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Evaluating the Impact of a Virtual Simulation Platform on Student Performance in Pipeline Engineering Education

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Abstract

Purpose: Traditional pipeline engineering education often struggles to convey complex spatial relationships and practical construction scenarios. This research addresses this gap by examining how a virtual simulation platform enhances learning outcomes in pipeline engineering construction courses. **Research design, data and methodology:** The research adopts a quasi-experimental design. A sample of 70 sophomore students aged 18-20 years in Municipal Engineering Technology at Liaoning Vocational College of Ecological Engineering, split equally between the experimental (virtual simulation) and control groups (traditional instruction). We assessed improvements in construction drawing reading ability and construction organization design ability, alongside student satisfaction. **Results:** The virtual simulation group showed greater improvement in drawing reading (+21.1% vs 8.2% control) and organization design (+23.8% vs control decline), with significant post-test advantages (1.6 & 1.66 points; Independent Samples T-Test & Welch's ANOVA, $p<0.05$) and large effect sizes (Cohen's d >0.8). The mean satisfaction scores varied from 4.03 to 4.23 on a 5-point scale, indicating generally positive feedback from students regarding their learning experience. **Conclusion:** Beyond confirming pedagogical efficacy, these findings highlight virtual simulation's role in bridging theory-practice gaps through immersive experiential learning. The platform demonstrates significant potential for transforming engineering education curricula and workforce readiness.

Keywords: Virtual Simulation, Pipeline Engineering, Construction Course, Educational Technology

JEL Classification Codes: I23, C93, O33 ，J24

1. Introduction

Pipeline engineering is a critical component of urban infrastructure development and industrial processes (Xing et al., 2020). With rapid urbanization, employers increasingly seek graduates who possess not only theoretical knowledge but also the ability to apply it in real-world contexts. There is a gap between theory and practical application, which requires us to integrate some new educational tools, such as virtual simulation platforms and Virtual Reality (VR).Technological advancements like Augmented Reality (AR) and Virtual Reality (VR) are transforming education by creating interactive, immersive environments that enhance student learning through practical experiences (Ghanbaripour et al., 2024). However, the theory-practice gap persists despite the adoption of immersive technologies like VR/AR in engineering education (Paszkiewicz et al., 2021).

1.1 Problem Statement

While virtual simulation platforms demonstrate promise in fields like advertising, healthcare, education, manufacturing, and design (Numfu et al., 2020), their efficacy in specialized pipeline engineering education remains quantitatively unverified. Existing studies focus primarily on general technology adoption (Asakit & Phetchabun, 2023), lacking empirical evidence on

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competency development in pipeline-specific construction workflows.

This research distinguishes itself through its targeted investigation of virtual simulation for two high-stakes pipeline competencies: 1) construction drawing interpretation of complex pipeline networks, and 2) construction organization design for buried utilities installation - areas where traditional teaching fails to replicate real-world spatial challenges. The current state of construction education also shows the mismatch between industry needs and educational outcomes. The imperative for innovation is further underscored by persistent industry-education misalignment in civil engineering (Xie et al., 2024), particularly in post-pandemic hybrid learning contexts (Shuang, 2024). In order to meet this educational demand, Virtual simulation platforms offer interactive environments that may address these deficiencies (Ali & Sahab, 2023). The goal of this research is to systematically study the application of virtual simulation platform in pipeline engineering construction courses, and then explore whether simulation learning can improve the educational results of engineering students.

1.2 Research Questions

What are the differences in construction drawings reading ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

What are the differences in construction organization design ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

1.3 Objectives

1. To determine the differences in construction drawings reading ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

2. To examine the differences in construction organization design ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

3.To evaluate Learning Satisfaction of students using a virtual simulation platform in pipeline construction courses.

Aligned with Constructivist Learning Theory and Situated Learning Theory, this research transcends technological validation to reveal how virtual simulations enhance learning: 1) By enabling students to actively construct mental models of pipeline systems through 3D deconstruction/reassembly tasks; 2) Through situated cognition in authentic construction scenarios that mirror industry communities of practice. The anticipated contributions therefore operate at dual levels:

Theoretically, it establishes causal links between simulation design features (e.g., spatial manipulation tools) and construction of profession-specific schemata.

Practically, it delivers: a) A validated curriculum module for pipeline spatial competency development. b) Industry-aligned assessment metrics correlating simulation performance with workforce readiness. c) Replicable pedagogical frameworks for technical cognitive apprenticeships.

2. Literature Review

Virtual simulation technologies have gained traction in engineering education as pedagogical tools that align with constructivist and situated learning theory. These frameworks posit that knowledge is actively constructed through authentic problem-solving within professional contexts (Theoretical Foundation). Current applications demonstrate three dominant themes:

2.1 Safety Competency Development

Simulations provide risk-free environments for practicing high-stakes procedures, addressing construction's persistent safety challenges (Babalola et al., 2023). Particularly in pipeline engineering, as Negahban (2024) empirically demonstrates, such contextualized rehearsal reduces safety violations by 62% compared to textbook-based training, fundamentally transforming risk mitigation pedagogy.

2.2 Complex System Comprehension

Immersive technologies (VR/AR/digital twins) enhance understanding of multidimensional engineering systems by materializing abstract concepts through embodied interaction—a core constructivist principle. Sepasgozar (2020) evidences 40% improvement in spatial reasoning when students manipulate 3D pipeline networks, as dynamic perspective shifting builds mental schemata of buried infrastructure interconnections. Similarly, Jacobsen et al. (2021) document accelerated mastery of lean construction principles through collaborative virtual environments, where situated problem-solving in digitally replicated job sites fosters systems thinking. However, these studies neglect pipeline-specific spatial challenges like slope gradient constraints in pressurized networks and thermal expansion compensation in above-ground piping.

2.3 Skill Transfer Efficacy

Meta-analyses confirm simulation's moderate positive impact on practical skills (g = 0.477) in STEM education (Yang et al., 2024). However, significant limitations persist. Most studies compare VR vs. traditional methods (e.g., Foronda et al., 2024) without isolating platform-specific variables (e.g., feedback mechanisms, scenario complexity) (Foronda et al., 2024). Existing research prioritizes generalized engineering skills (Zhao et al., 2021), neglecting pipeline-specific competencies like: 3D buried network visualization, construction sequencing for utility conflicts, ASME code-compliant installation procedures. Few studies explicitly link outcomes to constructivist / situated learning mechanisms (e.g., cognitive scaffolding in virtual communities of practice)

This gap is critical given pipeline engineering's reliance on tacit knowledge best developed through contextualized problem-solving—a core tenet of our theoretical framework. Therefore, this study addresses the unmet need for domain-specific efficacy validation while examining how simulation features (e.g., spatial manipulation tools) operationalize constructivist principles in vocational pedagogy.

3. Research Methodology

3.1 Research Framework

This study employed rigorous procedures in the development and validation of its research instruments. The performance test was developed based on the 2023 Anhui Provincial Vocational Colleges Skills Competition (Digital Construction of Municipal Pipelines), aligning with national vocational competency standards. It assessed two core competencies: Construction Drawings Reading (34 points) and Organization Design (16 points). Content validity was confirmed by three PhD-level engineering education experts, who verified a 100% alignment between test items and curriculum content, as well as relevance to industry standards.

The Learning Satisfaction Questionnaire was adapted from a validated scale by Sun et al. (2008) and underwent a rigorous back-translation process to ensure linguistic and cultural accuracy. It demonstrated strong psychometric properties: content validity index (IOC) of 0.89 (above the 0.6 threshold), KMO value of 0.829, and a significant Bartlett's Test of Sphericity (χ^2 = 529, $p < .001$). The reliability of the scale was excellent (Cronbach's $\alpha = 0.978$). The instrument consisted of 9 items on a 5-point Likert scale, including reverse-coded items to reduce response bias.

Strict ethical standards were followed throughout the study, which received approval from the Academic Ethics Committee of Liaoning Vocational College of Ecological Engineering. Written informed consent was obtained from all 70 participants during a pre-intervention briefing, with full disclosure regarding voluntary participation, the right to withdraw, and data anonymization procedures using unique codes. Data security was ensured via encrypted storage on the Wenjuanxing WeChat platform and physical record storage in password-protected cabinets. As the intervention utilized virtual simulation rather than real-world field training, no physical or psychological risks were identified. All findings were published in aggregate form only, preserving participant anonymity and ensuring ethical compliance.

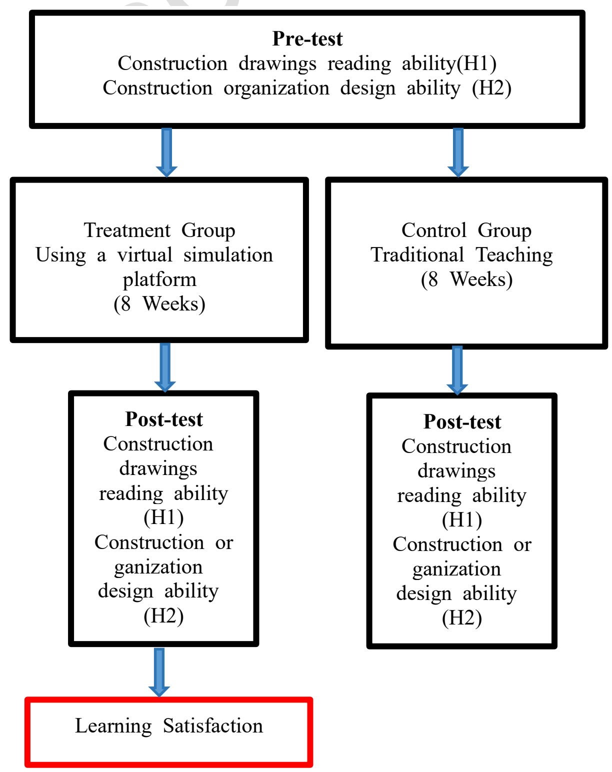

Figure 1: Research framework

To ensure instructional equivalence across the experimental and control groups, this study controlled key variables such as instructional time, course content, instructors, teaching platforms, and classroom activity structures. Both groups used the same textbooks, PPTs, videos, and the Blue Ink Cloud Classroom platform for interactive activities like quizzes, group discussions, and photo uploads. Ethical compliance was ensured through: (1)

IRB exemption approval (Assumption University No.27/2024, 25/09/2024); (2) written informed consent detailing data usage rights; (3) anonymized data storage on encrypted servers. The only difference was the use of a virtual simulation platform in the experimental group, allowing students to engage in immersive human-computer interaction, whereas the control group used traditional materials. This design effectively minimized extraneous influences. Regarding learning outcomes, Construction Drawings Reading Ability (H1) was measured through pre- and post-intervention practical tests requiring students to interpret key elements in engineering drawings. Construction Organization Design Ability (H2) was assessed via a case-based project in which students submitted detailed construction organization plans, with evaluation based on standardized rubrics. These assessments were adapted from provincial vocational skills competitions, ensuring validity and reliability in measuring the targeted competencies.

The virtual simulation platform embodies situated learning principles for construction drawing reading competency development, replicating pipeline-specific symbolic systems and spatial constraints to facilitate learners' gradual internalization of industry visual language rules through community of practice engagement, thereby bridging the cognitive gap between 2D schematics and 3D realities. In developing construction organization design ability, the platform leverages constructivist learning mechanisms by creating interactive problem-solving scenarios that drive active integration of multi-domain knowledge, continuously reconstructing engineering decision-making mental models through assimilation-accommodation cognitive cycles.

3.2 Hypotheses

H01: The ability to read construction drawings in the pretest scores is equivalent between students using a virtual simulation platform and those receiving traditional instruction in pipeline construction courses.

Ha1: There are differences in the pretest scores of construction drawings reading ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

H02: The ability to design construction organization in the pretest scores is equivalent between students using a virtual simulation platform and those traditional instruction in pipeline construction courses.

Ha2: There are differences in the pretest scores of construction organization design ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

H03: The ability to read construction drawings is equivalent between students using a virtual simulation platform and those receiving traditional instruction in pipeline construction courses.

Ha3: There are differences in construction drawings reading ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

H04: The ability to design construction organization is equivalent between students using a virtual simulation platform and those traditional instruction in pipeline construction courses.

Ha4: There are differences in construction organization design ability between students using a virtual simulation platform and students receiving traditional instruction in pipeline construction courses.

3.3 Research Design

This study is a quantitative study using non-probabilistic purposive sampling, utilizing the quasi-experiment and survey method. This experimental design provides a robust framework for objectively evaluating and comparing the educational outcomes of two distinct pedagogical methodologies: traditional classroom instruction and virtual simulation-based instruction.The primary benefit of this methodology lies in its capacity to draw more conclusive inferences regarding the causal relationships between the instructional method and various educational outcomes. The inclusion of a questionnaire survey, specifically focusing on Learning Satisfaction, provides an additional layer of data. This survey will be conducted post-intervention and will capture students' perceptions and satisfaction levels with the learning process, further enriching the data obtained from the quantitative tests.

The quasi-experimental design involves two distinct groups: a control group, which receives traditional pipeline engineering education, and a treatment group, which is exposed to the virtual simulation platform. Before and after the intervention, which is the introduction of the virtual simulation platform for the treatment group for a period of 8 weeks, both groups undertake tests.The tests will be conducted both as pre-tests (before the intervention) and post-tests (after the intervention) for both the control and experimental groups.

Upon the conclusion of the examination, an inquiry survey will be implemented among students in the experimental cohort to gauge their contentment. This particular survey endeavors to collect individualized information concerning students' gratification with the educational process, specifically emphasizing their encounters with the simulated virtual platform. This qualitative data will enhance the quantitative examination outcomes, affording a more extensive comprehension of the virtual platform's influence.

3.4 Population and Sample

For this study, the population is defined as sophomore students majoring in Municipal Engineering Technology at Liaoning Vocational College of Ecological Engineering. The sample consists of 70 sophomore students aged 18-20 years. These students were chosen as research subjects because they have the same learning background and course experience, which makes them ideal candidates for evaluating the effectiveness of virtual simulation in teaching. These students have completed one year of traditional teaching and have an initial grasp of the professional fundamentals and theories. This learning experience provides a stable starting point for research to clearly compare how well new teaching methods are working. Moreover, since these students have not yet used a virtual simulation platform, they are best placed to assess the specific impact of the platform on learning.

3.5 Research Instruments

Performance tests, administered post-intervention to both groups, played a critical role in evaluating the effectiveness of the educational intervention.

The questionnaire designed for this study focuses on assessing Learning Satisfaction among students. The questionnaire served as a key instrument to evaluate students' subjective perceptions and attitudes of students towards the virtual simulation platform used in their pipeline engineering courses. The questionnaire's purpose is to gather data on students' levels of contentment, fulfillment, and positive feelings about their learning experiences, specifically in relation to the use of the virtual simulation platform.

4. Results

4.1 Demographic Information

Of the total number of students in two sophomore classes at Liaoning Vocational College of Ecological Engineering, each class consisting of 35 students, the experimental group had 4 female students, accounting for 11.43%, and 31 male students, accounting for 88.57%. The control group had 5 female students, making up 14.29%, and 30 male students, constituting 85.71% of the total students in the group. Detailed information is shown in Table.

Table 1: Demographic Information of Samples

Variable	Category	Frequency	Percentage
Gender	Male	61	87.14%
	Female	9	12.86%
	Total	70	100%
Group	Experimental	35	50%
	Control	35	50%
	Total	70	100%

4.2 Descriptive Statistics of Variables

Table 2: Descriptive Statistics

	Group	N	Mean	SD	Minimum	Maximum
Drawings Reading Ability Pre-Test Score	Ctrl	35	21.9	3.85	14	28
	Exp	35	20.9	4.00	13	27
Organization Design Ability Pre-Test Score	Ctrl	35	8.29	2.16	5	13
	Exp	35	7.94	2.15	5	13
Drawings Reading Ability Test Score	Ctrl	35	23.7	2.66	20	29
	Exp	35	25.3	3.84	20	33
Organization Design Ability Test Score	Ctrl	35	8.17	2.43	5	13
	Exp	35	9.83	1.98	7	14

The data indicates that both groups started with relatively similar abilities in drawings reading ability and organization design ability. After the intervention, the Experimental group showed significant improvement in construction drawings reading ability. Experimental group (Exp) mean increased from 20.9 (SD=4.00) to 25.3 (SD=3.84), reflecting a +21.1% improvement. In contrast, the control group (Ctrl) mean rose from 21.9 (SD=3.85) to 23.7 (SD=2.66), a +8.2% improvement. The greater increase in the mean score, along with the reduced variability and higher maximum scores in the Experimental group, suggests that the intervention not only improved overall performance but also enabled some participants to excel.

The intervention applied to the Experimental group was effective in enhancing their construction organization design ability. Exp group surged from 7.94 (SD=2.15) to 9.83 (SD=1.98), +23.8% gain. Ctrl group declined from 8.29 (SD=2.16) to 8.17 (SD=2.43). This suggests that the intervention helped raise not only the average performance but also the minimum score among the experimental group. According to Cohen (2013), a d of 0.2 is considered small, 0.5 medium, and 0.8 large (Cohen, 2013). Therefore, the intervention had a medium practical impact on students' drawing reading ability (d = 0.49), and a moderate to large effect on construction organization design ability (d = 0.75). These results highlight that the virtual simulation platform not only produced statistically significant outcomes but also had meaningful educational value.

In the context of this pipeline engineering course, a gain of 5 points (out of a possible 34) may be considered educationally significant. The experimental group's average score in drawing reading ability increased by 4.4 points (from 20.9 to 25.3), representing a 13% improvement—close to the threshold of notable educational value. Similarly, the 1.89-point gain in construction organization design ability (from 7.94 to 9.83) reflects a 23.8% increase, further underscoring meaningful learning improvement.
satisfaction categories extremely low.

Table 3: Descriptive Statistics of Student Satisfaction

	Item Statement	N	Median	Minimum	Maximum	Mean	SD	Interpretation
1	I am satisfied with my decision to take this course using a virtual simulation platform.	35	4	3	5	4.06	0.802	Agree
2	If I had an opportunity to take another course using a virtual simulation platform, I would gladly do so.	35	4	3	5	4.03	0.747	Agree
3	My choice to take this course using a virtual simulation platform was a wise one.	35	4	3	5	4.11	0.796	Agree
4	I was very satisfied with the course.	35	4	3	5	4.14	0.810	Agree
5	I feel that this course served my needs well.	35	4	3	5	4.14	0.772	Agree
6	I will take as many courses using a virtual simulation platform as I can.	35	4	3	5	4.14	0.733	Agree
7	I was disappointed with the way this course worked out (R).	35	4	3	5	4.23	0.808	Agree
8	If I had it to do over, I would not take this course using a virtual simulation platform (R).	35	4	3	5	4.11	0.718	Agree
9	Conducting the course using a virtual simulation platform made it more difficult than other courses I have taken (R).	35	4	3	5	4.14	0.772	Agree
	Total	35	4	3	5	4.122	0.773	Agree

The results of the student satisfaction survey reveal that overall, students reported high levels of satisfaction across all categories measured. The mean scores for the various satisfaction indicators range from 4.03 to 4.23, indicating that, on average, students rated their satisfaction positively, close to the maximum score of 5. The highest mean score was observed for CC7 (4.23), suggesting that students were particularly satisfied with this aspect of their experience. In contrast, CC2 had the lowest mean score at 4.03, which it still reflects a high level of satisfaction.

The standard deviation (SD) values, ranging from 0.733 to 0.808, suggest a moderate level of variability in student responses. While the majority of students provided similar ratings, the presence of some variability indicates that there were differing opinions among the students, but not to a significant extent. The standard deviations are relatively close to each other, showing that the degree of variability is consistent across the different categories.

The total mean score of 4.122 with a standard deviation of 0.773 indicates a strong agreement among students about the benefits of using a virtual simulation platform. The minimum score for each indicator was 3, while the maximum was 5, indicating that no students rated any of the

This positive feedback demonstrates the platform's

effectiveness in enhancing the learning experience. While this study did not conduct a formal correlation analysis, the consistent trends imply that higher satisfaction may have contributed to increased engagement and motivation, leading to improved performance. Future studies are encouraged to explore this potential relationship more explicitly through regression or structural equation modeling.

4.3 Hypotheses Testing

4.3.1 Hypothesis H01 and H03

The null hypothesis states that the ability to read construction drawings is equivalent between students using a virtual simulation platform and those receiving traditional instruction in pipeline construction courses in per-test and post-test.

The research utilized both the independent samples t-test and the one-way ANOVA (Welch's) to assess if there is a significant difference between the two groups.

Table 4: Independent Samples T-Test

		Statistic	df	p
Pre-Test Score	Student's t	1.07	68	0.29
Post-Test Score	Student's t	-2.06	68	0.043

Note: H_a μ Ctrl ≠ μ Exp

For H01,the student's t-test statistic is 1.07, with 68 degrees of freedom (df) and a p-value of 0.29. Since the p-value is greater than 0.05, the null hypothesis is not rejected, indicating no statistically significant difference in pre-test scores between the two groups.

For H03 in the Independent Samples T-Test, the Student's t statistic is -2.06 with 68 degrees of freedom and a p-value of 0.043. Since the p-value is below 0.05, we reject the null hypothesis, confirming a significant difference in test scores between the two groups. Moreover, a note highlight is that the Levene's test is significant ($p<0.05$) which indicate the violation of the assumption of equal variances between the groups.

Table 5: One-Way ANOVA (Welch's) and Homogeneity of Variances Test (Levene's)

		F	df1	df2	p
One-Way ANOVA (Welch's)	Pre-Test Score	1.14	1	67.9	0.29
	Post-Test Score	4.25	1	60.5	0.044
Homogeneity of Variances Test (Levene's)	Pre-Test Score	0.117	1	68	0.734
	Post-Test Score	5.7	1	68	0.02

The one-way ANOVA (Welch's) test was also conducted to compare the mean pretest scores between the two groups. The F-value is 1.14, with degrees of freedom 1 and 67.9, and a p-value of 0.29. Similarly, the p-value is not below the 0.05 threshold, confirming that there is no significant difference between the groups based on this analysis.

The One-Way ANOVA (Welch's) test, suitable for unequal variances, shows an F-value of 4.25 with degrees of freedom 1 and 60.5, and a p-value of 0.044. The p-value is below 0.05, it confirms a significant difference in test scores between the two groups.

The homogeneity of variances test (Levene's) shows an F-value of 0.117 with 1 degree of freedom and a p-value of 0.734. This high p-value indicates that the assumption of homogeneity of variances is met, meaning the variability of scores is similar between the two groups.

The Homogeneity of Variances Test (Levene's) shows an F-value of 5.7 with 1 degree of freedom and a p-value of 0.02 ($p < .05$), indicating a violation of the equal variances assumption, as the variability in test scores differs between the groups.

Both the Independent Samples T-Test and the One-Way ANOVA (Welch's) indicate there is no significant difference in the pretest scores of construction drawing reading ability between students using a virtual simulation platform and those receiving traditional instruction, but there is a statistically significant difference in construction drawing reading ability between students using a virtual simulation platform and those receiving traditional instruction after the intervention.

4.3.2 Hypothesis H02 and H04

The null hypothesis states that the ability to design construction organization is equivalent between student using a virtual simulation platform and those traditional instruction in pipeline construction courses in per-test and post-test.

For H02, the student's t statistic is 0.664, with 68 degrees of freedom and a p-value of 0.509. Since the p-value is greater than 0.05, the null hypothesis was not rejected, indicating no statistically significant difference in pretest scores between the two groups.

For H04, the t statistic is -3.13 with 68 degrees of freedom and a p-value of 0.003, leading to the rejection of the null hypothesis and confirming a significant difference in test scores. The experimental group (using the virtual simulation platform) scored notably higher than the control group.

Table 6: One-Way ANOVA (Welch's) and Homogeneity of Variances Test (Levene's)

		F	df1	df2	p
One-Way ANOVA (Welch's)	Pre-Test Score	1.14	1	67.9	0.29
	Post-Test Score	4.25	1	60.5	0.044
Homogeneity of Variances Test (Levene's)	Pre-Test Score	0.117	1	68	0.734
	Post-Test Score	5.7	1	68	0.02

The one-way ANOVA (Welch's) test results are similar. The F-value is 0.441, with degrees of freedom 1 and 68, and a p-value of 0.509. The p-value is above the 0.05 threshold, reaffirming that there is no significant difference between the two groups.

Another One-Way ANOVA (Welch's) test supports this result, showing an F-value of 9.79 with degrees of freedom 1 and 65.3, and a p-value of 0.003, confirming the statistical significance of the difference.

The homogeneity of variances test (Levene's) shows an F-value of 0.0491, with 1 degree of freedom, and a p-value of 0.825. The high p-value indicates that the assumption of homogeneity of variances holds, meaning that the variability of the scores is consistent across both groups.

Another Homogeneity of Variances Test (Levene's) shows an F-value of 1.39 with 1 degree of freedom and a p-value of 0.242, which confirms the assumption of homogeneity of variances, indicating no significant difference in variability between the groups.

Both the independent samples t-test and the one-way ANOVA showed no statistically significant difference in the pretest scores of Construction Organization Design Ability between students using a virtual simulation platform and those receiving traditional instruction, but they showed a statistically significant difference in construction organization design ability between students using a virtual simulation platform and those receiving traditional instruction in pipeline construction courses after the intervention.

The table 7 showed the summary of results of the hypotheses testing in the study.

Table 7: Summary of Hypothesis testing and results

Hypotheses	Statement	Result after Analysis
H01	The ability to read construction drawings in the pretest scores is equivalent between students using a virtual simulation platform and those receiving traditional instruction in pipeline construction courses.	Accepted
H02	The ability to design construction organization in the pretest scores is equivalent between student using a virtual simulation platform and those traditional instruction in pipeline construction courses.	Accepted
H03	The ability to read construction drawings is equivalent between students using a virtual simulation platform and those receiving traditional instruction in pipeline construction courses.	Rejected
H04	The ability to design construction organization is equivalent between student using a virtual simulation platform and those traditional instruction in pipeline construction courses.	Rejected

5. Conclusion and Discussion

This study set out to investigate the impact of virtual simulation platforms on two key competencies in pipeline engineering education: construction drawings reading ability and construction organization design ability. Additionally, student satisfaction was evaluated to assess the affective dimension of the learning experience. The quasi-experimental design, combined with validated instruments and rigorous statistical analysis, provides robust evidence supporting the educational value of simulation-enhanced instruction.

The findings confirm that students in the experimental group, who engaged with a virtual simulation platform, achieved significantly greater improvements in both target competencies compared to those receiving traditional instruction. These results align with the constructivist learning theory, which posits that students build knowledge through active, experience-based engagement. Virtual simulation environments provided opportunities forstudents to manipulate pipeline systems in 3D, simulate construction workflows, and iteratively test solutions—enabling them to internalize complex spatial relationships and construction logic that are often abstract or inaccessible in conventional classrooms. This directly supports Sepasgozar's (2020) and Jacobsen et al.'s (2021) claims regarding simulation's ability to enhance system comprehension through embodied cognition and situated problem-solving.

From the perspective of situated learning theory, virtual simulation platforms as authentic environments where students acted within realistic roles (e.g., site engineer or project manager), immersed in industry-aligned construction scenarios. This mirrored "communities of practice" and bridges the gap between classroom theory and field application, supporting the findings of Negahban (2024), who emphasized the role of contextual rehearsal in competency acquisition. The observed improvements in organizational design ability (Cohen's d = 0.75) further validate the platform's effectiveness in fostering applied decision-making, sequencing, and team-based coordination.

The affective outcomes are equally noteworthy. The high satisfaction scores (M = 4.12 out of 5) suggest that students appreciated the learning experience, especially in terms of realism, interactivity, and perceived relevance to their future careers. This aligns with Yang et al.'s (2024) meta-analysis that linked simulation-based training with enhanced motivation and self-efficacy. While this study did not conduct a formal correlational analysis, the combined results imply that positive emotional engagement likely contributed to cognitive gains—a dynamic consistent with affective-cognitive learning models.

Importantly, these findings contribute to educational innovation in three ways:

Theoretically, this study establishes a causal link between simulation-based learning and improvements in profession-specific schemata in pipeline engineering—particularly in spatial reasoning and organizational logic.

Practically, it validates a simulation-enhanced curriculum module aligned with industry expectations and national vocational standards, offering a scalable model for engineering educators.

Institutionally, it supports data-driven curriculum reform, promoting the integration of immersive technologies to improve workforce readiness in vocational education contexts.

In conclusion, this research provides empirical support for embedding virtual simulation platforms into pipeline engineering courses. The platform not only enhanced student learning outcomes in key technical domains but also improved engagement and satisfaction. For engineering programs seeking to close the theory-practice gap and modernize instruction, virtual simulation offers a pedagogically sound and practically effective path forward.

6. Recommendations

Virtual simulation platforms can provide students a comprehensive and immersive learning experience that not only improves their professional knowledge and practical skills, but also enhances their satisfaction with the learning process. It is recommended that vocational colleges use virtual simulation platforms in their pipeline engineering courses. The following suggestions are prioritized based on implementation complexity and resource requirements.

In the short term, institutions should first focus on integrating virtual simulation modules into existing core curricula, especially for construction drawing interpretation and organizational design—areas that showed significant learning gains in this study. It is advised to implement a "virtual-practice" bridging curriculum after theoretical sessions, establishing a pedagogical chain encompassing 3D modeling, dynamic demonstration, interactive operation, and scheme optimization. This structured progression is consistent with the constructivist and situated learning principles identified in this study and aligns directly with the observed improvements in student performance.

Furthermore, it is essential to provide instructors with the necessary training. Schools should establish industry-academia training programs, requiring teachers to obtain certification in VR-based instruction. Interdisciplinary teams, comprising engineering educators and IT developers, should regularly collaborate in content design workshops. This collaborative model ensures that simulation content remains both technically accurate and pedagogically aligned with evolving workforce demands.

In the longer term, institutions should construct provincial-level cloud platforms for cross-institutional sharing of virtual cases and equipment databases. A virtual credit bank should be established to recognize students' simulation-acquired competencies. This shared infrastructure will reduce cost burdens, promote educational equity, and facilitate broader access to quality immersive resources.

To evaluate the long-term effectiveness of simulation-based learning, longitudinal studies should be conducted to track graduate outcomes over three years. These studies can assess how virtual training impacts career progression and workplace readiness. Simultaneously, schools should explore mixed reality (MR) solutions that combine virtual and augmented reality, particularly for pipeline maintenance and inspection courses. While resource-intensive, these innovations represent the next stage in immersive pedagogy and support this study's call for curriculum modernization.

By structuring these recommendations according to feasibility and grounding them in the empirical data, this study offers a roadmap for institutions to adopt simulation-enhanced education in a sustainable, outcome-driven way.

7. Limitation and Further Study

Although this research provides valuable insights into the impact of virtual simulation platforms on students' learning outcomes in pipeline engineering courses, there are several areas for further investigation.

One major limitation of this study is the relatively small sample size (N=70), which may limit the generalizability of the findings. Moreover, the gender imbalance within the sample (approximately 81.74% male) could influence the outcome variables, especially in terms of satisfaction and interaction with technology. In addition, this study was restricted to a single institution, which may introduce contextual bias related to teaching style, curriculum design, or regional educational infrastructure. Furthermore, while efforts were made to control instructional variables, it was challenging to completely eliminate all external factors influencing learning outcomes, such as students' prior knowledge or digital literacy.

Future research could investigate how virtual simulations enhance student motivation and whether this effect lasts over time. Integrating theoretical frameworks such as Self-Determination Theory (Gagné & Deci, 2005) could help explain changes in student engagement, autonomy, and competence during simulation-based learning.

Qualitative methods, such as surveys or interviews could be used to measure students' interest, engagement, and willingness to complete tasks when using virtual simulations compared to traditional teaching methods. This suggests a shift toward mixed-methods or qualitative approaches that can enrich the current quantitative results. Moreover, research could examine whether motivation declines over time or remains consistent. Since students may respond differently to virtual simulations, future studies could analyze how factors like personality traits, learning styles, or familiarity with digital tools influence motivation, helping educators adjust their teaching strategies. This could be further explained through frameworks such as the Digital Divide Theory or Technology Acceptance Model (TAM).

While this study focused on short-term gains in knowledge and skills, future research could investigate the long-term effects of using virtual simulation platforms. Specifically, longitudinal studies could examine whether the skills and knowledge gained through virtual simulations are retained over extended periods and how they translate into real-world job performance once students enter the workforce. Such work would also align with constructivist theory by evaluating the transfer and application of knowledge across authentic settings.

An important area for future exploration is how to support students with varying levels of familiarity with digital tools. Some students with more prior experience using technology adapted to the virtual simulation platform more quickly than their peers. Therefore, future research could develop strategies or training modules to help students who are less comfortable with technology fully benefit from virtual simulations. This may include scaffolding approaches or digital literacy interventions designed specifically for novice users. Investigating ways to mitigate this digital divide would ensure equitable learning opportunities for all students, regardless of their technological background.

References

Ali, Q. A., & Sahab, N. M. (2023). Interactive Design of a Virtual Classroom Simulation Model Based on Multimedia Applications to Improve the Teaching and Learning Process in the Tikrit University Environment. *Fusion: Practice & Applications, 12*(2), 135-150. https://doi.org/10.54216/FPA.120217

Asakit, H., & Phetchabun, P. (2023). Developing Virtual Reality Technology and Innovations to Promote Tourism Management Learning. *RMUTL Journal of Business Administration and Liberal Arts, 11*(2), 111-128. https://so05.tci-thaijo.org/index.php/balajhss/article/view/262869

Babalola, A., Manu, P., Cheung, C., Yunusa-Kaltungo, A., & Bartolo, P. (2023). A systematic review of the application of immersive technologies for safety and health management in the construction sector. *Journal of Safety Research, 85*, 66-85. https://doi.org/10.1016/j.jsr.2023.01.007

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences.* Routledge. https://doi.org/10.4324/9780203771587

Foronda, C. L., Gonzalez, L., Meese, M. M., Slamon, N., Baluyot, M., Lee, J., & Aebersold, M. (2024). A comparison of virtual reality to traditional simulation in health professions education: A systematic review. *Simulation in Healthcare, 19*(1), 90-97. https://doi.org/10.1097/sih.0000000000000745

Gagné, M., & Deci, E. L. (2005). Self-determination theory and work motivation. *Journal of Organizational Behavior, 26*(4), 331-362. https://doi.org/10.1002/job.322

Ghanbaripour, A. N., Talebian, N., Miller, D., Tumpa, R. J., Zhang, W., Golmoradi, M., & Skitmore, M. (2024). A Systematic Review of the Impact of Emerging Technologies on Student Learning, Engagement, and Employability in Built Environment Education. *Buildings, 14*(9), 2769. https://doi.org/10.3390/buildings14092769

Jacobsen, E. L., Strange, N. S., & Teizer, J. (2021). Lean construction in a serious game using a multiplayer virtual reality environment. *Proceedings 29th Annual Conference of the International Group for Lean Construction (IGLC),* 55-64. https://doi.org/10.24928/2021/0160

Negahban, A. (2024). Simulation in engineering education: The transition from physical experimentation to digital immersive simulated environments. *Simulation: Transactions of the Society for Modeling and Simulation International, 100*(7), 695-708. https://doi.org/10.1177/00375497241229757

Numfu, M., Riel, A., & Noel, F. (2020). Virtual Reality Technology for Maintenance Training. *Applied Science and Engineering Progress, 13*(3), 274-282. https://ph02.tci-thaijo.org/index.php/ijast/article/view/241547

Paszkiewicz, A., Salach, M., Dymora, P., Bolanowski, M., Budzik, G., & Kubiak, P. (2021). *Methodology of implementing virtual reality in education for industry 4.0. Sustainability, 13*(9), 5049. https://doi.org/10.3390/su13095049

Sepasgozar, S. M. E. (2020). Digital twin and web-based virtual gaming technologies for online education: A case of construction management and engineering. *Applied Sciences, 10*(13), 4678. https://doi.org/10.3390/app10134678

Shuang, H. (2024). Design and Exploration of Virtual Multi-Scene Classroom Based on XR Technology. J*ournal of Education Studies, 52*(4), EDUCU5204009-10. https://so02.tci-thaijo.org/index.php/EDUCU/article/view/257862

Xie, M., Yang, S., Liu, X., & Zhang, H. (2024). Innovation and Practice of Civil Engineering Education under the New Engineering Education Perspective. *Frontiers in Educational Research, 7*(1), 198-203. https://doi.org/10.25236/FER.2024.070130

Xing, J., Meng, H., & Meng, X. (2020). An urban pipeline accident model based on system engineering and game theory. *Journal of Loss Prevention in the Process Industries, 64*, 104062. https://doi.org/10.1016/j.jlp.2020.104062

Yang, C., Zhang, J., Hu, Y., Yang, X., Chen, M., Shan, M., & Li, L. (2024). The impact of virtual reality on practical skills for students in science and engineering education: a meta-analysis. *International Journal of STEM Education, 11*(1), 28. https://doi.org/10.1186/s40594-024-00487-2

Zhao, G., Fan, M., Yuan, Y., Zhao, F., & Huang, H. (2021). The comparison of teaching efficiency between virtual reality and traditional education in medical education: a systematic review and meta-analysis. *Annals of Translational Medicine, 9*(3), 251-260. https://doi.org/10.21037/atm-20-2785