ITcon
www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

IMPROVING LEARNERS' SELF-EFFICACY IN PERFORMING DESIGN REVIEWS WITH VIRTUAL REALITY

SUBMITTED: October 2023
REVISED: January 2024
PUBLISHED: February 2024
EDITOR: Robert Amor
DOI: 10.36680/j.itcon.2024.001

Fadi Castronovo Ph.D., Evaluation and Assessment Consultant,
Castronovo Educational Assessments and Evaluations LLC
ORCID: 0000-0001-6143-1777
fadi@castronovoevaluations.com

SeyedReza RazaviAlavi Ph.D., Assistant Professor, Department of Architecture and Built Environment,
Northumbria University
ORCID: 0000-0002-7372-0354
reza.alavi@northumbria.ac.uk

Pablo Martinez Rodriguez Ph.D., Assistant Professor, Department of Architecture and Built Environment,
Northumbria University
ORCID: 0000-0003-3397-9617
pablo.rodriguez@northumbria.ac.uk

SUMMARY: *Research on the use of innovative technology, such as virtual reality (VR), in Architecture, Engineering, and Construction (AEC) education, has been growing in the past twenty years. However, such research still requires robust investigation, as few studies have adopted educational psychology theories and rigorous methods. Furthermore, most of the research has focused on the cognitive effects of VR and additional research is also needed to investigate the affective effects, such as motivation, engagement, and self-efficacy. This study aims to evaluate the effects of technology decision-making between immersive virtual reality (IVR) and non-immersive virtual reality (nIVR) setups for a learning activity on AEC learners. For this, three hypotheses are formulated and tested on 165 UK students. Based on the results, both the designed IVR and nIVR learning activities had significant positive effects on learners' self-efficacy and user experience with no significant difference between IVR and nIVR delivery. With this research, the authors contribute to the growing literature on VR implementation in AEC classrooms by showcasing a study founded on educational psychology theory and by using a rigorous research methodology. Furthermore, this study illustrates the effects that IVR and nIVR have on students' affective learning and opens the possibility of new research in the field.*

KEYWORDS: *Virtual Reality, Self-Efficacy, Motivation, Education, Built Environment, Design Review*

REFERENCE: *Fadi Castronovo, SeyedReza RazaviAlavi, Pablo Martinez Rodriguez (2024). Improving Learners' Self-Efficacy in Performing Design Reviews with Virtual Reality. Journal of Information Technology in Construction (ITcon), Vol. 29, pg. 1-15, DOI: 10.36680/j.itcon.2024.001*

1. INTRODUCTION

The use of information and communication technologies (ICTs) has increased exponentially in the past decades, and educational institutions and their classrooms are not any different. ICTs have been slowly but uninterruptedly introduced in the classroom to facilitate learning and acquiring knowledge, skills, and positive values. With the recent pandemic, it has grown to become a fundamental pillar to improve students' attitudes towards learning (Lazar and Panisoara 2018; McGovern et al. 2020). Among ICTs, virtual platforms are revolutionizing educational experiences by providing simulated environments in which users can interact with the environment in an apparent real-time manner. These virtual environments can recreate classrooms, ensure safe experimentation of otherwise risky learning experiences, and oftentimes, a more viable and inclusive solution to overcome logistical and organizational challenges and expose learners to certain professional scenarios (Tzanavari and Tsapatsoulis 2010). For construction education, for example, it facilitates bringing numerous students at once to a construction site, transforming the logistics and safety problems related to having students in a hazardous environment into a technological problem. From a technical aspect, virtual platforms are usually created to be accessed through virtual reality (VR) hardware and software. These systems provide the simulated experience employing pose tracking and 3-dimensional near-eye displays to give the user an immersive feel of the virtual platform. When VR hardware has the capability of providing an immersive experience, it can be defined as immersive VR (IVR), if immersion is not available it can defined as non-immersive VR (nIVR).

One of the many advantages of implementing VR in education is that it provides a more immersive and engaging learning experience. Students are able to better understand the subject and engage with the learning material when they are given a unique perspective (Marougkas et al. 2023). It also provides different opportunities to promote student collaboration and collaborative learning. Learners can interact with their peers and the virtual environment, making the educational experience more active and individualized (Jochecová et al. 2022). Students can explore and engage with the content at their own pace, following their own limitations and preferences while VR can be preset to deliver personalized feedback based on user inputs (Wee et al. 2022). Overall, VR has the capacity and potential to revolutionize the learning experience for students by deeper sensorial immersion than current educational processes. The students' perception of their ability to perform certain tasks and competence facing challenges on the learned material, as known as self-efficacy, improves through the immersive experience (Srinivasa et al. 2021). Providing an interactive VR experience eases the connection between theoretical and practical, and considering technological advances of ICTs in the past decades, VR will highly likely become an essential component of educational systems (Freina and Ott 2015).

From an educator's perspective, the development of an effective VR learning experience depends on two elements: 1) the incorporation of adequate learning theories and 2) the adoption of a proper technological approach. On the one hand, educational learning theories refer to working frameworks regarding students' knowledge and skills acquisition by comprehending the learning processes involved. On the other hand, technological approaches to VR are numerous and vary greatly with technological advancements. Selecting the proper technology for a specific educational experience is an initial decision oftentimes motivated by economic opportunistic investments that occur early in the activity design phase. This technological decision determines the delivery methods, impacting student experience of VR in terms of immersion, as hardware and software are usually tied together to a specific commercial platform. As both immersion and interactivity influence the learning experience, platform selection should be a primary consideration. Once a platform is selected, any change requires time and additional expenses that are hardly justifiable within educational timeframes and budgets. On top of that, the consequences of technological selection on the learning experience are still uncertain although some models start to bring some insight regarding the educational impact of immersive learning (Makransky and Petersen 2021; Petersen et al. 2022). Thus, acknowledging and addressing these aspects before the design of the virtual environment is crucial when proposing methodologies for the use of VR in a classroom (Marougkas et al. 2023).

Specific to Architecture, Engineering, and Construction (AEC) education, VR platforms have been used to improve communication and enable students to interact with each other within virtual three-dimensional (3D) environments while increasing their self-efficacy. By virtue of the benefits of VR, it has been accordingly used to educate students on multiple topics such as construction safety (Goedert and Rokooei 2016), building information modeling (Pedro et al. 2016; Wang et al. 2014), or construction design management (Pedro et al. 2016), among others. This study focuses on the design review process, a key but time-consuming activity for the industry, from the learners' perspective while offering different technological approaches. The aim of the study is to understand the effect of technology selection between IVR and nIVR on design review education and learners' self-efficacy.

2. LITERATURE REVIEW

2.1 Motivation and Self-Efficacy in Education

The motivation of learners is an important factor in education as it can foster creativity and critical thinking, cultivate resilience and self-assurance of the learners (Schunk 2012), and enhance enthusiasm and persistence in learning (Alfiah et al. 2021). Motivation is defined as the "psychological forces that determine the direction of a person's level of effort and a person's level of persistence in the face of obstacles" (Kanfer 1990). There are two main types of motivation: intrinsic and extrinsic motivation (Schunk 2012). Intrinsic motivation is the natural human propensity to learn and assimilate (Ryan and Deci 2000), while extrinsic motivation is mostly reflected by external factors and satisfaction coming from extrinsic consequences such as meeting a deadline or avoiding poor grades (Deci and Ryan 2002). Employing investigatory approaches and by interviewing students in higher education, Savage et al. (2011)found that students are mostly extrinsically motivated to be successful in summative assessment, while some students are motivated by a desire to learn and for self-actualization.

Self-efficacy is one of the key contributing factors to the motivation of learners. Self-efficacy in the education context refers to "one's perceived capabilities to learn or perform actions at designated levels" (Schunk and DiBenedetto 2021). In past research, it was shown that those with a high level of self-efficacy are more likely to succeed and recover from failure (Resnick 2008). Schunk (2012) outlined how self-efficacy influences the choice of activities, effort, persistence, and achievement and how interventions involving models, goal setting, and feedback can affect self-efficacy. Eliyana et al. (2020) found that self-efficacy of entrepreneurial students influences achievement, and motivation significantly mediates the effect of self-efficacy on entrepreneurial achievement.

The use of technology is one of the methods that can foster self-efficacy and motivation of learners. Zhang (2022) emphasized that educational technology such as simulations, adaptive instructors, virtual laboratories, video games, and computer/mobile applications can increase self-efficacy. Schunk and DiBenedetto (2021) suggested the use of social media for improving the self-efficacy of students as these media offer several ways for students to have social contact with others, which is a source of learning from each other and improving self-efficacy. In recent years, there have been some studies that used virtual/augmented reality in education and evaluated its effect on self-efficacy. For instance, Lin and Wang (2021) investigated the effect of VR on the self-efficacy of English-as-a-Foreign-Language (EFL) learners. Their results showed that VR facilitated the students' efficacy for creative thinking, but its effect on their efficacy for creative production and their own competence while facing negative feedback was insignificant. Huang et al. (2023) compared VR-based learning tools with video-based ones and revealed that VR could outperform videos in promoting student teachers' situational interest and self-efficacy in classroom management. These studies show the potential of VR in enhancing self-efficacy of learners. However, there are few studies focusing on evaluating the effect of VR on the self-efficacy of learners in AEC education. The next subsection reviews the VR applications in AEC education.

2.2 VR in AEC Education

Conventional teaching methods in AEC education have encountered difficulties in providing students with hands-on experience and experiential learning. Establishing labs, visiting construction sites, and reviewing case studies are some approaches for exposing students to real-life construction projects. However, they are not affordable, feasible, and the most effective options in many cases. Establishing labs requires space and investment for purchasing equipment and maintaining them; visiting construction sites is difficult to manage due to safety concerns and required logistics planning and costs for traveling; and reviewing case studies using only 2D drawings, videos, and pictures is not interactive and intuitive for students. These limitations underscore the pressing need for the use of technology and innovative approaches that bridge the gap in educational practice. Due to the capabilities of VR in addressing these limitations, its applications in AEC education are becoming popular, and it is being used by many educators for teaching various subjects.

Design review is one of key applications of VR in construction projects as VR can provide a collaborative environment for reviewing the project design and overcoming the challenge of communication between different stakeholders. Wolfartsberger (2019) analyzed the potential of VR for engineering design review and realized that VR can reduce the review process time, and more faults can be identified in VR than in 3D engineering models. Boton (2018) adopted IVR for collaborative constructability review of a construction project using BIM 4D simulation created in Navisworks. Prabhakaran et al. (2021) developed an interactive VR-based approach for enhancing design communication in the furniture, fixture, and equipment sectors. They found that VR can reduce the time required for the stakeholders to comprehend the design options and improve the quality of the design, leading to more stakeholders' satisfaction. Paes et al. (2017) compared IVR to nIVR in an architectural design review and found that IVR can provide better spatial perception of virtual models for users depending on their professional experience and age. Due to these proven advantages of VR in design review, some educators and researchers adopted VR for enhancing design review skills of learners. For instance, Kandi et al. (2020a) developed and used a VR educational game to improve the design review skills of undergraduate construction management students. The results of their study showed that students could find a higher number of design mistakes when performing design reviews in VR compared to reviewing physical construction drawings. Mastrolembo Ventura et al. (2022) emphasized that VR-based games are more effective than traditional instruction because they allow students to fail, but the in-process reflection enables them to modify their strategies and repeat the process until they reach their goals. Tennakoon et al. (2023) developed a VR sandbox to provide students with hands-on experience for exploring complex geological features that make up well-known terrains. They demonstrated the potential of VR as an affordable option for replacing expensive lab spaces and equipment. Sampaio and Martins (2014) developed a VR application for learning different bridge deck construction methods and showed that VR can support visualization of the physical progress of the construction work, the monitoring of the construction sequence, and the visualization of details of the forms.

In addition, VR has been a suitable approach to address the shortcomings of conventional methods for safety training and education, such as poor interactions and lack of practical exercise Zhang et al. (2017). VR is able to model the construction site in the 1:1 scale to identify hazards and simulate unsafe situations in a risk-free virtual environment to assess the behavior of the workers in different work conditions. Moreover, training through VR can upskill construction workers and improve their productivity while it is more conclusive and cost-efficient than traditional approaches (Hafsia et al. 2018). For improving construction workspace planning, Getuli et al. (2020) developed a BIM-based VR approach and demonstrated the benefits of this approach in sharing planning and safety-related information between project partners. Shi et al. (2019) utilized a multi-user VR system for assessing the effects of reinforced learning methods on construction workers' fall risk behavior and indicated that VR can effectively contribute to safety training and improve the learning processes of workers. Another VR application for safety training was designed and developed in the roofing sector by Rokooei et al. (2023) that focused on preventing falling hazards in this sector. Masullo et al. (2022) created a VR overhead crane simulator to investigate the effect of different typologies of noise on the performance of the crane operators and their physiological responses. For modular construction and installing bulky modules, Zhang et al. (2023) developed a VR system to train lifting crew and realized that the system improves trainees' memory stability by 33% compared with handbook training. To improve construction safety education and provide students with an experiential opportunity to apply their safety knowledge, Le et al. (2015) developed a mobile-based VR and AR application. Using the application in a pilot study, the students who participated in the study felt positive and comfortable about using mobile devices to access hazard information and recognized several advantages, including ease of use, higher level of visual output, and improvement in their safety cognition safety memory. Pham et al. (2018) used a 360-degree panoramic VR to create a virtual site tour to bring construction field trips to the classroom and provide practical experience to improve students' safety knowledge. Zhang et al. (2017) developed a VR-based fire safety education system in which fire safety scenes were presented in a virtual environment, and the students could experience and learn fire safety operation skills.

Despite the past efforts in developing educational VR applications for the AEC industry, conceptual and empirical challenges for the justification of these applications from the pedagogical, methodological, and theoretical perspectives still exist (Mastrolembo Ventura et al. 2022). According to their study, since 2001 only 40% of studies in VR implementation in AEC education declared a sample size and most studies did not leverage validated assessment instruments. In addition, there is no research about the effect of using VR on the self-efficacy of learners in AEC education. Therefore, this study intends to evaluate the effect of VR on the self-efficacy of students in learning design review as one of the important tasks in the AEC industry, while also expanding current research by having sound methodology, sample size, and validated instruments.

3. METHODOLOGY

3.1 Research Questions

The literature review highlighted that the current implementation of IVR and nIVR in AEC education requires the investigation of learners' affective domain, particularly their self-efficacy. Additionally, as Section 2.2 discussed, future research in the implementation of IVR and nIVR in AEC education requires the use of sound methodological assessment methods and procedures. To address the research gap, the research team aims to assess the effects of IVR and nIVR implementation on learners' self-efficacy. In particular, the aim was to explore how these effects are present when learners are conducting design reviews with IVR and nIVR. The chosen population for this study is learners in higher education, such as university students, who are pursuing AEC-related degrees, both undergraduate and graduate.

Based on this goal, the following research questions are proposed:

1. What are the effects on learners' self-efficacy when IVR or nIVR is implemented when performing design review learning activities?
2. Are there differences in learners' self-efficacy after engaging in IVR or nIVR design review learning activities?
3. What is the learners' experience when using IVR or nIVR?

These research questions lead the authors to pose three null hypotheses. First, learners would self-report the same average self-efficacy before and after the learning activity. Second, there would be no difference in learners' self-efficacy when using IVR or nIVR. Third, the learners' experience would be neutral after the learning activity.

3.2 Experimental Design and Procedure

The team conducted a quasi-experiment due to the lack of randomization of the treatment groups to test the null hypotheses. The quasi-experiment is designed to have two groups with a pre and post-test assessment. Two groups are chosen to combat test learning effects and increase the generalization of the results (Knapp 2016). The procedure is designed to have two independent variables or treatments. The independent variables are based on the activity and technology that the learners are exposed to, IVR versus nIVR, while performing design reviews. The learning activity is designed to introduce two different learner populations. The first activity uses IVR to introduce first-year AEC learners to the concepts of designed reviews. Meanwhile, the second activity uses desktop-based VR to engage master-level AEC learners in performing design reviews and proposing solutions for any changes. The dependent variable for both treatments is the students' self-reported self-efficacy, measured with an assessment instrument described in Section 3.4. The assessment instrument is administered as a pre and post-test ten minutes before and after the learning activity. The procedure for the quasi-experiment can be found in Figure 1.

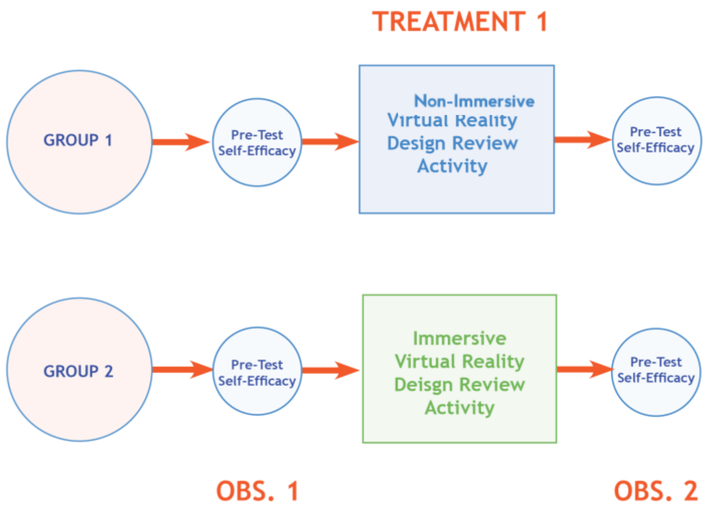


Figure 1: Schema of the quasi-experimental procedure.

3.2.1 IVR Learning Activity

After the participants are asked to fill out the pre-test, they are introduced to how to use an IVR head-mounted display system. The team gives the participants about ten minutes to learn how to use the head-mounted display systems and the controls. Furthermore, the participants are taught how to navigate the virtual environment. Any participants who had difficulty with navigation or motion sickness were provided with support and additional training. During this activity, the participants have to navigate a BIM model of a residential house and identify and review any type of design mistake (see Figure 2). The participants are suggested to look for three different types of design issues, such as coordination, spatial layout, and material issues, but are not limited to identifying others. The participants are paired into groups of two to three, where one with the headset would be the “navigator,” meanwhile the others would be the “notetaker(s)” (see Figure 3). The participants are asked to cycle between the navigator and notetaker for every five design issues they identify. The notetaker can also visualize what the navigator sees as the video output of the headset is duplicated onto desktop computer screens. The notetaker has the choice of writing the design issues either on a piece of paper provided by the team or a Word document on their respective desktop computer (see Figure 4). The notetaker was asked not to help the navigator in finding design issues but just to focus on documenting what the navigator was sharing verbally. To limit motion sickness, the participants are given a total of thirty minutes to complete the design review. At the end of the activity, the participants are given ten minutes to complete the post-test.

Figure 3: IVR activity.

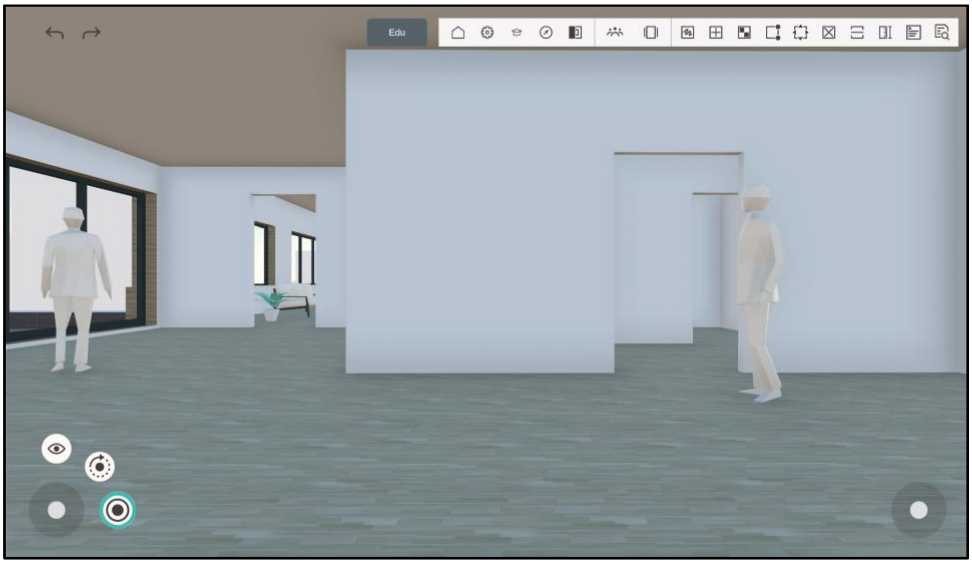
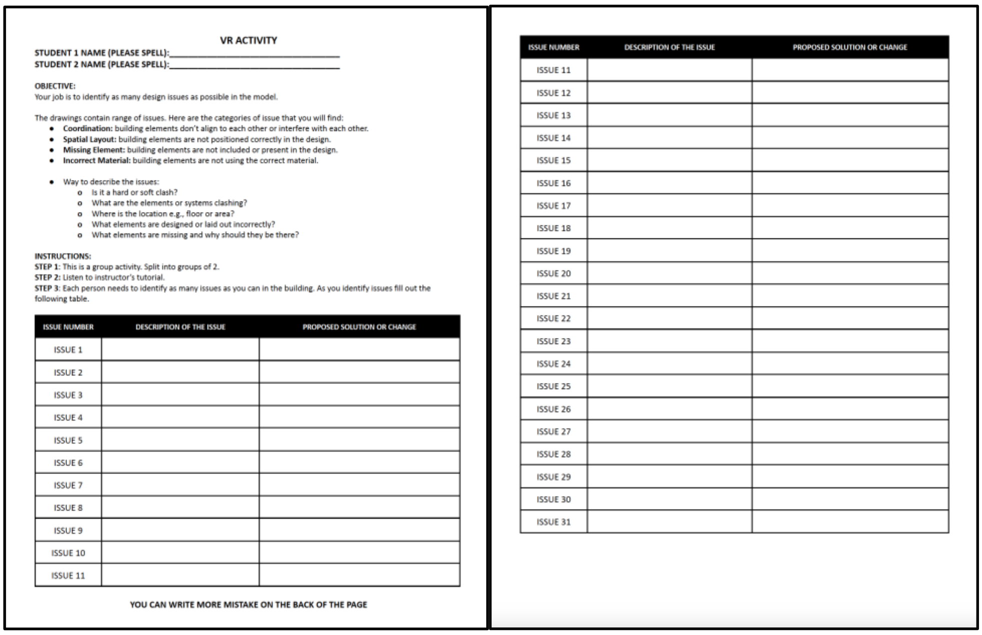


Figure 2: Screenshot of the imported informational model in Arkio.



VR ACTIVITY

STUDENT 1 NAME (PLEASE SPELL):______________________

STUDENT 2 NAME (PLEASE SPELL):______________________

OBJECTIVE:

Your job is to identify as many design issues as possible in the model.

The drawings contain range of issues. Here are the categories of issue that you will find:

- **Coordination:** building elements don't align to each other or interfere with each other.
- **Spatial Layout:** building elements are not positioned correctly in the design.
- **Missing Element:** building elements are not included or present in the design.
- **Incorrect Material:** building elements are not using the correct material.

- Way to describe the issues:
    - Is it a hard or soft clash?
    - What are the elements or systems clashing?
    - Where is the location e.g., floor or area?
    - What elements are designed or laid out incorrectly?
    - What elements are missing and why should they be there?

INSTRUCTIONS:

STEP 1: This is a group activity. Split into groups of 2.

STEP 2: Listen to instructor's tutorial.

STEP 3: Each person needs to identify as many issues as you can in the building. As you identify issues fill out the following table.

ISSUE NUMBER	DESCRIPTION OF THE ISSUE	PROPOSED SOLUTION OR CHANGE
ISSUE 1		
ISSUE 2		
ISSUE 3		
ISSUE 4		
ISSUE 5		
ISSUE 6		
ISSUE 7		
ISSUE 8		
ISSUE 9		
ISSUE 10		
ISSUE 11		

YOU CAN WRITE MORE MISTAKE ON THE BACK OF THE PAGE

ISSUE NUMBER	DESCRIPTION OF THE ISSUE	PROPOSED SOLUTION OR CHANGE
ISSUE 11		
ISSUE 12		
ISSUE 13		
ISSUE 14		
ISSUE 15		
ISSUE 16		
ISSUE 17		
ISSUE 18		
ISSUE 19		
ISSUE 20		
ISSUE 21		
ISSUE 22		
ISSUE 23		
ISSUE 24		
ISSUE 25		
ISSUE 26		
ISSUE 27		
ISSUE 28		
ISSUE 29		
ISSUE 30		
ISSUE 31		

Figure 4: Activity participant handout document.

3.2.2 nIVR Learning Activity

Similar to the IVR activity, during the nIVR activity, the participants are asked to fill out the pre-test. After the assessment, the students are introduced to the design review software and are taught how to navigate the virtual environment. During the activity, the participants are asked to review a BIM model of an educational building located on their campus (see Figure 5). The model includes various building elements and systems, e.g., architecture, structural members, mechanical, electrical, and plumbing. The participants are suggested to look for three different types of design issues, such as coordination, spatial layout, and material issues, but are not limited to identifying others. Just like in the IVR activity, in this activity, the participants are given the roles of navigator and notetaker and are similarly asked to cycle through the roles (see Figure 6). The participants are given a total of thirty minutes to review the model and note as many issues as possible. At the end of the activity, the participants are given ten minutes to complete the post-test.

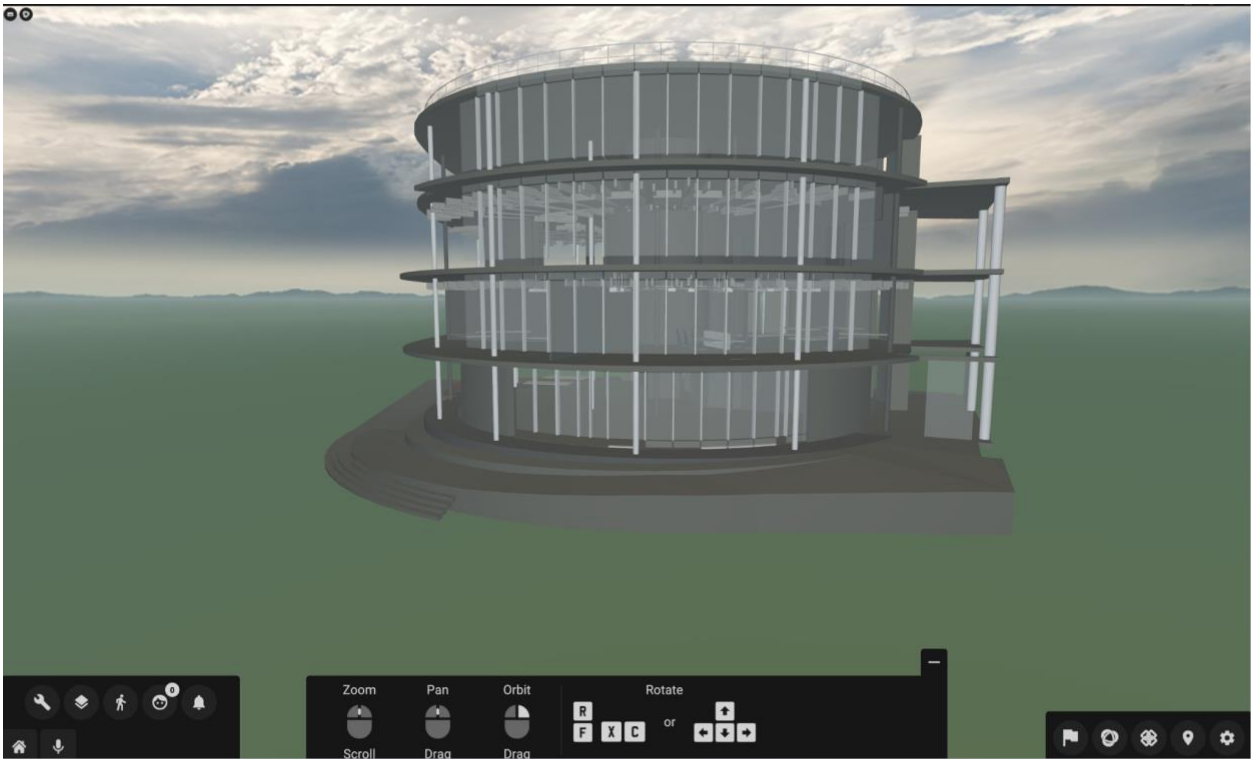


Figure 5: Screenshot of the imported informational model in Vrex.


Figure 6: nIVR Activity.

3.3 Participants

The participants for the quasi-experiment are split into two groups. For the IVR learning activity, the experimental population consists of first-year students from a university in the south of England currently enrolled in an 'Introduction to the Built Environment' module. In this activity, 54 students are recruited to participate. The recruitment was for the nIVR learning activity, the experimental population consists of master students from a university in the northeast of England currently enrolled in an 'Integrated BIM Project' module. In this activity, a total of 165 students are recruited to participate. A total of six sessions are conducted to host all of the participants. Ethical approval for this project was received by the universities' respective ethics boards. The participants are asked to give the team consent to collect and analyze the data before participating in the study. Students who did not want to participate in the study are given the option of not answering the pre or post-test and still engage in the module activities.

3.4 Equipment and Assessment Instruments

During the IVR activity, students used Meta Quest 2 head-mounted display systems. A total of twenty untethered headsets are provided, which allows for a total of forty participants to engage simultaneously in the learning activity. The video output of the headsets is cast on Chrome web browsers installed on desktop computers. The design view is conducted using a collaborative IVR software called Arkio®. Meanwhile, for the VR activity, the participants are provided with another collaborative virtual environment software called VREX®. A total of fifty desktop computers are provided to the participants. Virtual meeting rooms for both activities are hosted where the models are preloaded.

To measure the dependent variable, the participants' self-efficacy and experience, a questionnaire is developed on a 5-point Likert Scale. The questionnaire is modified from the "General Self-Efficacy Scale" (GSS) by Schwarzer and Jerusalem (1995). The questions from the GSS are modified so that the participants could self-report their perceived ability to complete a design review. These questions are used for both the pre and post-test. For the post-test, additional questions are added to evaluate the participants' experience. These questions are based on the "Online Motivation Questionnaire" developed by Boekaerts (2002). These questions are presented in Table 1.

Table 1: Pre- and Post-Tests Questions.

Pre- and Post- Tests Self-Efficacy Questions	Post-Test Participant Experience
1. How good do you think you are at reviewing design proposals?	11. How do you feel just after finishing the activity?
2. I am able to review most of the design proposals that I am presented with.	12. How easy was this activity?
3. When facing a difficult design proposal, I am certain that I can review it.	13. How well do you think you did in this activity?
4. In general, I think that I can successfully review most design proposals.	14. How useful do you consider this activity in learning about design reviews?
5. I believe I can succeed at reviewing most design proposals.	15. How important do you find it to do well on design reviews?
6. I am able to successfully review design proposals.	16. I felt the time used for the activity was beneficial.
7. I am confident that I can perform effective design reviews.	17. I saw the value in the activity.
8. Compared to other people, I can do most review design proposals very well.	18. How enthusiastic were you about this activity?
9. Even when the design of a building is complex, I can review it quite well.	19. How pleasant did you find this activity?
10. How difficult did you find the topic of design reviews?	20. How much did you enjoy yourself during this activity?
	21. How much would you recommend this activity to your classmates?

4. RESULTS AND ANALYSIS

The results from the quasi-experiment can be found in Tables 2 and 3. The total number of participants recruited for the IVR and nIVR activities are 50 and 107, respectively. However, due to participants either not attending the activity or not completing the pre- and post-test, only 29 data points are collected for the IVR activity and 94 for the nIVR activity. All participants gave permission to use the collected data. Table 2 shows the average and standard deviation for each question for the questionnaire for the self-efficacy dependent variable, as well as the total average for each test of each activity. Table 3 shows the participants' experience post-activity average results. A series of statistical tests are conducted to answer the research questions and test for the posed hypothesis. The tests are conducted using the statistics software package IBM SPSS Statistics. The analysis is structured based on each of the research questions.

Table 2: Self-Efficacy Pre and Post-Test Average Answers.

	IVR Activity Results		nIVR Activity Results	
	n=29		*n=94*	
Question	Pre-Test Average	Post-Test Average	Pre-Test Average	Post-Test Average
1. How good do you think you are at reviewing design proposals?	3.14	3.90	3.49	4.12
2. I am able to review most of the design proposals that I am presented with.	3.43	4.03	3.45	4.12
3. When facing a difficult design proposal, I am certain that I can review it.	2.90	3.79	3.26	4.03
4. In general, I think that I can successfully review most design proposals.	3.41	4.07	3.43	4.16
5. I believe I can succeed at reviewing most design proposals.	3.52	4.07	3.51	4.17
6. I am able to successfully review design proposals.	3.28	4.10	3.49	4.07
7. I am confident that I can perform effective design reviews.	3.17	3.86	3.47	4.13
8. Compared to other people, I can do most review design proposals very well.	3.14	3.76	3.14	3.99
9. Even when the design of a building is complex, I can review it quite well.	2.97	3.69	3.11	3.90
10. How difficult did you find the topic of design reviews?	2.93	3.66	3.26	3.67
Self-Efficacy Average	3.190	3.890	3.36	4.04
Standard Deviation	0.498	0.440	0.15	0.15

Table 3: Participants' Experience Average Answers.

	IVR Activity Results	nIVR Activity Results
Question	Participants' Experience	Participants' Experience
11. How do you feel just after finishing the activity?		
11.A How relieved do you feel after the activity?	3.62	4.16
11.B How at ease do you feel after the activity?	3.90	4.12
11.C How nervous do you feel after the activity?	2.97	2.51
11.D How satisfied do you feel after the activity?	4.14	4.23
11.E How worried do you feel after the activity?	3.38	2.34
11.F How confident do you feel after the activity?	3.90	4.16
11.G How concerned do you feel after the activity?	3.34	3.18
12. How easy was this activity?	3.97	4.01
13. How well do you think you did in this activity?	4.00	4.12
14. How useful do you consider this activity in learning about design reviews?	4.24	4.45

15. How important do you find it to do well on design reviews?	4.31	4.45
16. I felt the time used for the activity was beneficial.	4.31	4.48
17. I saw the value in the activity,	4.34	4.45
18. How enthusiastic were you about this activity?	4.07	4.50
19. How pleasant did you find this activity?	4.55	4.48
20. How much did you enjoy yourself during this activity?	4.45	4.51
21. How much would you recommend this activity to your classmates?	4.48	4.60
Participants' Experience Average	3.998	4.04
Standard Deviation	0.606	0.692

What are the effects on learners' self-efficacy when IVR or nIVR is implemented when performing design review learning activities?

The first research question tested the hypothesis that the participants' self-reported self-efficacy would be the same before and after the activities. To answer this question, two paired-sample t-tests are conducted for each activity to test if there is a significant difference between the pre and post-test for the participants' self-efficacy. Outliers, as defined as observations that lie an abnormal distance from other values in the sample, are also evaluated. In this study, any value 50% inferior to the first quartile or 50% superior to the third quartile of the sample is considered an outlier and excluded from the analysis. **For the IVR activity**, no outliers are detected. Participants report a higher self-efficacy after participating in the activity (3.890 ± 0.440) when compared to before the activity (3.190 ± 0.498), a statistically significant increase of 0.70 (95% CI, 0.885 to 0.536), $t(28) = 8.042$, $p < .0001$, $d = 1.493$. Therefore, the researchers confidently reject the null hypothesis that the averages for the pre and post-test are identical, as indicated by the significant difference and p-value being below 0.005. Furthermore, the effect size of the sample is quite large, as indicated by the Cohen's D being 1.493 (Cohen 1988). **For the nIVR activity**, no outliers are detected. Participants report a higher self-efficacy after participating in the activity (4.04 ± 0.15) when compared to before the activity (3.36 ± 0.15), a statistically significant increase of 0.67 (95% CI, 0.8403 to 0.5150), $t(93) = 8.2753$, $p < .0001$, $d = 1.20$. Therefore, the researchers confidently reject the null hypothesis that the averages for the pre and post-test are identical, as indicated by the significant difference and p-value being below 0.005. Furthermore, the effect of the sample size is quite large, as indicated by Cohen's D being 1.20 (Cohen 1988).

Are there differences in learners' self-efficacy after engaging in IVR or nIVR design review learning activities?

The second question tests the hypothesis that there would be no difference in learners' self-efficacy, post-activity, when using IVR or nIVR. To test this hypothesis, an unpaired-sample t-test is conducted using the average score for each post-test to test if there is a significant difference between subjects. With a similar approach to the previous subsection, no outliers are detected in this sample. Participants report a higher self-efficacy after participating in the nIVR activity (4.04 ± 0.15) when compared to after the IVR activity (3.890 ± 0.440), but the difference of 0.15 is not statistically significant (95% CI, 0.35283 to 0.05283), $t(130) = 1.4631$, $p > .05$. Therefore, the researchers can not confidently reject the null hypothesis that the averages for the post-tests are identical, as indicated by the non-significant difference and p-value being above 0.005.

What is the learners' experience when using IVR or nIVR?

For the third question, a one-sample t-test is conducted to test if the participants' experience is significantly different than neutral (Likert scale value of 3). **For the IVR activity,** no outliers are detected. The mean participants' experience score is significantly higher by 0.998 (0.95 CI, 0.7502 to 1.2205) than a neutral score of 3, $t(28) = 8.792$, $p < 0.0001$, $d = 0.606$. Therefore, the researchers confidently reject the null hypothesis that the average for participants' experience is neutral, as indicated by the significant difference and p-value being below 0.005. Furthermore, the effect of the sample size is between medium and large, as indicated by Cohen's D being 0.606 (Cohen 1988). **For the nIVR activity,** no outliers are detected. The mean participants' experience score is significantly higher by 1.04 (0.95 CI, 0.958 to 1.128) than a neutral score of 3, $t(103) = 24.4147$, $p < 0.0001$, $d = 5.06$. Therefore, the researchers confidently reject the null hypothesis that the average for participants' experience is neutral, as indicated by the significant difference and p-value being below 0.005. Furthermore, the effect of the sample size is quite large, as indicated by Cohen's D being 5.06 (Cohen 1988).

5. CONCLUSION

The evaluation and assessment of design proposals is a critical step in the delivery of a project, and it is an essential skill for any learner who graduates with a degree in AEC disciplines. Current literature has shown the growing implementation of different media in the classroom, such as nIVR and IVR, to improve the knowledge and skills acquisition for AEC learners. In particular, there have been efforts to train learners to gain lower-order thinking skills, such as remembering and understanding, necessary to perform design reviews (Kandi et al. 2020b). However, an instructor's role goes beyond just introducing knowledge and getting learners to gain knowledge; it is also to support them in developing their confidence and self-efficacy in performing the necessary tasks to deliver projects. To address this research gap, the research team aimed to evaluate innovative technology's role in supporting students' self-efficacy in performing design reviews.

Based on the analysis, significant evidence that both IVR and nIVR can support learners' self-efficacy in performing design reviews is reported. When evaluating the first research question, there is significant evidence that learners self-reported higher levels of self-efficacy after participating in both activities. It is essential to highlight that learners indicated such an increase whether or not they are fully immersed in a virtual environment. This finding is further reinforced when looking at the second research question. When comparing the post-test results for both the IVR and nIVR activity, there is no statistically significant evidence that the mean student experience is different. This finding can be useful for instructors who do not have access to immersive virtual reality headsets. This finding should not lead to the conclusion that IVR is not necessary in the classroom, especially since the experiment did not consider metrics such as spatial presence and immersion. However, these findings show that both nIVR and IVR can support the increase of students' self-efficacy and that they can be both useful tools in an instructor's toolbox. Lastly, while using innovative technology, it is important to spark students' interest and increase their confidence, as they must have a positive experience while engaging with VR. Based on the analysis for the third question, the team has found significant evidence that the experience is positive (above neutral). To conclude the discussion, the team has found significant evidence that virtual environments have a positive effect on learners' affective skills.

In future research, the team will aim to both address the current study's limitations and tackle new research questions. The current study needs to increase the sample size of the IVR activity in order to address potential generalization threats. The size must also include a wider population for IVR activity that includes students beyond their first year. Furthermore, while the current procedure has two groups, performing a repeated measure study, such as a cross-over experiment, can tackle threats to the study's internal and external validity, such as test-learning effects. Additionally, the design of IVR activity required the students to alternate between IVR and nIVR, this might have added an impact on the study. In future research, the team will focus on just having IVR and isolating the independent variable. The design of the research method can be further improved by adding additional learning activities, such as think-pair-share and video site tour. These activities would be additional levels of the independent variables and would support isolating their effects. In another next step, the team can also look at how learning objectives are mediated by self-efficacy so that a clear line between motivation and meeting learning objectives can be drawn. Lastly, the team considers expanding this research by evaluating the effects of VR on other affective metrics, such as sense of belonging and STEM identity. These metrics have been identified as being key to increasing retention and engagement (Trujillo and Tanner 2014).

ACKNOWLEDGEMENTS

The authors would like to thank Arkio and VREX companies for their support in this research.

REFERENCES

Alfiah, S., S. Istiyati, and H. Mulyono. 2021. "Analisis penyebab rendahnya motivasi belajar dalam pembelajaran ips peserta didik kelas V sekolah dasar." *Didaktika Dwija Indria*, 9 (5).

Boekaerts, M. 2002. "The On-line motivation questionnaire: A self-report instrument to assess students' context sensitivity." *New directions in measures and methods*, P. R. Pintrich and M. L. Maehr, eds., 77–120. Emerald Group Publishing.

Boton, C. 2018. "Supporting constructability analysis meetings with Immersive Virtual Reality-based collaborative BIM 4D simulation." *Automation in Construction*, 96: 1–15. Elsevier.

Cohen, J. 1988. "Statistical power analysis for the behavioral sciences (2 ed.)." Hillsdale, NJ: Lawrence Erlbaum Associates.

Deci, E. L., and R. M. Ryan. 2002. "Self-determination research: Reflections and future directions." University of Rochester Press.

Eliyana, A., A. R. S. Musta'in, and N. Aviantari. 2020. "Linking self efficacy on motivation and entrepreneurial achievements." *Systematic Reviews in Pharmacy*, 11 (8): 328–334. Medknow Publications.

Freina, L., and M. Ott. 2015. "A literature review on immersive virtual reality in education: state of the art and perspectives." *The international scientific conference elearning and software for education*, 10–1007.

Getuli, V., P. Capone, A. Bruttini, and S. Isaac. 2020. "BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach." *Automation in Construction*, 114: 103160. Elsevier.

Goedert, J. D., and S. Rokooei. 2016. "Project-Based Construction Education with Simulations in a Gaming Environment." *International Journal of Construction Education and Research*, 12 (3): 208–223. https://doi.org/10.1080/15578771.2015.1121936.

Hafsia, M., E. Monacelli, and H. Martin. 2018. "Virtual Reality Simulator for Construction workers." *Proceedings of the Virtual Reality International Conference - Laval Virtual*, 1–7. Laval France: ACM.

Huang, Y., E. Richter, T. Kleickmann, and D. Richter. 2023. "Comparing video and virtual reality as tools for fostering interest and self-efficacy in classroom management: Results of a pre-registered experiment." *British Journal of Educational Technology*, 54 (2): 467–488. https://doi.org/10.1111/bjet.13254.

Jochecová, K., M. Černỳ, Z. Stachoň, H. Švedová, N. Káčová, J. Chmelík, V. Br\uuža, O. Kvarda, P. Ugwitz, and A. Šašinková. 2022. "Geography education in a collaborative virtual environment: a qualitative study on geography teachers." *ISPRS International Journal of Geo-Information*, 11 (3): 180. MDPI.

Kandi, V. R., P. Brittle, C. Gaedicke, and F. Castronovo. 2020a. "Application of a Virtual Reality Educational Game to Improve Design Review Skills." *Construction Research Congress (CRC)*. Tempe, AZ.

Kandi, V. R., F. Castronovo, P. Brittle, S. M. Ventura, and D. Nikolic. 2020b. "Assessing the Impact of a Construction Virtual Reality Game on Design Review Skills of Construction Students." *Journal of Architectural Engineering*, 26 (4): 04020035. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000434.

Kanfer, R. 1990. "Motivation theory and industrial and organizational psychology." *Handbook of industrial and organizational psychology*, 1 (2): 75–130.

Lazar, I., and I. O. Panisoara. 2018. "Understanding the role of modern technologies in education: A scoping review protocol." *Psychreg Journal of Psychology*, 2: 74–86.

Le, Q. T., A. Pedro, and C. S. Park. 2015. "A social virtual reality based construction safety education system for experiential learning." *Journal of Intelligent & Robotic Systems*, 79: 487–506. Springer.

Lin, Y.-J., and H. Wang. 2021. "Using virtual reality to facilitate learners' creative self-efficacy and intrinsic motivation in an EFL classroom." *Education and Information Technologies*, 26 (4): 4487–4505. https://doi.org/10.1007/s10639-021-10472-9.

Makransky, G., and G. B. Petersen. 2021. "The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality." *Educational Psychology Review*, 33 (3): 937–958. https://doi.org/10.1007/s10648-020-09586-2.

Marougkas, A., C. Troussas, A. Krouska, and C. Sgouropoulou. 2023. "Virtual reality in education: a review of learning theories, approaches and methodologies for the last decade." *Electronics*, 12 (13): 2832. MDPI.

Mastrolembo Ventura, S., F. Castronovo, D. Nikolic, and A. L. Ciribini. 2022. "Implementation of virtual reality in construction education: a content-analysis based literature review." *Journal of Information Technology in Construction*, 27: 705–731. CIB.

Masullo, M., A. Pascale, R. A. Toma, G. Ruggiero, and L. Maffei. 2022. "Virtual Reality Overhead Crane Simulator." *Procedia Computer Science*, 200: 205–215. Elsevier.

McGovern, E., G. Moreira, and C. Luna-Nevarez. 2020. "An application of virtual reality in education: Can this technology enhance the quality of students' learning experience?" *Journal of Education for Business*, 95

(7): 490–496. https://doi.org/10.1080/08832323.2019.1703096.

Paes, D., E. Arantes, and J. Irizarry. 2017. "Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems." *Automation in Construction*, 84: 292–303. Elsevier.

Pedro, A., Q. T. Le, and C. S. Park. 2016. "Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality." *Journal of Professional Issues in Engineering Education and Practice*, 142 (2): 04015011. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000261.

Petersen, G. B., G. Petkakis, and G. Makransky. 2022. "A study of how immersion and interactivity drive VR learning." *Computers & Education*, 179: 104429. Elsevier.

Pham, H. C., N. Dao, A. Pedro, Q. T. Le, R. Hussain, S. Cho, and C. Park. 2018. "Virtual field trip for mobile construction safety education using 360-degree panoramic virtual reality." *International Journal of Engineering Education*, 34 (4): 1174–1191.

Prabhakaran, A., A.-M. Mahamadu, L. Mahdjoubi, P. Manu, C. K. I. Che Ibrahim, and C. O. Aigbavboa. 2021. "The effectiveness of interactive virtual reality for furniture, fixture and equipment design communication: an empirical study." *Engineering, Construction and Architectural Management*, 28 (5): 1440–1467. Emerald Publishing Limited.

Resnick, B. 2008. "Theory of self-efficacy." *Middle range theory for nursing*, 2: 183–204. Springer, New York.

Rokooei, S., A. Shojaei, A. Alvanchi, R. Azad, and N. Didehvar. 2023. "Virtual reality application for construction safety training." *Safety science*, 157: 105925. Elsevier.

Ryan, R. M., and E. L. Deci. 2000. "Intrinsic and extrinsic motivations: Classic definitions and new directions." *Contemporary educational psychology*, 25 (1): 54–67. Elsevier.

Sampaio, A. Z., and O. P. Martins. 2014. "The application of virtual reality technology in the construction of bridge: The cantilever and incremental launching methods." *Automation in Construction*, 37: 58–67. https://doi.org/10.1016/j.autcon.2013.10.015.

Savage, N., R. Birch, and E. Noussi. 2011. "Motivation of engineering students in higher education." *Engineering Education*, 6 (2): 39–46. https://doi.org/10.11120/ened.2011.06020039.

Schunk, D. H. 2012. *Learning theories an educational perspective*. Pearson Education, Inc.

Schunk, D. H., and M. K. DiBenedetto. 2021. "Self-efficacy and human motivation." *Advances in motivation science*, 153–179. Elsevier.

Schwarzer, R., and M. Jerusalem. 1995. "Generalized self-efficacy scale." *J. Weinman, S. Wright, & M. Johnston, Measures in health psychology: A user's portfolio. Causal and control beliefs*, 35: 37.

Shi, Y., J. Du, C. R. Ahn, and E. Ragan. 2019. "Impact assessment of reinforced learning methods on construction workers' fall risk behavior using virtual reality." *Automation in Construction*, 104: 197–214. Elsevier.

Srinivasa, A. R., R. Jha, T. Ozkan, and Z. Wang. 2021. "Virtual reality and its role in improving student knowledge, self-efficacy, and attitude in the materials testing laboratory." *International Journal of Mechanical Engineering Education*, 49 (4): 382–409. https://doi.org/10.1177/0306419019898824.

Tennakoon, D., A. S. Di Nunzio, and M. A. Jadidi. 2023. "Game-based and Virtual Reality Sandboxes: Inclusive, Immersive, Accessible, and Affordable Learning Environments." *2023 ASEE Annual Conference & Exposition*.

Trujillo, G., and K. D. Tanner. 2014. "Considering the role of affect in learning: Monitoring students' self-efficacy, sense of belonging, and science identity." *CBE—Life Sciences Education*, 13 (1): 6–15. Am Soc Cell Biol.

Tzanavari, A., and N. Tsapatsoulis. 2010. *Affective, interactive and cognitive methods for e-learning design: Creating an optimal education experience: Creating an optimal education experience*. IGI Global.

Wang, X., M. Truijens, L. Hou, Y. Wang, and Y. Zhou. 2014. "Integrating Augmented Reality with Building Information Modeling: Onsite construction process controlling for liquefied natural gas industry."

Automation in Construction, 40: 96–105. Elsevier.

Wee, C., K. M. Yap, and W. N. Lim. 2022. "iProgVR: Design of a Virtual Reality Environment to Improve Introductory Programming Learning." *IEEE Access*, 10: 100054–100078. IEEE.

Wolfartsberger, J. 2019. "Analyzing the potential of Virtual Reality for engineering design review." *Automation in Construction*, 104: 27–37. Elsevier.

Zhang, K., J. Suo, J. Chen, X. Liu, and L. Gao. 2017. "Design and implementation of fire safety education system on campus based on virtual reality technology." *2017 Federated Conference on Computer Science and Information Systems (FedCSIS)*, 1297–1300. IEEE.

Zhang, Y. 2022. "The Effect of Educational Technology on EFL Learners' Self-Efficacy." *Frontiers in Psychology*, 13: 881301. Frontiers.

Zhang, Z., M. O. Wong, and W. Pan. 2023. "Virtual reality enhanced multi-role collaboration in crane-lift training for modular construction." *Automation in Construction*, 150: 104848. Elsevier.