Collaborative Virtual Reality for Surveying Education

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Key words: virtual reality, surveying education, collaborative learning, teamwork

SUMMARY

Immersive technologies have experienced rapid advancement in recent years, and they have experienced widespread dissemination and implementation in several disciplines including engineering. These virtual reality implementations demonstrate a capability to support education. However, implementations often lack connections with theoretical pedagogical structures, leading to suboptimal results. This paper presents virtual reality implementations following two different pedagogical frameworks, namely experiential learning and situated cognition / collaborative learning. In the former case students engage in a virtual experience and learn by doing, while in the latter students learn through communication and deriving solutions as a team. It is widely accepted that teamwork and collaboration are increasingly important skills in engineering. This paper demonstrates an example of virtual reality labs in surveying engineering that follow a situated cognition framework. The situated cognition labs are compared with virtual reality labs that follow an experiential learning approach. The paper presents the first assessment results of collaborative learning and evaluate the role of collaborative virtual reality to enhance student learning and support surveying education.

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1. INTRODUCTION

Immersive technologies typically include Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR). Immersive technologies have experienced rapid advancement and development in the past decade, with uses in the surveying profession and surveying education. In the surveying profession it is worth highlighting Trimble SiteVision (Trimble 2022) and the Leica vGIS (Leica-Geosystems 2022). These are AR systems that allow accurate visualization of 3D models in the real world, integrating 3D models with data collected in real time. Although, this is an AR example, it shows how the industry is starting to utilize immersive technologies. Virtual Reality, and immersive technologies in general, have found more applications in education and training. Thanks to their rapid advancement, we can find application examples in several disciplines ranging from engineering, medicine and surgery, social sciences, liberal arts, and more (examples of recent cases can be found in: Chheang et al. 2021; Hur et al. 2021; Ma 2021; Singh et a. 2021). In recent years, we also note several remarkable examples in surveying education. For instance, O'Banion et al. (2020) used immersive visualization to demonstrate the process of data acquisition from airborne laser scanning. In Levin et al. (2020) students used a virtual total station to collect topographic data to generate contours. Bolkas et al. (2022) have developed software that allows students to collect differential leveling data in an immersive and interactive VR. In Sakib et al. (2020) an unmanned aerial vehicle (UAV) virtual training software was developed to assist student preparedness with flying a UAV. We notice that VR in surveying education is being used to prepare students for hands-on labs, connect practical and theoretical concepts, develop specific skills, and provide experiences that cannot be completed in the real world due to cost, access, or liability limitations.

Virtual reality implementation should relate to an appropriate theoretical framework and educators should have a solid rationale for the use of VR and integration in existing curriculum (Johnston et al. 2018). Many of the existing VR implementations are often focused on assessment of longstanding objectives not tailored to VR and unfortunately the pedagogical structures are not clearly addressed (Vincent et al. 2008; Solak and Erdem 2015; Johnston et al. 2018). The lack of a robust link between VR application and pedagogical principles and concepts leads to suboptimal implementations of VR in education (Psotka 2013; Johnston et al. 2018). The pedagogical foundations that are often found in VR, discussed in this paper, are derived by Kebritchi and Hirumi (2008) and used in Johnston et al. (2018). These are briefly described as follows:

i. Direct instruction: students acquire skills through tutorials, presentation of information, repetitive instructions, drill, and practice;
ii. Experiential learning: students engage in real-life or virtual experience; students observe, think, do and conceptualize and experiment, learn by doing;
iii. Discovery learning: students build on existing knowledge to learn new concepts through discovery, inquiry, applying problem-solving and decision-making;
iv. Situated cognition: students are observers and actors, follow others, engage in social interaction and communications to learn, derive solutions as a team to problems; and,
v. Constructivism: closely related to experiential and discovery learning; knowledge is built by the learner, students gain knowledge by making sense of experiences, students act, experiment, and reflect within the experiences.

Of the above pedagogical foundations, experiential learning is often cited in VR studies, and is the primary role in VR implementations. VR opens the door to experience environments that are difficult to access, dangerous, socially or culturally unacceptable, and/or very expensive (Fowler 2015; Johnston et al. 2018). For this reason, Johnston et al. (2018) also make note of secondary pedagogical foundations with their analysis showing that discovery learning and constructivism appear as a secondary role in most applications. This result is related to the nature of role-play gaming where the gamer explores the environment and discovers artifacts, clues, and information required to continue to the next level or mission. Of particular note, there are few studies that use situated cognition and collaborative learning as pedagogical approach (Johnston et al. 2018). The same observation is found in Potkonjak et al. (2016), who also analyzed many implementations of VR in engineering education despite the implementations being desktop based and not immersive. Many immersive VR implementations that utilize situated cognition are from the military realm where soldiers are trained as a team to respond in various threat situations (e.g., Bink et al. 2015).

In situated cognition, knowledge is embedded in its context, activity, and culture within which it is developed and used for learning (Brown et al. 1989; Kebritchi and Hirumi 2008). The social interactions and communications with others are fundamental to achieve learning (Brown et al. 1989; Kebritchi and Hirumi 2008). Therefore, learners are not isolated (as they are in many VR implementations); rather, they learn while interacting with other students within shared activities that are designed to facilitate communication, discussion, problem-solving, transfer of knowledge, and skills (Aydede and Robbins 2009). Situated cognition is based on social development theory where social interactions are the main method for developing cognition (Vygotsky 1978). The activity used as means for learning is also an important component of the theory of situated cognition, as activities must be authentic and framed by the domain's (or profession's) culture and ordinary practices (Brown et al. 1989). Concepts such as teamwork, engaging in technical and diverse discussion, learning from peers and/or instructors, and collaborative learning are integral to engineering and essential aspects of Accreditation Board for Engineering and Technology (ABET) accreditation for many surveying / geomatics programs. Collaborative learning is an integral aspect of situated cognition, and it can be achieved by designing activities and labs that have situated cognition as their primary pedagogical focus.

Situated cognition provides the means for context-based collaborative learning, transferring of knowledge and skills between learners, and simulates real-world learning settings. Immersive technologies become the "next big thing" and an important tool for many engineering disciplines (Piroozfar et al. 2018); therefore, integrating such technologies in the surveying curriculum is vital for preparing future surveyors. This paper demonstrates an example of situated cognition implemented through VR surveying engineering labs. The VR labs are designed under the situated cognition framework, and compared with VR labs that follow an experiential learning approach. The main research question is: can situated cognition support and assist learning of surveying engineering principles in activities that are designed in immersive and interactive VR? The paper presents the first assessment results of situated cognition / collaborative learning and evaluates the role of collaborative VR to enhance student learning and support surveying education.

2. VIRTUAL REALITY LABS

The VR labs that were used in this paper were on differential leveling and using the Surveying Reality (SurReal) software that was presented in Bolkas et al. (2021). The software simulates differential leveling in immersive and interactive VR. It was expanded to include GNSS labs, and, in the future, is expected to support exercises that utilize a total station instrument. The software uses the Oculus Rift for controls and for the head mounted display (HMD), and it can also use similar Oculus devices that can connect to a desktop computer such as the Oculus Quest. The software and instrument handles were developed in Unity, while several of the 3D models and buildings were developed in Autodesk 3DS Max and Blender (see Bolkas et al. 2020; Bolkas et al. 2021). Students can grab and move the differential level instrument, level it by adjusting the legs and tribrach screws, and make measurements and record them in a virtual fieldbook (Bolkas et al. 2021; Bolkas et al. 2022). The lab is based on a three-benchmark leveling loop (Figure 1), where for each setup we increase the level of difficulty to challenge the student (Bolkas et al. 2022).

Figure 2 shows a side of the benchmark locations. In the first segment (BM1 to BM2), there is no real challenge, as we want to give time to the student to get familiar with the software and the VR controls. In the second segment (BM2 to BM3), there is a road sign next to BM2, which can block the line of sight; therefore, the student needs to select a suitable instrument location. In the third segment (BM3 to BM1), we have added a car as an obstacle, there is high terrain variability, and tree branches can block the view. If the student does not select an appropriate location to setup the instrument, then the student will either aim to low at BM1 or the view to BM3 will be blocked by trees.

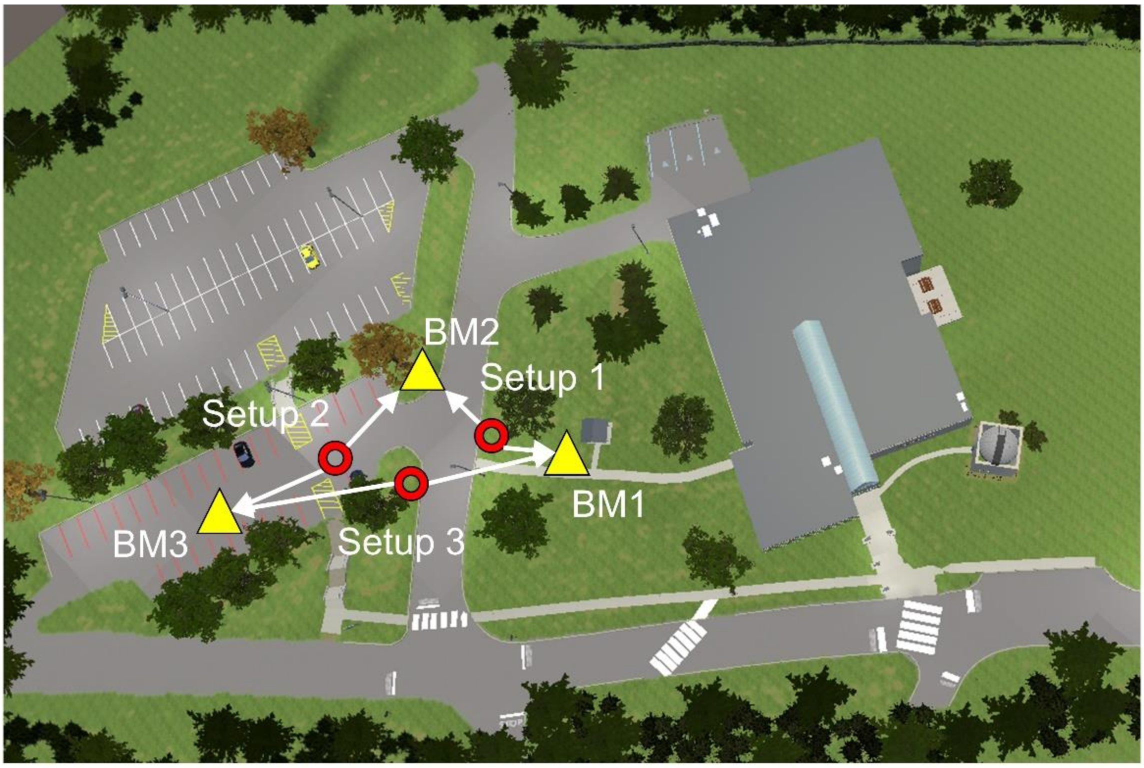

Figure 1. Virtual environment and virtual lab. The figure shows the benchmark (BM) locations and example instrument setups.

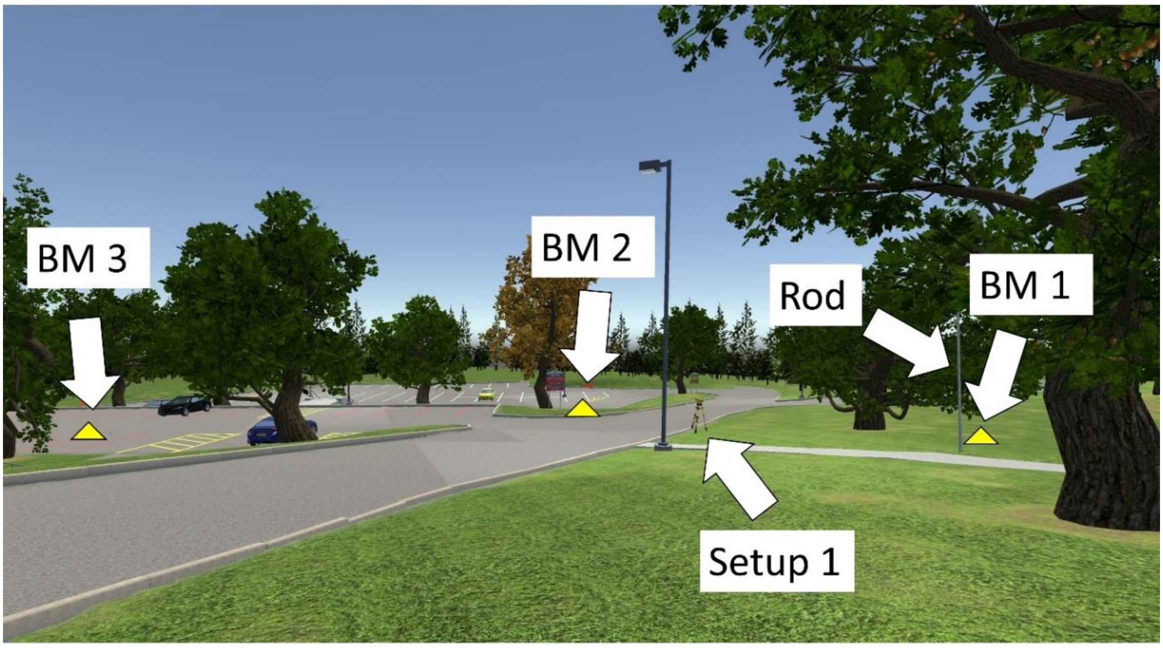

Figure 2. Ground level perspective view of the benchmark locations in the three-benchmark leveling loop.

2.1 Experiential learning approach

In the experiential learning approach, the students complete the virtual lab on their own, meaning that they are the only surveyor in their specific virtual lab. The focus of the virtual experience is to prepare students for the physical lab by allowing the students to learn by doing. Prior to the virtual lab, the students receive theoretical instruction on differential leveling through traditional means i.e., class demonstrations and presentations. In the virtual experience, the instructor demonstrates the main controls and the process of completing a differential leveling loop in VR. Students then conduct the lab in VR on their own, handling both the differential level instrument and the leveling rod. This approach has the advantage of exposing the student to both the instrument and rod roles, giving them a complete understanding of the differential leveling process. Therefore, in the experiential learning approach students engage in the virtual experience, and in general learn by doing. In addition to the experiential learning, the virtual lab also has elements of discovery learning, as students build knowledge by problem solving, decision making, inquiry, and trial and error. For instance, consider the student making decisions about the optimal position of the differential level considering terrain and line of sight constraints. At the end of the experience, students receive a report of their observations along with the true observations generated by the software. This introduces elements of constructivism, as students can identify their mistake and make sense of their experience and decisions.

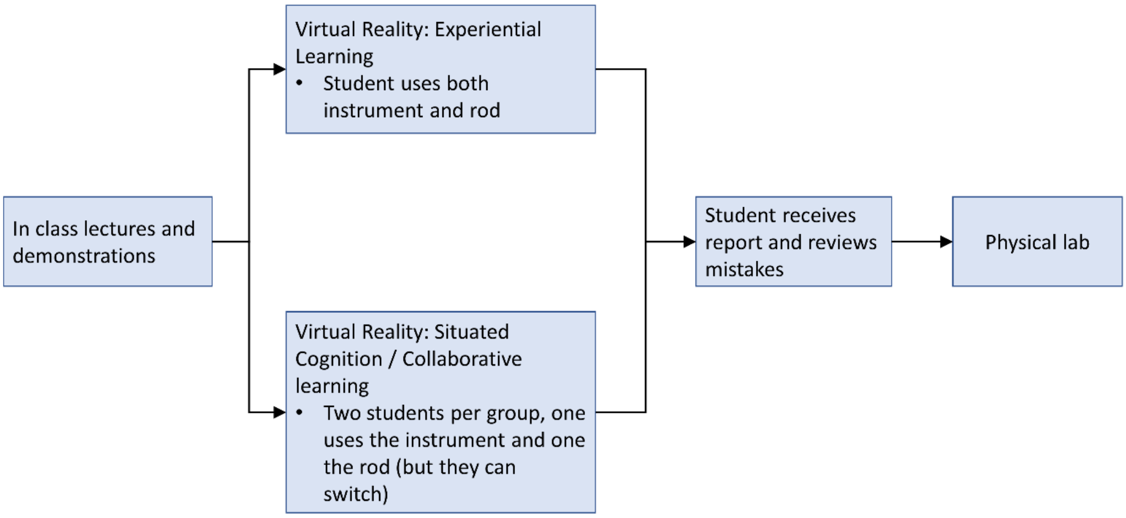

Figure 4. Flowchart of the experiential learning and the situated cognition implementation approaches

2.2 Situated Cognition / Collaborative Learning

For the situated cognition approach, the focus of the lab is to use collaboration, communication, and interaction to learn and derive solutions as a team. The group of students that completed the collaborative virtual lab followed the same surveying process as the individual student group; however, two students were able to co-exist in the same virtual environment and work together. For each team of two, one student assumed a leadership role and operated the leveling telescope instrument, while the other took a follower role and handled the leveling rod (Figure 5). Instructions about the leader-follower roles were emphasized before conducting the virtual lab. Participants were able switch roles at any point throughout the virtual exercise and were encouraged to do so following each instrument setup. Following their collaborative completion of the differential leveling loop, each team was able to review the exercise performance report where they can identify any mistakes made and discuss possible mitigation strategies. As mentioned above, the focus of the virtual exercise is for students to learn through collaboration, communication, and interaction; however, it is important to highlight that the exercise still maintains elements of experiential learning, discovery learning, and constructivism. A disadvantage of this method is that the students experience only one role if they do not switch; however, this can take place in the real-world as well. To counter this in the virtual world, a forced role change could be implemented.

Figure 5. Students collaboratively complete a virtual lab in SurReal. The student in the background is handling the differential level instrument, while the student in the foreground is handling the leveling rod.

2.3 Student Sample and Assessment

The two experiential and situated cognition labs were implemented at Penn State Wilkes-Barre in an introductory surveying course in Fall of 2021. In addition, the experiential learning labs were implemented at the United States Military Academy (USMA) at West Point, New York. The situated cognition labs were not operational at the time of the USMA trials due to a technical issue with the multiplayer SDK of the software. Therefore, the focus is placed on the Penn State Wilkes-Barre sample. There were 14 students in SUR 111, the introductory surveying course at Penn State Wilkes-Barre, in Fall of 2021. Of those students, 8 were randomly selected to complete the virtual leveling lab in the situated cognition framework; thus, forming 4 groups of 2 students. The remaining 6 students completed the virtual leveling lab in the experiential learning framework.

To assess the two learning approaches, students completed pre- and post-tests. The pre-test had questions related to trigonometry such as calculating angles and distances in a right triangle using the sine, cosine, and tangent formulas, using the law of cosines, and the Pythagorean Theorem. The post-test, was a midterm exam, and we focus on a question that asked students to prepare a set of leveling notes, calculate the page check, and calculate the adjusted elevation for one BM. The leveling line had three leveling setups with three backsight and three foresight measurements. In addition to the post-test, we use the student performance during two physical leveling labs at Penn State Wilkes-Barre that followed the virtual lab.

Assessment using pre- and post-tests may not be the most suitable measure to show learning differences and differences related to teamwork and collaboration. Therefore, we augment our assessment with student-to-student evaluations about their collaboration. This evaluation is concentrated around a three-question survey where students were asked to rate their partners with scores ranging from 1 to 5:

- Demonstrates good and encourages communication among teammates;
- Demonstrates participation in decision making;
- Demonstrates active team member participation in assigned-role duties.

Furthermore, after the students completed the situated cognition virtual lab they answered the following questions, again providing scores ranging from 1 to 5:

- I liked the ability to communicate in the VR lab;
- Rate the communication quality;
- Rate the collaboration with your partner;
- Working in a group helped me learn;
- Working in a group in VR was enjoyable.

3. RESULTS

3.1 Student Background

Table 1 provides information about the background of students with respect to surveying and VR. Almost all students in both samples have no prior experience with surveying and the differential leveling process. In terms of their experience with VR, 4 students in the situated cognition and 2 students in the experiential learning samples had used VR before. However, their experience was very minimal, and they indicated that they had used VR only a few times as part of a course or for gaming purposes. Both samples can be considered as non-experienced with both surveying and VR. This is important and worth highlighting because it makes the process of learning using immersive technologies challenging. Students have to learn VR and then be able to conduct the virtual lab; therefore, sometimes their ability to learn how to use VR can affect their learning and progress in the virtual lab. Compared to previous years, we find that an increased number of students have had some exposure to immersive visualization technologies, which is encouraging for future virtual lab implementations, as students may come more prepared to use this technology and be able to focus on the virtual task / lab.

Table 1. Sample background and experience with surveying and VR

	Worked in surveying	Conducted leveling before	Prior VR experience
Experiential learning	0/6	0/6	2/6
Situated Cognition / Collaborative learning	1/8	1/8	4/8

3.2 Virtual Leveling Lab Results

First, we evaluate the virtual leveling lab results in terms of their misclosure and ability to balance the backsight and foresight distances (Table 2). Of the 4 groups in the collaborative student sample, two achieved a misclosure of 5 mm or less. While two groups had higher misclosures at the level of a few decimeters. For the one group, this was due to a blunder measurement. For the other group, it was because one student forgot to level the instrument in one setup. In contrast of the six students conducting the lab on their own, two students achieved a misclosure of less than 3 mm, two students achieved a misclosure of 2-4 cm, and two students did not finish the lap. The moderate accuracy (2-4 cm) of the two students was due to poor leveling of the instrument. The two students that did not finish the lab was because they exceeded the time allowed (i.e., more than 60 minutes). We notice that the situated cognition group needed less time to complete the labs than the experiential learning group. In the situated cognition group the tasks are shared; however, in the experiential learning lab students need to level the instrument and then the rod, thus needing more time to complete the lab. Of note is that several students of the experiential learning group did not follow the suggested format for recording measurements, which is not the case for the situated cognition student sample. It was observed that the situated cognition students communicated on how to set up the fieldbook, record the measurements and therefore, followed the suggested format. Some students in the experiential learning sample who did not know how to properly record their measurements hesitated to ask the instructor for assistance and ended up with incorrect fieldbook formats. After the virtual lab, the instructor showed the report to the students, and discussed the mistakes and how to improve their surveying in the future. In the physical lab (introduction to leveling), where students complete a three-benchmark loop similar to the virtual lab, all groups achieved the required misclosure in their first attempt, and all groups followed the correct fieldbook format. This demonstrates the ability of both VR approaches to prepare students for the physical lab.

Table 2. Virtual lab statistics. There are 6 students in the experiential learning lab and 4 groups (8 students) in the situated cognition lab.

	Achieved <1 cm misclosure	Blunder / mistake	Did not finish	Average distance balancing	Wrong field book format	Average time
Experiential learning	2/6	2/6	2/6	6.5 m	3/6	44.8 min
Situated Cognition / Collaborative learning	2/4	2/4	0/4	5.0 m	0/4	24.0 min

Table 3. Student feedback related to general pedagogy and surveying pedagogy questions. Average scores are shown (Scores range 1 to 5).

	Question	Experiential learning (*n*=6)	Situated Cognition / Collaborative learning (*n*=8)
General pedagogy	Gave more incentive to learn	3.8	3.7
	Added to the fun of learning	4.0	4.3
	Improved overall learning experience	3.8	3.7
	I liked the VR lab overall	4.0	4.7
Surveying pedagogy	Helped understand surveying methods and techniques	4.0	4.0
	Helped understand how to operate surveying instruments	4.0	4.0
	Can help me prepare for real labs	4.4	4.2
	Is a useful training tool	4.0	4.3

Table 4. Student feedback of the situated cognition virtual lab related to their ability to work in a group and communicate in VR. Average scores are shown (Scores range 1 to 5).

Question	Average score
I liked the ability to communicate in the VR lab	4.4
Working in a group helped me learn	5.0
Working in a group in VR was enjoyable	4.7
Rate the communication quality	3.6
Rate the collaboration with your partner	4.4

Table 3 shows the student feedback related to the pedagogical contributions of VR. Both groups provided similar feedback and they indicate that VR helped students learn, improve their learning experience, understand surveying techniques, and helped them prepare for the physical labs. Furthermore, the student group who conducted the situated cognition labs expressed their strongly positive feedback for the ability to work in groups in VR, and that working in a group it helped them learn (Table 4).

3.3 Pre-test and Post-test Assessment and Peer-to-Peer Evaluation

The average pre-test grade for the experiential learning and situated cognition groups were 43.1% and 46.0%, respectively for the two groups. Statistically they are not significantly different, as the t-value is -0.197; the p-value is 0.848; therefore, the result is not significant at $p < 0.05$. This indicates that there is no inherent bias between the test and control groups. The scores of the post-test question were 88.9% and 88.1%, for the experiential learning and situated cognition groups respectively. The post-test question was given as part of the class midterm exam. The overall grades of the midterm exam, which contained leveling and other non-leveling questions, were very similar as well i.e., 90.4% and 88.9%, respectively. The scores of the introduction to leveling lab, where students complete a three-benchmark loop similar to the virtual lab, were 92.5% and 95.0%, respectively. While for the second differential leveling lab, which is a leveling circuit starting from one benchmark and ending at a different benchmark, the scores were 95.0% and 95.6%, respectively. A notable difference was found with respect to the peer-to-peer evaluations. Table 5 shows the average scores for three questions asked in each group. We notice higher scores for the situated cognition group. Q1 and Q3 yield statistically significant differences; therefore, indicating a positive effect of the situated cognition labs in student collaboration.

Table 5. Peer-to-peer student evaluations related to their teamwork and collaboration in the physical lab.

	Q1: Demonstrates good and encourages communication among teammates	Q2: Demonstrates participation in decision making	Q3: Demonstrate active team member participation in assigned-role duties
Experiential learning	4.4	4.6	4.4
Situated Cognition / Collaborative learning	5.0	4.9	5.0

3.4 Comparison with Previous Years

In Table 6, we show a comparison of average grades for the midterm exam, which contains several leveling questions, and two outdoor differential leveling labs. Years 2019 and 2021 are years where students conducted VR labs. In 2019 all students conducted the experiential learning lab, and in 2021 6 students conducted the experiential learning lab and 8 students the situated cognition lab. Some years are missing student grades due to instructor turnover. In general, we note the positive effect in student grades when VR is used. The three-benchmark loop lab, which is conducted a week after the virtual lab, seems to have the most benefit of the virtual labs. Students are better prepared for the physical lab; having conducted a very similar virtual lab first.

Table 6. Average grades in related exams and assignments. 2019 and 2021 are the years where VR technology was used. In 2019 an experiential learning approach was used. In 2021 students were separated into an experiential learning and a situated cognition group.

Assessment method	2016 (*n*=11)	2017 (*n*=9)	2018 (*n*=11)	2019 (*n*=7) (VR)	2020 (n=9)	2021 (n=14) (VR)
Lab (Three-benchmark loop)	89.5%	86.7%	79.6%	99.0%	84.4%	91.8%
Lab (Benchmark-to-benchmark)	90.5%	86.7%	84.7%	87.6%	Not conducted	93.9%
Midterm (selected numerical problem on leveling)	59.1%	65.9%	No data	71.4%	No data	90.7%
Midterm (overall grade)	80.3%	79.4%	81.1%	83.0%	81.8%	89.8%

The results of this paper demonstrate that both experiential learning and situated cognition / collaborative learning approaches are suitable for preparing students for physical labs. In both approaches the lab and exam scores were higher compared to the years without VR, indicating that both methods can be used to enhance learning. The main difference between the two virtual learning approaches is in the student satisfaction of their collaboration during the physical labs. These first results show that a collaborative VR approach is able to enhance their teamworking skills and help students prepare for a successful collaboration in the physical labs (Table 6). However, additional implementations in larger student populations are needed to further understand the differences of experiential learning and situated cognition, and the role of the latter approach in surveying engineering education.

4. CONCLUSIONS

Surveying engineering is a profession that continuously experiences and embraces new technological advancements. Virtual reality technology has found its way into the surveying profession and surveying education. With respect to the latter, we see in an increased number of case studies testing and integrating immersive technologies in surveying engineering education. It is important that the integration of immersive technologies takes place under a theoretical framework to identify and attain specific pedagogical goals. This study presented the pedagogical foundations that we often encounter in immersive technologies. We have presented and implemented VR labs that followed two different approaches, namely experiential learning and situated cognition / collaborative learning. In the former approach students engage in a virtual experience and learn by doing, while in the latter the focus is placed on communication and collaboration. The assessment of the two approaches showed that both immersive implementations are capable of supporting surveying engineering education and assisting in preparing students for physical labs. We find no significant difference between the two VR implementations; however, comparison with years without the support of VR, shows a significant difference in favor of the VR technology. We observed a significant difference in the peer-to-peer evaluations in terms of the teamwork and collaboration in the physical labs, indicating that the situated cognition approach is able to also enhance teamwork skills. Despite the many benefits of conducting collaborative VR labs, we do find an important limitation. The multiplayer support in VR makes the implementations more complex, and there is higher potential for software issues, which we experienced in the USMA implementation. There are also challenges related to hardware, software, and driver updates; thus, maintaining a VR system for teaching is still demanding. In future years, we plan to conduct additional tests and using larger student samples to further explore and understand how the two different learning approaches can support surveying engineering education.

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