VR in environmental education: A feasibility study with high-school students

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Abstract: Virtual reality (VR) technology has become more common in engineering education. However, in most educational settings, there is still limited evidence regarding student acceptance of the technology and its educational advantages. This study examined how high-school students experienced their first VR lesson in environmental engineering, focused on ultraviolet (UV) water disinfection, during a university summer camp. A within-subjects pre-post design was used, involving 35 high-school students who completed questionnaires on expectations, learning confidence, motivation, and interest before the lesson. After the VR experience, participants evaluated the system's perceived usefulness and ease of use, perceived learning value, sense of presence, engagement, satisfaction, self-assessed comprehension, and overall enjoyment. Descriptive statistics and Cronbach's α were used to assess internal consistency, nonparametric tests were applied to compare pre- and post-session responses, and Spearman correlations were calculated to examine relationships between constructs and actual reported changes. Students rated the lesson highly for its usefulness, learning value, and ability to maintain attention. The evaluation of multiple constructs showed that participants rated them higher after the session than before it, while the gender-based subgroup analysis did not reveal statistically significant differences.

Keywords: Virtual Reality, Pre-university, Engagement, User acceptance, Perceived learning value.

Realitatea virtuală în educația de mediu: un studiu de fezabilitate în rândul elevilor de liceu

Rezumat: Tehnologia realității virtuale (RV) a devenit tot mai răspândită în educația inginerească, însă, în majoritatea mediilor educaționale, lipsesc dovezi privind acceptarea acestei tehnologii de către studenți și avantajele sale educaționale. Studiul a evaluat modul în care elevii de liceu au experimentat prima lor lecție de realitate virtuală despre ingineria mediului, axată pe dezinfecția apei prin radiații cu ultraviolete (UV), în cadrul unei școli de vară universitare. Cercetarea a utilizat un design pre-post cu măsurători repetate pentru a colecta date de la 35 de elevi de liceu, care au completat chestionare privind așteptările, încrederea în învățare, motivația și interesul înainte de lecție. După experiența VR, participanții au evaluat utilitatea sistemului, ușurința în utilizare, valoarea percepută a învățării, sentimentul de prezență, implicarea, satisfacția, nivelul de înțelegere autoevaluat. Statisticile descriptive și coeficientul alfa Cronbach au fost utilizate pentru evaluarea consistenței interne, testele neparametrice au fost folosite pentru compararea datelor pre-post, iar corelațiile Spearman au fost utilizate pentru examinarea relațiilor dintre constructe și schimbările raportate de participanți. Elevii au apreciat lecția ca fiind utilă, cu o valoare educațională ridicată și cu capacitatea de a le menține atenția. Analiza constructelor investigate a indicat că participanții au evaluat experiența mai favorabil după sesiune comparativ cu perioada anterioară acesteia, însă analiza pe subgrupuri de gen nu a evidențiat diferențe semnificative.

Cuvinte-cheie: realitate virtuală, educație pre-universitară, implicare, acceptarea tehnologiei, valoare percepută a învățării.

1. Introduction

Virtual Reality (VR) has become an essential educational tool used by virtual laboratories to teach engineering subjects across mechanical, electrical, civil and chemical disciplines (Coutinho, Magana & Dias, 2023; Grigore & Turcu, 2025). VR functions as an educational tool that can serve both as an addition to physical laboratories and an alternative to addressing problems associated

https://doi.org/10.33436/v36i2y202606

with expensive equipment, substantial infrastructure and hazardous operational conditions (Bucăța et al., 2023). Students need to handle intricate systems and machinery during their learning process (Coutinho, Magana & Dias, 2023; Grigore & Turcu, 2025). Research studies have focused primarily on system viability and user feedback rather than on producing conclusive data regarding their teaching effectiveness, as users tend to demonstrate strong system interaction with VR systems, recognize their educational value and maintain favorable perceptions of them (Li et al., 2023; Jindal, Mittal & Bansal, 2023; Anjos et al., 2024).

VR serves as an educational tool which enables students to practice interactive scenarios that prove difficult to implement through standard teaching approaches (Botezatu et al., 2024; Nedelcu & Petre, 2024). Research shows this technology enables students to feel more engaged and motivated, experiencing a stronger sense of presence in simulated environments and develop a deeper understanding of engineering concepts through practical applications (Li et al., 2023; Jindal, Mittal & Bansal, 2023; Hamurcu, Timur & Rizvanoğlu, 2023; Anjos et al., 2024; Parlier, 2024). The current research findings stem from participant self-reports, which involved limited study groups and brief experimental periods, therefore demonstrating user approval and expected educational advantages, while not establishing actual learning outcomes.

The following sections of this paper present the overall structure of the study. Section 2 reviews previous research on virtual reality in engineering and environmental education, with emphasis on user experience evaluation and perceived learning value. Section 3 describes the research methodology, including the study design, participants and the VR educational environment. Section 4 presents the results of the statistical and qualitative analyses. Section 5 discusses the findings in relation to previous studies and examines the feasibility of the proposed approach. Section 6 outlines the main limitations of the study and directions for future research. Finally, Section 7 presents the conclusions.

2. Related work on VR in engineering education

Virtual Reality implementation in higher engineering education occurs mainly through virtual laboratory environments and simulation systems, which solve the problems of physical lab expenses, limited space and safety issues (Coutinho, Magana & Dias, 2023; Jindal, Mittal & Bansal, 2023). The controlled learning spaces let students work with intricate systems while their schools avoid spending significant money on infrastructure while also protecting their students from dangerous situations (Grigore & Turcu, 2024). The section presents typical VR applications used by engineering students and environmental students for learning, while showing the evaluation methods which combine perception-based approaches to assess learning benefits and interface satisfaction.

Research studies about VR in education use self-report tools together with psychological models, including the Technology Acceptance Model (TAM), instead of measuring actual performance outcomes (Anjos et al., 2024). The Technology Acceptance Model (TAM) evaluates student VR acceptance through two main factors, which are Perceived Usefulness and Perceived Ease of Use (Cook-Chennault & Farooq, 2023). The Student Perceived Value of an Engineering Laboratory (SPVEL) instrument combines TAM with additional models, and its factor analysis revealed that ease of use and usefulness form an independent factor (Vergara et al., 2022; Vlahovic, Suznjevic & Skorin-Kapov, 2022; Trigos & Tamayo-Enriquez, 2022). The teaching staff believe VR functions as an effective educational instrument, but their opinion stems from their personal observations instead of actual data from extended periods (Vergara et al., 2025).

The assessment process targets three primary elements, which consist of engagement, motivation and attractiveness. Research findings show that students achieve better satisfaction and enjoyment ratings when they use VR-based activities because they find these activities more engaging and interactive than traditional learning methods (Vlahovic, Suznjevic & Skorin-Kapov, 2022; Grewe & Gie, 2023; Vergara et al., 2025).

The research includes three fundamental metric clusters: Presence, Immersion and Realism. Students demonstrate their highest appreciation for interactive learning when teachers show them realistic three-dimensional models, which help students understand complex concepts better (Wang et al., 2022; Grigore & Turcu, 2024; Vergara et al., 2025). The DICE framework (Dangerous, Impossible, Counterproductive and Expensive) shows that VR provides valuable experiences that users cannot access through traditional means, while merging theoretical knowledge with practical simulated environments (Trigos & Tamayo-Enriquez, 2022; Cook-Chennault & Farooq, 2023; Parlier, 2024).

VR and simulation technologies provide realistic training and conceptual visualization across engineering disciplines (Coutinho, Magana & Dias, 2023; Grigore & Turcu, 2026). The field of mechanical and production engineering uses three main applications, which consist of a VR production sequencing model with parameter control (Vergara et al., 2022; Cook-Chennault & Farooq, 2023), a crank-slider kinematic visualization tool (Grigore & Turcu, 2025) and a virtual CNC machining laboratory, which serves as an introductory training resource (Kloth, Kim & Lee, 2020).

Civil engineering professionals use VR technology to develop safety training programs, which let students practice emergency response procedures and accident simulations through multiple repetitions of training sessions (Wang, 2020; Liang, 2021; Jindal, Mittal & Bansal, 2023). The system allows users to view construction operations and building locations through dynamic visualization (Wang et al., 2022; Jindal, Mittal & Bansal, 2023), while also supporting virtual material assessment (Wang, 2020; Vergara et al., 2022).

Virtual Electromagnetism Laboratory (Castro-Gutiérrez, Flores-Cruz & Gutierrez-Magallanes, 2021) and VR Raman spectroscopy classroom (Li et al., 2023) and immersive environments for fluid flow parameter inspection (Ciolacu et al., 2023) serve as examples of electrical and chemical engineering applications. The implementations show that VR systems can be successfully integrated into educational contexts and that system users generally provide positive feedback after using them.

Unity functions as the main software tool which engineers use to create VR content for educational purposes through its ability to generate interactive three-dimensional real-time environments (Chen et al., 2024; Kloth, Kim & Lee, 2020). The software enables students to handle objects while they explore the virtual environment through the construction of virtual laboratories and simulations (Vergara et al., 2022). Specific applications include:

- Production Engineering: Modeling dynamic systems and generating 3D VR images, often with Plant Simulation (Anjos et al., 2024).
- Manufacturing Training: Developing virtual labs, such as a VR CNC machine that simulates a real control panel (Kloth, Kim & Lee, 2020).
- Concept Visualization: Creating interactive environments like a Virtual Electromagnetism Laboratory with avatar navigation (Castro-Gutiérrez, Flores-Cruz & Gutierrez-Magallanes, 2021).

Unity offers multiple advantages because it enables developers to create complex animations through basic C# programming, which educators can easily use, and it supports exporting content into portable files that work across different devices (Kloth, Kim & Lee, 2020). The Unreal Engine serves as an additional major game engine which designers use to create VR educational content that helps students focus and build learning programs for mechanisms such as the crank-slider (Vergara et al., 2025; Maruko et al., 2023; Ciolacu et al., 2023; Grigore & Turcu, 2025).

3. Research methodology

3.1. Study design and participants

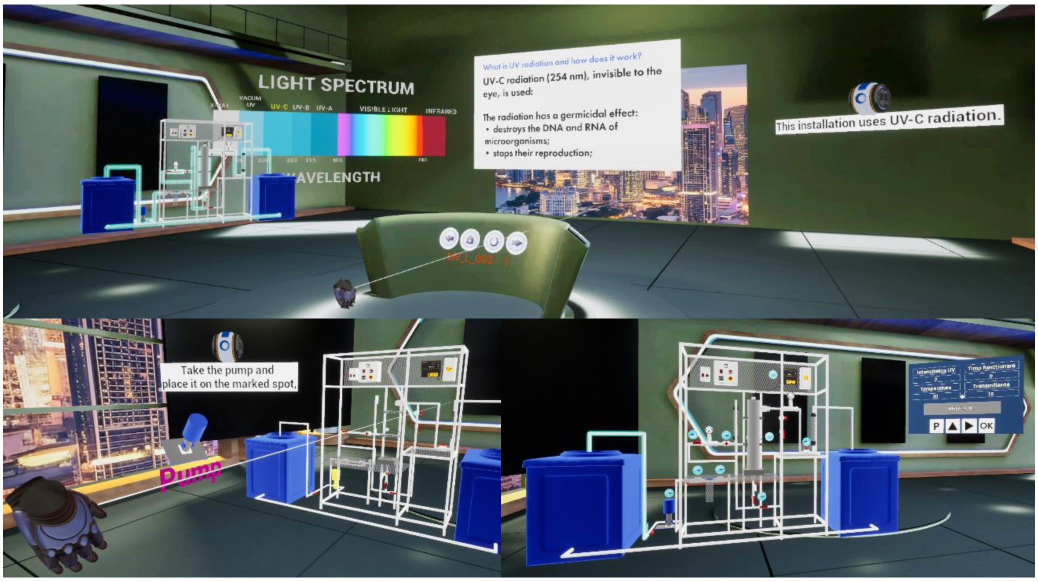
The research used a single VR instructional session as its foundation for a pre-post study which incorporated a within-subjects methodology to examine higher engineering education.

The research sample consisted of 35 high school students who studied environmental engineering during their summer school at a public university. The program included a VR lesson that functioned as one of its educational components. The research team analyzed 20 male students together with 15 female students from the pre-post dataset to form their final analytical sample. The students were aged between 15 and 18 years, with an average age of 16.7 years and a median age of 16 years. The students belonged to a senior high school group which prepared them for STEM university education. The study collected binary data about students' previous VR experience through a yes/no question, which served to show how students learned and accepted VR technology instead of conducting statistical tests between groups. Students had the freedom to join the study without any connection to their school evaluation process. The research followed all institutional rules which protect students during studies at their institution because students and parents were fully informed about the research goals, procedures and privacy protections, and consent was obtained prior to data collection.

3.2. VR educational environment

The VR lesson presented an environmental engineering subject about UV water disinfection through a dedicated proof-of-concept educational module. The design elements focused on creating educational materials which would help students grasp the UV treatment process and recognize its essential components: filters, UV lamp core and valves, as well as understand system performance in terms of UV dose and exposure time.

The activity used a virtual installation together with a physical UV stand, allowing students to observe the differences between virtual and physical components, verify information and recognize real-world engineering applications of the simulation. The lesson (Figure 1) was structured into three sequential activities. The training started with a brief theoretical session which taught students about water treatment procedures, UV radiation properties, and the essential components of a UV disinfection system.


What is UV radiation and how does it work?

UV-C radiation (254 nm), invisible to the eye, is used:

The radiation has a germicidal effect:
- destroys the DNA and RNA of microorganisms;
- stops their reproduction;

This installation uses UV-C radiation.

Take the pump and place it on the marked spot.

Figure 1. Screenshots from the VR educational environment illustrating virtual stand interaction and instructional overlays
(Source: authors' own research)

Students in the second phase of the project built the virtual stand by attaching essential components, which included filters, the UV lamp core and valves, to their correct positions inside the simulation. The virtual system operation required them to handle valve operations while they operated the installation and selected UV dose targets and water exposure durations from the available options.

The students used head-mounted displays and controllers to explore the environment while they used the actual UV stand to verify what they saw and to seek clarification about their observations. The VR lesson was implemented using a standalone head-mounted display connected to a VR-capable PC via a dedicated router to ensure low-latency wireless streaming. The virtual environment was created using the Unreal Engine, which developers used to build the UV disinfection system, simulate water movement and handle user interactions for component construction and parameter modification.

The device on which the app was run had a 12th-generation Intel Core i9 CPU; 64 GB of RAM, an NVIDIA GeForce RTX 3050 Ti graphics card, and an NVMe 2 TB SSD drive for storage. This particular hardware configuration provided additional processing power for complex algorithms, enabling smooth rendering and timely feedback to the user. The union of Meta Quest 3, Unreal Engine and Wi-Fi 6 integration not only assigned the teams to their own play areas but also substantially aided them in interacting with the virtual UV stand. All questionnaire variables were derived directly from self-reporting and were used as indicators of perceived learning value, user experience and acceptance of the VR activity indicators, rather than as objective tests of students' knowledge.

3.3. Pre-session measures

The pre-session questionnaire collected demographics and baseline perceptions:

- Demographics: The demographic information covered age (in years) and gender (male/female) as reported by the participants.
- Prior VR experience in education (Q10): One binary item captured whether participants had previously used VR in an educational context (0 = no, 1 = yes).
- Expectancy: Three items assessed expectations about the usefulness and value of the upcoming VR activity for learning. Responses were given on a 5-point Likert-type scale, with higher values indicating stronger positive expectations. The scale score was computed as the mean of Q1–Q3. In this sample, internal consistency was $\alpha = .62$ ($N = 35$).
- Learning Confidence: Three items captured participants' confidence in their ability to understand the upcoming content and to learn effectively in this context. Responses used the same 5-point format and the scale score was the mean of Q4–Q6. Internal consistency in this dataset was $\alpha = .60$ ($N = 35$).
- Motivation: Three items measured initial motivation and interest in engaging with the forthcoming learning activity. The scale score was the mean of Q7–Q9 on the same 5-point scale. Internal consistency was $\alpha = .66$ ($N = 35$).
- Tech Interest: One single item (Q11) indexed general interest in technology. This variable was analyzed as a standalone indicator of baseline technological interest on the 1–5 response scale, with higher scores reflecting stronger interest. These pre-session constructs were used as predictors and reference points for later perceived experience and change indices.

3.4. Post-session measures

The post-session questionnaire focused on perceived usability, learning value, presence, satisfaction, and changes in interest after using the VR application.

- Technology Acceptance Model: Three items assessed perceived usefulness and perceived ease of use of the VR application. Responses were given on the same 5-point Likert-type scale (1–5). The score was computed as the mean of Q1–Q3. Internal consistency in this sample was $\alpha = .71$.
- Perceived Learning: Three items captured perceived learning efficiency and clarity of the explanations provided by the VR activity. The scale score was the mean of Q4–Q6. Internal consistency was $\alpha = .66$.

- Presence: Three items measured perceived immersion and sense of "being there" in the virtual environment. The score was the mean of Q7–Q9. Internal consistency was α = .76 (N = 35). • Satisfaction: Two items assessed post-session satisfaction and motivation to continue learning with similar technologies. The scale score was the mean of Q11 and Q12. Internal consistency was α = .64.
- Binary post-session indicator: One yes/no item (Q10) captured a global evaluative judgement about the VR activity. In this sample, all participants selected the positive category, which indicates uniformly favorable endorsement on this specific dimension but provides no variability for comparative analyses.
- Self-evaluated understanding: One single item (Q13) captured perceived understanding of the topic after the VR session on the 1-5 response scale, with higher scores indicating higher self-reported understanding.
- Interest Gain: One single item (Q14) assessed perceived gain in interest in the topic following the VR experience, again on the 1-5 scale, with higher scores indicating higher perceived interest.

The pre-lesson scales showed basic internal consistency (α = 0.60–0.66), which meets the standards for exploratory feasibility research but limits the ability to draw definite conclusions.

3.5. Scale construction and derived measures

The research computed multi-item scale scores as the mean of the answered items. No items were left unmarked or reverse-scored. In all scales, higher scores indicate more favorable perceptions (i.e., stronger expectations and greater perceived usefulness, stronger presence and greater satisfaction). Two scales were developed to study differences in experiential perceptions. The Motivation Change index is the difference between post-satisfaction and pre-motivation reported scores and measures the self-reported change in motivation. The learning experience discrepancy index is the difference between post-learning and pre-expectation assessment. Positive values indicate that the assessment improved post-participation, whereas negative values indicate that the assessment was lower post-participation. As these indices are difference score variables that indicate how a participant perceives a change, positive and negative values may vary in scale or absolute magnitude between participants.

The multi-item scales reported moderate to low levels of internal-consistency reliability, with coefficient α ranging from .60 to .76, due to the small number of participants and the general nature of the initial design. All measures were self-report indicators of perceived learning value, usability and user experience.

3.6. Data analysis

The data was analyzed within the framework of a feasibility and perception study. To characterize user perceptions and feasibility, a before/after design was used within-subjects; no controlled studies with performance-based outcomes were conducted. For each multi-item construct, scale scores were the arithmetic mean of the items; single items were separately analyzed. Most variables showed non-normal distributions and all variables were collected on 5-point ordinal scales; thus, subsequent analyses followed non-parametric procedures. Wilcoxon signed-rank tests were applied to conceptually aligned pre-post pairs to depict the shifts in perceived experience; for these comparisons, medians, test statistics, p-values and rank-based effect sizes (r) were reported.

Basic perceptions, later ratings and change indices were related through Spearman rank correlations, seen as linkages between the patterns of the self-reported experience. Gender pretest comparisons were exploratively carried out through Mann-Whitney U tests; medians and rank-biserial correlations were the indicators of the effect size. All tests were two-tailed with α = .05, and the main focus was on effect sizes and association patterns of preliminary evidence of user acceptance and perceived learning value.

An inductive thematic analysis was performed on open-ended responses. Two researchers independently went through all responses and identified common themes. They later on compared and discussed their original codes and reached a consensus over problems. The final themes were used to compute the percent of students mentioning each theme. Since the dataset is small and the research has an exploratory aim, inter-rater reliability statistics were not calculated.

4. Results

All the results in this part are based on self-reported perceptions, and they were not treated as performance measures but instead as an indication of how feasible the system was, how much learning occurred and how acceptable the system was to the users. Table 1 provides a summary of the means and standard deviations, Shapiro-Wilk normality tests, and the Cronbach's α coefficients for all pre- and post-session perceptual measures. Pre-session measures: Expectancy, Learning Confidence, Motivation, and Tech Interest, all reflected favorable baseline attitudes, with mean scores of 3.95 (SD = .64), 3.93 (SD = .67), 4.04 (SD = .76), and 3.86 (SD = 1.06), respectively (all medians = 4.00). Expectancy, Motivation, and Tech Interest violated the normality assumption (all $p \leq .007$); Learning Confidence did not ($W = .951$, $p = .123$).

Table 1. Descriptive statistics, shapiro-wilk normality tests, and cronbach's α coefficients

Scale	**Time**	**Mean**	**SD**	**Median**	**IQR**	**Shapiro-Wilk**		**Cronbach's α**
						w	p	
Expectancy	Pre	3.952	0.637	4.00	0.667	0.909	0.007	0.623
Learning Confidence	Pre	3.933	0.666	4.00	0.667	0.951	0.123	0.596
Motivation	Pre	4.038	0.757	4.00	1.500	0.902	0.004	0.659
Tech Interest	Pre	3.857	1.061	4.00	2.000	0.862	0.000	-
TAM	Post	4.438	0.541	4.67	1.000	0.864	0.000	0.710
Learning	Post	4.238	0.640	4.00	1.333	0.900	0.004	0.659
Presence	Post	4.114	0.736	4.00	1.500	0.895	0.003	0.759
Satisfaction	Post	4.500	0.717	5.00	1.000	0.736	0.000	0.643
Understanding	Post	4.457	0.611	5.00	1.000	0.732	0.000	-
Interest Gain	Post	4.371	0.770	5.00	1.000	0.756	0.000	-

All post-session measures revealed highly positive perceptions. Post-session means were as follows: TAM = 4.44 (SD = .54, median = 4.67), Perceived Learning = 4.24 (SD = .64, median = 4.00), Presence = 4.11 (SD = .74, median = 4.00), Satisfaction = 4.50 (SD = .72, median = 5.00), Understanding = 4.46 (SD = .61, median = 5.00) and Interest Gain = 4.37 (SD = .77, median = 5.00). All post-session measures deviated significantly from normality (all $p \leq .004$).

As we expected, since the scales are very short, the internal consistency indices were low. Pre-session internal consistency was $\alpha = .62$ (Expectancy), .60 (Learning Confidence) and .66 (Motivation). Post-session values were $\alpha = .71$ (TAM), .66 (Perceived Learning), .76 (Presence) and .64 (Satisfaction). Tech Interest, Understanding and Interest Gain were single-item indicator measures, and thus Cronbach's alpha is not applicable and is shown as "-" in Table 1. In sum, these alpha coefficients do indicate that it is reasonable to use the multi-item sets as indicators of underlying perceived constructs for this sample in this situational context. However, as anticipated, values are somewhat low, and shared method variance and/or the impact of the programmatic context may be inflating the estimates of internal consistency.

4.1. Comparisons between pre-and post-session perceptions

Pairs of conceptually aligned pre- and post-reports were analyzed via Wilcoxon signed-rank tests (Table 2). The observed pre-to-post shifts reflect changes in perceived experience rather than objective differences in learning performance.

Table 2. Wilcoxon signed-rank tests for pre- and post-session perceptions

Pair	N	W	p	Median Pre	Median Post	Median Diff	Effect r
Motivation vs Satisfaction	35	83.0	0.019	4.00	5.00	0.167	0.398
Expectancy vs Learning	35	82.5	0.031	4.00	4.00	0.333	0.365
Learning Confidence vs Understanding	35	36.0	0.000	4.00	5.00	0.333	0.600

The ratings of post-session Satisfaction were recorded as higher than the pre-session Motivation ratings. The medians increased from 4.00 to 5.00, with a small positive median difference (≈ 0.17), and the Wilcoxon test yielded W = 83.0, p = .019, with an effect size which r ≈ 0.40, indicating a medium-magnitude change in perceived motivation/satisfaction. Expectancy (Pre) was compared with Learning (Post) in this context to establish the relationship between perceived learning value and initial expectations. Their median was 4.00; nevertheless, the median difference was positive (≈ 0.33).

The test result (W = 82.5, p = .031, r ≈ 0.36) indicated that the participants often rated their perceived learning slightly higher than their initial expectations. Learning Confidence (Pre) compared to Understanding (Post) showed a similar trend. Medians increased from 4.00 to 5.00, with a median difference of around 0.33.

The Wilcoxon test returned W = 36.0, p < .001 and r ≈ 0.60, which is in agreement with self-reported understanding being significantly higher in the post-session compared to baseline confidence. These patterns suggest that students perceived the VR activity positively, particularly in terms of learning value and self-reported understanding, without indicating objective learning gains.

4.2. Relationships between baseline and post-session measures

The Spearman correlation between pre-session and post-session perception data provides the first results, as shown in Figure 2. The post-session constructs showed positive correlations with Higher Expectancy scores through the following results: TAM (ρ = 0.44, p = .008), Learning (ρ = 0.37, p = .027), Presence (ρ = 0.47, p = .005) and Satisfaction (ρ = 0.44, p = .008). Users who joined the session with high expectations reported better usability, learning value, presence and satisfaction after the session. The Understanding relationship showed a positive trend but failed to achieve statistical significance at the standard level (ρ = 0.31, p = .075). The Learning index showed a negative correlation with Expectancy (Learning – Expectancy ρ = -0.51, p = .002). The group that began with minimal expectations achieved better learning results than they predicted, whereas the students who started with high expectations showed less improvement in positive scores.

Students who started with high learning confidence showed negative correlations with motivation change and actual learning performance. Students who started with high confidence showed smaller positive differences across motivation ratings, expected learning, and actual learning scores. The Pre-Motivation scores showed a strong inverse relationship with Motivation Change (ρ = -0.78, p < .001), which suggests a ceiling effect in self-report data, because higher initial motivation levels prevented further increases in self-report ratings, whereas lower initial motivation levels produced greater positive changes.

Tech Interest and VR Experience showed weak to moderate correlations with post-session scale results, but these relationships failed to achieve statistical significance at α = .05, except for a borderline relationship between Tech Interest and Learning (ρ = 0.33, p = .054). Research findings indicate that baseline interest, together with previous VR experience, had minimal influence on participant perceptions of their test results although these results remain ambiguous.

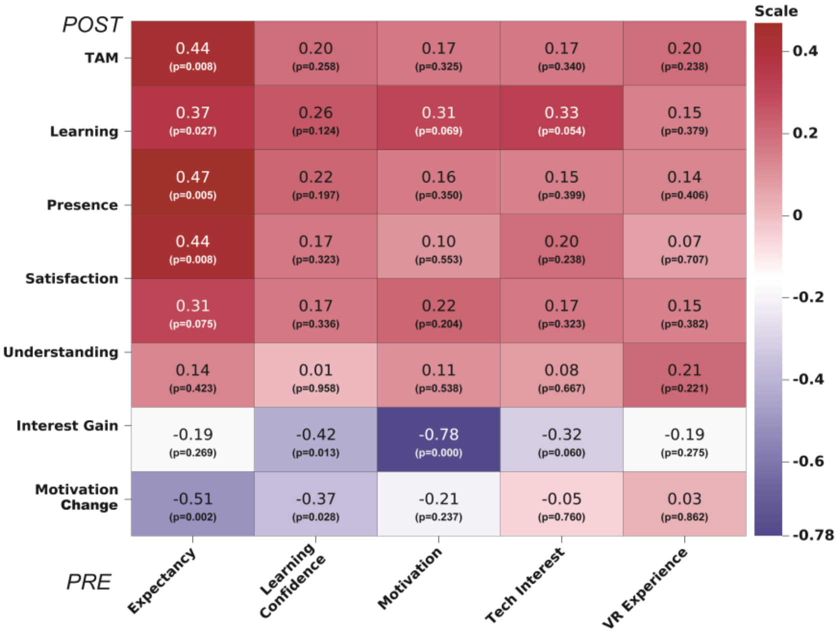


Figure 2. Heatmap of Spearman correlations between pre- and post-session perceived constructs

4.3. Subgroup comparisons by gender

We compared male (n_1 = 20) and female (n_2 = 15) participants' perceptions using Mann-Whitney U tests for the follow-up post-session measures presented in Table 3. Median scores were extremely high for both samples. Males appeared to have slightly higher medians on a few measures (e.g., TAM 4.67 vs 4.33; Satisfaction 5.00 vs 4.50; Interest Gain 5.00 vs 4.00), but there was no compelling evidence for differences between the groups on any comparison (all $p \geq .14$), and the resulting rank-biserial correlations were small ($|r\_rb| \leq 0.29$). In this preliminary evaluation, usability, learning value, presence and motivation impressions seemed quite comparable between males and females.

Table 3. Mann-whitney U tests for post-session perceptions by gender

Variable	U	p	Rank biserial r
TAM	193.50	0.140	-0.290
Learning Confidence	155.50	0.865	-0.037
Presence	163.00	0.672	-0.087
Satisfaction	187.00	0.182	-0.247
Understanding	163.00	0.638	-0.087
Interest Gain	154.50	0.882	-0.030
Motivation Change	141.00	0.775	0.060
Learning Discrepancy	107.00	0.151	0.287

A post-session item pool endorsement was obtained from all 35 participants (100%). Because there was no variance in the responses and this activity manifested consensus support from all participants, possibly indicating strongly positive results (but not precluding unanimously negative reactions), item Q10 (Post) can only serve, in this pilot sense, as an overall measure of unanimous participant endorsement of the associated construct.

4.4. Sensitivity and statistical power analysis

A sensitivity analysis for a two-tailed paired t-test at $\alpha = .05$ with a target power of 0.80, from $N_{paired} = 35$, also indicated that the design could reveal an effect of Cohen's dz ≈ 0.49. While non-parametric methods were favored, this benchmark clarifies that the pilot was most appropriately powered for moderate and larger positive shifts in user-reported experiences.

4.5. Qualitative feedback analysis

Post-session survey included three open-ended questions for participants to state their impressions of the VR activity: what they liked the most, what they found less satisfactory or challenging elements, and what they would like to improve. This arrangement encouraged personal reflection and complemented the Likert-type measures by providing qualitative insights into user acceptance.

The responses to the question "What did you like most about the VR lesson?" were grouped in broad categories. The top one was overall appreciation, which was the most frequently mentioned category (24%), followed by the improvement of components and processes (18%) and practical engagement through simulation and assembly (16%). Interactivity (12%) and realism or advanced technology (10%) were also pointed out, thereby emphasizing the need for hands-on, immersive experiences. A lesser number of responses concerned lesson structure (8%) and ease of use (4%), while 6% provided no specific answer. Thus, we can conclude that clarity, interactivity and practical engagement were the most valued aspects.

As for "What did you find difficult or less satisfactory?", responses were quite mixed, although most reported difficulties were minor. The most common concern was initial adaptation to the headset and physical space (31%). A notable portion of the responses consisted of vague answers or were left blank (23%, n = 8), and 17% reported no difficulties at all.

For the question "What would you add or change?", a considerable portion of responses were empty or not very clear (26%), and 14% of the respondents did not provide any suggestions. Yet, from the ones that were left, the participants' suggestions were related to improvements in equipment and space setting (9%), multi-user or collaborative features (11%), extra practice activities (9%), and broader lesson content (11%). Some other recommendations included increasing realism (11%) and restructuring the lesson (9%), which suggests that both technical and pedagogical aspects need further improvement. Overall, these suggestions provide a useful foundation and serve as a starting point for enhancement in VR learning design.

5. Discussion

The evidence demonstrates that the virtual reality (VR) lesson could effectively serve as a first-exposure teaching tool for pre-university learners in an environmental engineering context, where perceptions right after the session consistently exceeded pre-session baselines (Anjos et al., 2024; Hamurcu, Timur & Rızvanoğlu, 2023), a pattern that has been well-documented in short-term VR education studies.

The strong user acceptance and the fact that TAM ratings were higher than expected from the very beginning suggests that the activity delivered experiential value. However, participants were first-time users of VR and may have been influenced by the novelty effect of the medium, therefore direct attribution to the quality of instructional design was not straightforward. If this design is used across multiple sessions, it will be easier to separate the effects. The negative correlation observed between pre-session expectancy and Learning Discrepancy index illustrates the ceiling effect among very positive learners, confirming the findings of Grewe & Gie (2023). They suggested that expectation calibration should be addressed prior to the lesson, in the same way as designing the instruction; both are important.

Presence, TAM, and Satisfaction are positively correlated, which is in line with the immersion-engagement link reported by Vlahovic, Suznjevic & Skorin-Kapov (2022). However, qualitative data adds depth: students highlighted that interactivity and hands-on engagement were more important than immersion alone (Coutinho, Magana & Dias, 2023). The pre-adaptation difficulties and pacing management issues, raised by roughly one-third of the participants, were typical challenges of using a new product (Jindal, Mittal & Bansal, 2023) and rather indicate specific design enhancements instead of the whole approach being inadequate.

6. Limitations and future work

The findings of this feasibility study should be interpreted with caution, as they are based mainly on self-reported data. Therefore, the results reflect perceived learning value, usability, satisfaction and user acceptance rather than objective learning performance. Self-report measures may also be influenced by social desirability, response inflation and the novelty of first-time VR use.

The investigation is further constrained by its small, context-specific sample and single-session design. Further studies should target objective knowledge tests, performance-based tasks, delayed follow-up assessments, larger and more diversified samples, and comparisons of VR, traditional, and blended instruction. Future work should also carry out the refinement and validation of the measurement scales used in this study. Moreover, multi-user collaborative VR settings should also be investigated, as a number of students have declared that peer interaction should be improved the most within the learning experience.

7. Conclusion

The research study mentioned in this paper served as a primary proof that a single instance of a VR lesson on UV water disinfection was perceived quite positively by high-school students across all the constructs that were measured. The ratings received by the students after the session regarding user acceptance, perceived learning value, presence and satisfaction were consistently high, surpassing the pre-session expectations and the qualitative responses of the students clearly identified the clarity of content and the high-value hands-on interactivity as the main aspects that were prized by the students. These results provide evidence for the possibility of using VR as a supplementary teaching method in pre-engineering classes, and particularly in the situation where the physical devices are expensive or difficult to introduce due to safety concerns.

Author contributions

P.-I.G.: was involved in the whole process of study project structure, research plan management, VR application production, course scenario format, questionnaire construction, data collection, statistical analysis, manuscript writing. A.Z.: instructional design, VR activity implementation, participant coordination, data collection, results interpretation, manuscript review. C.O.T.: research supervision, methodological guidance, theoretical framing, measurement instrument selection, data analysis review, manuscript revision. V.N.: domain expertise in environmental engineering and water treatment, VR lesson content validation, results interpretation, manuscript review.

Acknowledgments

The authors express their gratitude to the Faculty of Electrical Engineering and Computer Science at Ștefan cel Mare University of Suceava and the Faculty of Engineering at Vasile Alecsandri University of Bacău for institutional support. Moreover, they also thank the participating high-school students for their feedback, and to the reviewers and the editor for their constructive comments. Additionally, the authors mention the use of AI-assisted writing tools for language editing. There was no external funding allocated for the research.

Submission received: 09 January 2026; Revised: 11 May 2026; Accepted: 13 May 2026; Published: 30 June 2026.

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