education. The work of Abd-Elrahman implements a VR tool for learning the centring and leveling of a total station using the Meta Quest 2 headset on the Unity software development platform.[24]

Regarding the field of geomatics, the works reported in the last decade by the Geovisualization, Singular Spaces and Heritage research group (GESyP) of the Universidad Politécnica de Madrid should be emphasized. This group has been carrying out applied work in the incorporation of geospatial technologies to acquire different educational competences.[25,26,27] The learning experiences reported in these works improved the acquisition of skills, knowledge, and attitudes to achieve the specific competences related to geospatial technologies. To perform these experiences, the students were instructed in a traditional way: the objective, the tasks to be carried out and the tools to be used were described on a blackboard and the students then went to the practical area to carry out the task. However, the students who participated in these experiences emphasized the difficulty of facing tools that they had not seen before and the partial lack of knowledge of how to develop the methodology to be applied. Therefore, both the lack of prior knowledge of the tools to be used and the methodology to be followed was the problem the students encountered when they started the task in the practical field.

This article attempts to respond to this deficiency by proposing the use of VR to enhance the teaching–learning process. Thus, the main objective of this work is to evaluate the use of VR to improve the teaching–learning process in courses involving geomatics in engineering degrees. To satisfy this objective, virtual environments generated using multimedia technology were used so that students, prior to the practical task, had the opportunity to explore the tools to be used and understand the methodology and learning objectives to be achieved in the development of the task. The impact of this VR technology was analyzed through a case study based on a quasi-experimental design and supported by several instruments that allow to assess learning performance and student's perceptions toward this technology.

RESEARCH METHODOLOGY

The research design is quasi-experimental and it is based on several instruments that allow to assess the knowledge acquisition of the involved students as well as their perceptions toward the learning experience.

Context and Sample

The population are engineering students who need to acquire skills and abilities in the handling of different tools in the area of Geomatics. To reach some of this population, this research in contextualized in the engineering Alimentary Engineering degree offered by the Universidad Politécnica de Madrid (Spain). Specifically, the research was carried out in a course named "Geomatics," a third-semester course of 5 European Credits Transfer System. The main objective of this course is that students acquire knowledge in processes and methodologies and train skills and abilities to use instrumentation and tools in the area of Geomatics. To take this course it is highly advisable to have taken the first-semester course "Graphic Expression," in which, among other objectives, spatial vision plays an important role. Finally, from a temporary perspective, the learning experience here reported was carried out during the 2021–2022 and 2022–2023 academic years.

The sample is composed by 170 students and is distributed as follows. The control group is composed of 78 students, of which 47 were women (60%) and 31 men (40%), who were enrolled in the afore-mentioned course in the academic year 2021–2022. The experimental group is composed of 92 students, of which 70 were women (76%) and 22 men (24%), who were enrolled in the aforementioned course in the 2022–2023 academic year. This information is summarized in Table 1.

The students of the control group performed the targeted task in a traditional way, meanwhile the students of the experimental group performed the same task in the same conditions, but with the opportunity to explore and use geospatial tools in a VR environment.

Procedure

The proposed task in both groups consisted of learning about and handling instrumentation in the area of geomatics by applying a specific method and

TABLE 1. Summary of the sample description.

	Year	Sample	Gender distribution
Control group (Traditional teaching)	2021–2022	78	47 women/ 31 men
Experimental group (VR Learning)	2022–2023	92	70 women/ 22 men
Total		170	117 women/ 53 men

visualizing a graphical output with the objective that students acquire skills and abilities in their learning process. The delivery of the task by each student was done by preparing an individual report and uploading it to the Moodle platform of the course. The deadline for the delivery of the task was one week. The learning outcomes were: to properly use surveying instruments in their application to engineering projects, to apply the geomatics methods studied, and to interpret the data obtained from the employed surveying instruments. The topographic method used was a closed polygon survey with three stations for a planimetric survey. These learning outcomes respond to specific competencies required for the student to know, understand and be able to demonstrate: the performance of a specific occupation or job position. The competence associated with the learning outcomes responds to the ability to know, understand, and use the principles of topographic surveying and stakeout, cartography, photogrammetry, geographic information systems, and remote sensing in agronomy. The tool used for the evaluation of the tasks was a rubric.

The students in the control group did this task in the traditional way (i.e., attending lectures and following the teacher's expository instructions for the assignment), and then go out to develop the task on the practice field. In the experimental group the task was performed under the same conditions as those of the control group (i.e., same course, same topics, same materials, same evaluation method and same teacher), but with a remarkable difference. The students of the experimental group were proposed to incorporate to the task the use of VR as a tool to promote a better performance. In the experimental group, a session was held prior to go out to the field. In this session, the students had the opportunity to explore the tools to be used and observe the methodology to be followed in the field using their smartphones supported by a Bercley VR cardboard. The students scanned the QR code generated on their mobile device and entered the virtual environment of the task to be carried out.

To make use of VR in the task, virtual environments were generated using multimedia technology so that the students, before the in-person class, had acquired the knowledge and understood the objectives that are intended to be achieved in the development of the proposed task. As will be detailed explained in the Educational Materials section, the simulation of this virtual environment is based on the interconnection of 360° panoramic images capable of providing a feeling of total immersion and it is accessible from any IOS or Android mobile device.

The HMD VR headsets used in the experiment are standalone devices that do not need to be connected to a computer, giving the student more freedom to move around and learn more about the surveying instrument. The student is completely immersed in the virtual environment without the usual distractions of the computer screen and the physical environment around them (emails, notifications, etc.).

Research Instruments

Three instruments were used in this research: one to measure student's prior knowledge (pretest), another to measure the student's knowledge after the task (posttest), and another to gather student's perceptions (questionnaire). These instruments are described next.

First, the final grades of the first-semester course "Graphic Expression." These grades partially serve as a measure of the student's prior knowledge and skill in the proposed task since, as mentioned before, in this course spatial vision plays an important role. Thus, these grades serve as a pretest measure.

Second, the grades of the proposed task, which serve as posttest measure. The task was graded using the rubric evaluation tool design which is depicted in Table 2. The rating of the rubric was then converted to a numerical value according to the following correspondence: A-10, B-7, C-5, D-2. It is remarkable that a rubric is an assessment tool that is adaptable to the needs of the evaluator and facilitates student engagement and understanding.[28]

Finally, in the experimental group, a questionnaire to gather students' perceptions toward the task and the usage of VR was also employed. This instrument was composed by 8 items, in which the students were asked to indicate their level of agreement with some statements on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). The items are depicted together the results. Moreover, the questionnaire also posed an open-ended textual question to collect comments to know the main problems faced by students before performing a task like the proposed.

TABLE 2. Evaluation rubric.

Rating	Explanation (How merit is determined)
A – Excellent	The presentation of the report, the data and calculations performed, demonstrate outstanding performance in this area.
B – Very good	The report presentation, data, and calculations performed demonstrate good performance in this area.
C – Good	The report presentation, data and calculations demonstrate acceptable performance with deficiencies in this area.
D- Poor	The report presentation, data and calculations performed demonstrate poor performance in this area.

Data Analysis Techniques

Data were collected through the aforementioned instruments. The obtained results were analyzed by using two descriptive statistics: mean (M) and standard deviation (SD).

Moreover, several statistical analyses were used to analyze the academic data collected through the student's grades in order to determine the educational impact of the VR tool incorporated to the task in the experimental group. The Kolmogorov–Smirnov test revealed that the data did not follow a normal distribution. So, nonparametric tests were employed. Specifically, Mann–Whitney test was employed to compare the differences between the scores achieved by the students of each group in the pretest and the posttest. The magnitude of these differences is determined through the r correlation coefficient, which is used as an effect size measure. According to Cohen's guidelines, the thresholds indicated for r correlation coefficient are as follows: the effect size is small from 0.1 to 0.29, medium from 0.3 to 0.49 and large from 0.5.

Finally, the qualitative data collected through the questionnaire were analyzed by means of thematic analysis and text coding technique.

EDUCATIONAL MATERIALS

The advancement of information and communication technologies (ICT) in education has contributed to the development of innovative tools dedicated to improving the teaching and learning process.[29] In our work, we aim to integrate the use of technology in teaching in order to improve student experiences and outcomes.[30]

The material developed as an educational resource in digital format is available on the website of the GESyP research group (https://blogs.upm.es/rumpeag/) for any teacher of the knowledge area. The digital educational material consists of both access to the virtual environment and a guide to explain and put into practice the proposed task.

FIGURE 1. QR code to access to the virtual environment.

The implemented immersive virtual environment gives access to a first-person observation of the methodology to be followed in the field to carry out the proposed task (see Figure 1). In our case, the use of a closed polygon method with three stations to carry out a planimetric survey located in the practice field (gardens of the School of Agricultural, Alimentary and Biosystems Engineering, ETSIAAB—Universidad Politécnica de Madrid). In this virtual environment, students can observe, move around, check the methodology to be followed, see both the critical points of the exercise and the different visualizations to be carried out, etc.

The virtual environment consisted of the interconnection of several 360° panoramic scenes and the implementation in each of them of additional information or buttons to interact with it. As soon as the student puts on the HMD, he/she is immersed in the same space where he/she will later carry out the field exercise and can visualize the different tasks to be performed by means of panels and interact with the application by means of buttons that inform him/her of the aspects to be taken into account in order to carry out the exercise correctly (see Figure 2). Buttons and information panels are activated through gaze-based interaction, allowing the user to select and activate buttons simply by focusing on them during two seconds, eliminating the need for manual controls and providing a more intuitive experience.

There are diegetic buttons that, when activated through the gaze, show an informative image of the exact point where the topographic instrument should be placed, and/or buttons that, when activated, show the points where the necessary data should be observed and recorded. There are also buttons that, when activated, move to the next scene to follow the methodology of the field exercise.

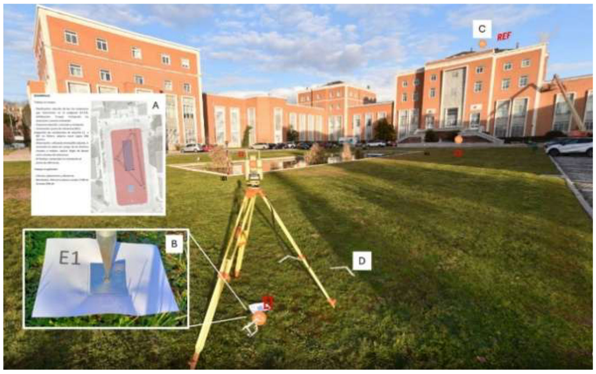

FIGURE 2. The interactive description of the immersive VR application is as follows: signs indicating the tasks to be performed (A) buttons explaining how to perform different tasks (B) or which points to observe (C), and buttons to move between the different immersive scenes (D).

FIGURE 4. Edited panoramic image, adding various hotspots to help students understand the task.

The implementation of the virtual environment was carried out according to the following process:

1) Using an SLR camera and/a fisheye lens, seven images were taken at 60° intervals, including one shot toward the sky. The SLR camera used was a Nikon D5600 equipped with a Nikkor 10.5 mm 1:28G fisheye lens, which captured high-resolution images (24 MPx). The camera's internal parameters such as exposure time, ISO, HDR mode, and aperture was properly configured. The camera was mounted on a photographic tripod and a Manfrotto 303SPH panoramic head to obtain the seven images at 60° intervals (see Figure 3).
2) The seven images were processed in the open source software Hugin (https://hugin.sourceforge.io/, accessed August 20, 2024). From the extraction and matching of key points between the different images using the scale-invariant feature transform algorithm, a global registration to minimize the accumulation of errors and optimize the parameters of camera distortion, focal length and angular positions, a panorama is generated by projecting the images into the spherical coordinate system.[31] A total of three panoramas in .jpg format were generated for the task.
3) In order to associate information with the panoramas and to facilitate the students' understanding of the task to be performed, the panoramas were edited in Photoshop software (https://www.adobe.com/, accessed 20 August 2024). Hotspots as image elements or workflows were used by the students to facilitate and understand their usability and the subsequent way of performing the proposed task (see Figure 4).
4) The stitching of the 360° panoramic images and the preparation of the immersive and interactive visualization for the website was done in Pano2VR software (https://ggnome.com/pano2vr/, accessed 20 August 2024). This is a Flash-based panoramic image conversion software. Its output format allows its implementation in web pages or direct playback. It has been used to disseminate and promote museum exhibitions,[32,33] cultural heritage,[34] location services,[35] etc., as a virtual tour, giving users an immersive, interactive experience without leaving home.
5) Finally, the corresponding hotspot information and navigation function on the website is achieved through the use of HTML5 technology. The virtual interaction function is added, allowing students to move between the different virtual scenes of the practice in question, giving them a sense of immersion. The virtual environment generated can be enjoyed by the students by using their smartphones supported by a Bercley VR cardboard (see Figure 5).

FIGURE 3. Arrangement of the reflex camera and the topographic total station used in one of the panoramic images taken (training field at ETSIAAB).

FIGURE 5. Pretrip session using the Bercley VR cardboards.

TABLE 3. Results.

	Pretest ("Graphic expression" grade)	Posttest (task grade)
Control group [M (SD)]	4.2 (2.6)	5.8 (1.1)
Experimental group [M (SD)]	4.0 (3.0)	6.8 (1.8)
Mann–Whitney test [p-value]	0.785	< 0.001
Effect size [*r* coefficient]	0.04	0.31

Finally, it is mentionable that in the reported learning experience the fieldwork was carried out in groups of 3 or 4 students who shared the different tasks: using the total station, using the survey prism pole, taking data, and making sketches. The students changed their roles in order to learn and acquire different skills and abilities in the use of surveying equipment. Accordingly, one of the strategies used by the students in the prepractice session was to use the immersive environment to better understand and comprehend the process of the task and the different functions to be performed. Any doubts or problems that arose in the navigation and use of the educational material were solved by the peers of the group.

EVALUATION

Knowledge and Competences Acquisition

Table 3 depicts the results of the grades obtained by the students of both groups on the previous course "Graphic Expression" (that serves as pretest measure), as well and the grades obtained by the students in the proposed task (that serves as posttest measure). It can be observed that the difference in the pretest between both groups are not statistically significant, but the difference in the posttest are statistically significant ($p < 0.001$) with medium size effect ($r = 0.31$) in favor to the experimental group.

The same grading rubric was used for both the control and experimental groups. The opportunity offered to the experimental group to explore in an immersive way, in a session prior to the field practice, the space where the practice will take place and the methodology to be followed, is reflected in the results of the qualification obtained through the rubric.

The groups of students who participated in the session prior to the field exercise using the VR application performed the different tasks more easily and followed the methodology necessary to carry out the topographic survey without having to consult the teachers. They were familiar with the space where the exercise took place and remembered the steps to be followed in order to carry out an accurate survey. It should be noted that the field exercise lasts for 2 h and a total of 50 students go out into the field in groups of 5, which means that since this is the first time they have "touched" a topographic instrument, they have many doubts about how it works and the methodology to be followed. The students are accompanied by two teachers who try to help each group and dispel their doubts.

The evaluation rubric has taken into account both the quality of the report presented and the quality of the data collected and their subsequent calculations. Typical errors that undermine the accuracy of the methodology applied are related to forgetting to collect the relevant data or not following the methodology correctly. Prior access to this space, where the field practice is developed through VR, significantly improves these "small" errors, which are mainly due to lack of knowledge of the methodology to be followed. The results of the rubric in the experimental group suggest a better knowledge of the methodology to be followed, and therefore favor the acquisition of skills and abilities in the use of instruments in the field of geomatics. The final results showed that both groups of students performed similarly on the pretest, but the students in the experimental group obtained significantly better results in the posttests than those who used traditional methods.

Student's Perceptions Toward the Need of the Experience

Students in the experimental group were asked through an open-ended textual item of the questionnaire about the main difficulties they faced when perform a task like the proposed. As mentioned before, this qualitative

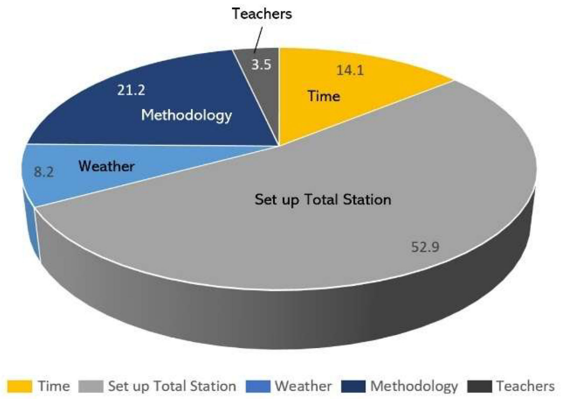

FIGURE 6. Qualitative results about the difficulties found by the students (%).

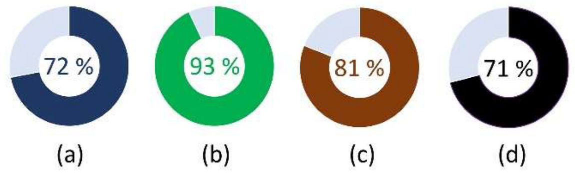

FIGURE 7. Questionnaire results: (a) Students who have never used VR in a subject before, (b) use of VR could be useful in geomatics, (c) improves understanding of the methodology to be followed, and (d) VR helps to acquire new ICT skills.

data were analyzed by means of thematic analysis and text coding technique.

A total of 85 comments were collected. The comments were interpreted and different labels were coded by a researcher. A review process was performed by another researcher to improve the reliability of the codification process and some adjustments were made. Finally, it was determined how many times each code appears in the comments (in terms of codification, how grounded is each code) to estimate its relevance (see Figure 6).

Category 1 (Time) refers to the comments made by the students about the lack of time to carry out the fieldwork. Some representative comments of this category are as follows: "Difficulty in using the equipment for the first time," "Spending more time getting to know the instruments," "Getting organized at the beginning," "Planning the field, a correct distribution of time," "Little time," or "Time available."

Category 2 (Set up total station) are comments related to the difficulty the students had in handling the surveying instrument used during the fieldwork: "Not knowing how to stabilize the instrument," "How the instrument works," "Calibrating the tachymeter correctly" or "It is complicated to use the instrument for the first time."

Category 3 (Weather) relates to the weather at the time of fieldwork. Comments such as "temperature" and "it is cold during the training."

Category 4 (Methodology) are difficulties encountered by the students, which are represented with comments such as "understanding the methodology," "not knowing how to start," "not having a guide for action," "not knowing the methods," "the explanation was not clear" or "partial lack of knowledge on how to carry out the activity."

Finally, category 5 (teachers) refers to teacher-related difficulties represented through comments such as "few teachers " or "the teacher does not understand me."

Finally, it can be noted the high percentage (88.2%) of three characteristics extracted from the thematic analysis: set up total station, methodology, and time. This points out the need to introduce new tools through multimedia technology to help students in the acquisition of knowledge and to help them understand how to plan the different tasks to be developed in the tasks like the proposed.

Student's Perceptions Toward the Learning Experience

In the experimental group, the questionnaire used reflected students' perceptions of VR use after the task. As can be observed in Figure 7, 72% percent of the students had not used a virtual system in any subject before, and after the experience more than 93% of them said that the use of VR could be a useful tool in the area of geomatics. Regarding the use of VR, more than 81% of the students say that its use prior to the practice improves the understanding of the methodology to be followed in the proposed task. Finally, 71% of the students agree that the use of VR helps them acquire new skills in the use of ICT.

Regarding improvement areas, students in the experimental group also responded an open-ended question about improvement suggestions. They mainly focused on the need of spend more time using VR to improve the learning experience and how the experience would be improved if there was a more detailed explanation of how the tool worked.

Finally, it is interesting for readers considering the adoption of VR in their own scenarios to report the number of students experiencing discomfort. Specifically, in this study four students (2.4%) experienced headaches and discomfort when using VR.

DISCUSSION

Recently, with increasing technological advances and the global pandemic, ICTs have had a significant impact on education and learning since the use of digital resources promotes, among other things, active learning. Bhute et al.[23] pointed out how the integration of different technologies, including VR, can help to develop new environments and modes of engineering education. Moreover, Radianti et al.[17] found that the most extended usage of VR in higher education was for teaching procedural–practical knowledge.

Abd-Elrahman[24] developed a VR educational application using Unity to teach geomatics, and highlights the difficulties of simulating the functions of the total station itself. Although with similar objectives, our study differs in the use of low-cost devices that facilitate their use by a large number of students. Moreover, we emphasize the usefulness of the feeling of immersion in the field where the field practice will take place to improve the learning of the methodology to be followed and to develop skills and abilities in the use of instruments in the field of geomatics beyond the management of a total station. Martín-Romero's[36] study also has similar objectives to ours, although the study presented shows an interactive scenario in which the user moves freely, which we believe favors immersion and interaction.

Several studies have explored the benefits and applications of VR in a number of different scenarios.[17,18,19,20,23,37] Overall, these studies conclude that the use of immersive VR has the potential to enhance learning experiences in engineering education. Our study supports these conclusions and applies VR in a new learning scenario, demonstrating how this technology serves as an effective tool to enhance learning and skill acquisition in geomatics.

Unlike CAVE systems, whose high cost and infrastructure requirements make them difficult to access widely and limit the ability to transport students to specialized centers, our approach allows for an accessible immersion experience that adapts to budget and mobility constraints, thus expanding educational opportunities in VR environments.

The results obtained related to the student's grades show that the boost provided by the presented VR tool was clearly effective for learning geomatics in engineering education from the instructional point of view. It can be stated that the initial level of knowledge and competences of the both groups of students were similar (no significant differences were identified in the pretest), but the level of knowledge and competence attained by the students of the experimental group, who had the opportunity to perform the task with the support of a VR tool, was significantly higher. Therefore, we can conclude that the use of immersive virtual environments facilitates the prior exploration of the geomatics tools to be used and the understanding of the methodology and learning objectives to be achieved in the development of tasks like the proposed.

Similarly to our study, Diaz et al.[19] and Kim et al.[20] provided VR-based resources through a 360° video tour as a learning tool prior to practical sessions in a chemistry laboratory. In this respect, we agree with this study that the use of VR in advance enhances the hands-on practical sessions in the laboratory. Both studies conclude that VR facilitates the understanding of the instrumentation and the procedure to be followed during the practical sessions. Other studies conducted in engineering contexts draw similar findings.[21,22]

Viitaharju's study[21] also focused on chemical engineering students. VR experiences were developed in a chemistry lab. The students performed the same lab exercise both in VR and in real life. As a result, they state that virtual labs cannot replace the experience in a real lab, but, as in our study, the authors concluded that VR helps to understand the methodology and procedures to be performed.

As in our study, Verner's study[22] took place in an engineering environment and employed an experimental design. In the experimental group, students were given the opportunity to experience VR in the operation of robotic systems outside the laboratory. Similar to the results reported in this study, the results of that study revealed significant advantages of the experimental group over the control group in terms of operational skills and greater appreciation of the learning experience. In our study, in addition, a pretest assessment was considered in order to ensure that the prior knowledge of both groups was similar.

Another advantage of VR educational applications is the accessibility of field exercises or virtual field trips from anywhere and at any time.[38] This allows students to explore interactive spaces that are difficult to access or to explore them at any time of the day. In our study, this advantage responds to one of the main problems identified by the students in characteristic 4 (methodology). The virtual visit aims to bring the students closer to what they will find on the day of the real practice in the field and to correctly develop the methodology to be carried out.

Coinciding with Andrievskaia's study,[39] some of the drawbacks identified in the current study relate to potential physical discomfort, such as headaches or eye strain, experienced by some students. Some students experienced headaches and discomfort when using the VR during intensive use of the experience. The sensation of being immersed in a virtual space and the intensity of its use may cause subjective discomfort, which is frequent when using VR.[40]

Nevertheless, in Viitaharju's study (88%), Verner's study (83%) and our study (81%), students agree that the use of VR prior to actual practice improves their understanding of the methodology of the proposed task and enhances their learning of the subject. Moreover, in Viitaharju's study (64%), Verner's study (85%) and our study (71%), students agree that the use of VR helps them to acquire new skills in using ICT. Unfortunately, this study, like those of Verner and Viitaharju, performs a survey evaluation of the experience that does not allow us to identify fine-grained performance metrics that would explain in detail what exactly causes the high performance and positive perception of students for this type of VR-based educational initiatives. Nevertheless, previous studies in other areas[17] emphasize that immersion plays a key role in the educational success of these initiatives.

CONCLUSION

Prior work in science and engineering education shows that VR offers the opportunity to simulate real-life experiences, allowing students to face challenges and develop strategies that they will later face in the field. The use of VR facilitates the understanding of instrumentation and procedures to be followed in the field. In this work, VR is proven to be an effective tool for enhancing learning and skill acquisition in geomatics. To the knowledge of the authors, this is the first work that proves the usefulness of VR in the learning process of geomatics.

Specifically, the results of this work prove that the developed VR tool (publicly available at https://blogs.upm.es/rumpeag/) clearly improve student performance in geomatics learning process by providing a more interactive and realistic learning experience. Moreover, we deem that the usage of VR tools like the presented favors the autonomous learning of the students, since they can access the implemented tool from anywhere and at any time, as well as group work, since students can use the VR tool in groups and can solve or share any doubts they may have when using it.

Anyhow, while VR experiences can be valuable in supporting the understanding of tools, concepts, and methodologies, they cannot completely replace hands-on learning experiences, especially when it comes to acquiring skills and abilities in the use of surveying and geodetics instruments. Therefore, we deem that combining virtual and real laboratory experiences is the most effective strategy for science and engineering education, allowing students to benefit from the best of both worlds: VR-enhanced learning and real hands-on experience.

Despite the robustness of the experimental design that supports the reported conclusions, this study is not free of limitations. The learning experience VR-supported here presented was performed in a single academic year group of a specific engineering degree. This may bias the results because results may vary in other academic years and engineering degrees since students' characteristics and needs may vary. Therefore, future work involves the replication of the presented experience in other academic years and other engineering degrees involving geomatics such as forestry engineering or topography and geodesy engineering.

Moreover, we recommend further investigation and development of enhancements to experiential learning through virtual simulations and the use of VR. These simulations can provide students a safe and realistic environment in which they can practice and gain an understanding of different geomatics methodologies, as well as acquiring practical skills on surveying equipment and geodetics instruments. Indeed, the following future work are proposed. First, to develop new immersive VR experiences for different geomatics tasks. Second, to develop a virtual environment that is not static or moving from one hotspot to another, but where the virtual environment changes as the observer moves in real time. The common goal of these research lines is to continue improving the teaching–learning process in the area of geomatics in engineering degrees. Third, to carry out similar studies to strengthen these conclusions, and to include in these studies finer-grained evaluations that will allow us to find out exactly what is behind the high performance and good perceptions of students.

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