Analysis Of The Effectiveness Of ETHNO-STEAM-Based Digital The Mathematics Learning To Improve Mathematical Problem-Solving Of Civil Engineering Students

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Abstract. This study aims to develop and evaluate the effectiveness of an Ethno-STEAM–based digital mathematics learning model to improve civil engineering students' mathematical problem-solving abilities in integral calculus. The study employed a Research and Development (R&D) approach adapted from the Borg and Gall model. The effectiveness test was conducted using a one-group pretest–posttest design with 40 civil engineering students. Data were collected using cognitive tests and analyzed through normality testing, hypothesis testing, effect size analysis, and normalized gain (N-Gain). The results showed a significant improvement in students' learning outcomes. The mean pre-test score increased from 47.13 to 84.25 in the post-test, with a gain of 37.12 points ($p < 0.05$). The effect size value (Cohen's $d = 2.65$) indicated a huge effect, while the N-Gain score of 70.21% was classified as high. These findings indicate that Ethno-STEAM–based digital mathematics learning is highly effective in enhancing mathematical problem-solving abilities and provides a meaningful, contextual learning experience for engineering students.

Keywords: Digital Mathematics Learning, Ethno-STEAM, Integral Calculus, Problem-Solving Skill

1 Introduction

Mathematics is a fundamental discipline that must be taught at all levels of education because it serves as the conceptual and analytical foundation for many fields of science and technology. Mastery of mathematics supports the development of essential intellectual abilities, including numerical literacy, precision, systematic thinking, logical reasoning, and analytical rigor. Beyond computational skills, mathematics also plays a crucial role in fostering creativity and flexibility in problem-solving, enabling learners to analyze complex situations, formulate strategies, and evaluate solutions effectively

[1], [2], [3], [4], [5]. These competencies are indispensable in higher education, particularly in engineering disciplines where mathematical reasoning is continuously applied to solve real-world problems.

In higher mathematics, integral calculus is a core subject of significant importance in civil engineering education. Integral calculus is widely used in calculate areas, volumes, centroids, and moments of inertia, which are essential in structural analysis and engineering design. While problems involving simple geometric forms can often be solved using standard formulas, many engineering applications involve complex or curved geometries that require integration as the primary method of solution. Consequently, civil engineering students are expected not only to master procedural techniques but also to develop strong conceptual understanding and mathematical problem-solving abilities in applying integrals to authentic engineering problems.

Along with the increasing complexity of engineering challenges, education is undergoing a fundamental transformation in response to the emergence of the Society 5.0 era. This paradigm emphasizes integrating digital technologies, information systems, and artificial intelligence into human-centered processes. In education, this shift requires a transition from traditional teacher-centered instruction toward student-centered learning, where learners actively construct knowledge through interaction with digital learning environments [6], [7], [8], [9], [10]. Digital learning enables flexible, interactive, and contextualized instruction, allowing students to engage with learning materials independently and meaningfully.

At the same time, problem-solving ability has become one of the most critical competencies required in the 21st century. To address this demand, the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach has gained prominence as an interdisciplinary framework that promotes creativity, collaboration, and higher-order thinking skills. The integration of STEAM with indigenous and local knowledge has led to the development of the Ethno-STEAM approach, which emphasizes scientific and technological competence while preserving cultural identity. When implemented within a digital learning environment, Ethno-STEAM offers an innovative pedagogical framework that contextualizes mathematical concepts through cultural and engineering perspectives, thereby enhancing both cognitive engagement and affective learning outcomes.

However, despite the growing body of research on digital learning and STEAM-based instruction, existing studies often address these approaches separately. Digital mathematics learning is frequently implemented without meaningful cultural integration, while STEAM-based learning models tend to overlook the systematic incorporation of local or indigenous knowledge. Moreover, research on Ethno-STEAM has predominantly focused on primary and secondary education, leaving a significant gap in its application within higher education, particularly in engineering mathematics courses such as integral calculus. In addition, many mathematics learning practices at the tertiary level remain procedural in nature and have not sufficiently emphasized the development of structured mathematical problem-solving abilities aligned with real engineering applications. There is also limited empirical evidence evaluating the effectiveness of Ethno-STEAM–based digital learning models using comprehensive statistical measures that demonstrate both statistical significance and practical impact.

Therefore, this study aims to address these gaps by developing and evaluating an Ethno-STEAM–based digital mathematics learning model for integral calculus in civil engineering education. Specifically, the objectives of this research are to develop a digital learning model that integrates Ethno-STEAM principles, cultural context, and digital technology; to examine

the feasibility of the developed model through expert validation in terms of media quality, content accuracy, and instructional design; to evaluate its effectiveness in improving civil engineering students' mathematical problem-solving abilities; and to analyze the magnitude of learning improvement using statistical measures such as significance testing, effect size (Cohen's d), and normalized gain (N-Gain). Through these objectives, this study seeks to contribute a validated and effective instructional model that supports meaningful, contextual, and problem-solving–oriented mathematics learning in engineering education.

2 Research Method

This study employed a Research and Development (R&D) approach to develop and validate an Ethno-STEAM–based digital mathematics learning model for integral calculus. The development procedure was adapted from the Borg & Gall model, which itself is derived from the instructional systems design framework proposed by Dick and Carey [11]. In this research, nine development stages were implemented, with the final summative evaluation stage excluded, as it typically involves external evaluators beyond the instructional designer's role. Table1 presents the activities implemented at each stage of the development process.

Table 1. Stages and Activities in the Development of Etno-STEAM Based Digital Mathematics Learning

Stage	Substage/Step	Main Activities
Pre-Development	Need Analysis	Identifying learning objectives and required competencies based on students' learning difficulties and curriculum demands. Conducting learning analysis to break down general competencies into specific sub-competencies and analyzing learner characteristics, prior knowledge, and learning materials.
	Product Design	Formulating specific and measurable learning objectives. Designing assessment instruments aligned with learning objectives. Developing instructional strategies based on learning theories, learner characteristics, content structure, and media considerations. Designing and selecting Ethno-STEAM–based digital mathematics learning materials.
	Realization	Developing the initial prototype of Ethno-STEAM–based digital mathematics learning along with supporting instructional components.
Development	Validation and Evaluation	Conducting expert validation to assess content validity, instructional quality, and feasibility. Implementing one-to-one evaluation, small-group trials, and field testing to refine the product and evaluate its effectiveness in real learning settings.

The effectiveness of the Ethno-STEAM–based digital mathematics learning was evaluated using students' cognitive learning outcomes, measured through pre-test and post-test scores within a one-group pretest–posttest design. The analysis aimed to determine whether the learning intervention produced a significant improvement in students' mathematical problem-solving abilities.

Prior to hypothesis testing, assumptions were tested. Data normality was examined using the Shapiro–Wilk test, which is recommended for small sample sizes. When the significance value (p-value) was less than 0.05, the data were considered not normally distributed. In this study, the pre-test and post-test data did not meet the normality assumption; therefore, further analysis employed non-parametric statistical methods.

When the normality assumption was satisfied, the effectiveness of the learning model was analyzed using a paired sample t-test. The paired sample t-test was applied to examine whether there was a statistically significant difference between the mean pre-test and post-test scores. This test was appropriate because the two sets of scores were obtained from the same participants under two different conditions, namely before and after the learning intervention.

To test learning effectiveness under non-normal data conditions, the Wilcoxon Signed Rank Test was used to compare students' pre-test and post-test scores. This test is appropriate for paired data and determines whether there is a statistically significant difference in learning outcomes before and after the intervention.

In addition to significance testing, the magnitude of the learning effect was analyzed using effect size (Cohen's d). Effect size analysis was conducted to assess the practical impact of the learning model beyond statistical significance. Cohen's d values were interpreted using established criteria to determine whether the instructional effect was small, medium, large, or very large.

Table 2. Criteria for Effect Size (Cohen's d)

d Value	Category	Description
≥ 2,00	Huge Effect	Very extraordinary effectiveness
1,20 – 1,99	Very Large	Extremely strong practical effect
1,80 – 1,19	Large	Strong and meaningful effect
0,50 – 0,79	Medium	Noticeable and meaningful effect
0,20 – 0,49	Small	Mild effect
0,00 – 0,19	Very Small	Almost no effect

Furthermore, learning improvement was measured using the normalized gain (N-Gain) score. N-Gain analysis was used to evaluate the extent of students' improvement relative to the maximum possible increase in score. The resulting N-Gain values were classified into high, medium, or low categories, providing an additional indicator of learning effectiveness that accounts for students' initial ability levels.

Table 3. Criteria for Normalized Gain (N-Gain)

Score (%)	Category	Description
N-Gain > 70	High	Learning is highly effective and produces significant improvement
30 ≤ N−Gain ≤ 70	Medium	Learning improvement is adequate and stable
N-Gain < 30	Low	Learning does not result in meaningful improvement

Overall, the effectiveness of the Ethno-STEAM–based digital mathematics learning was determined through a combination of paired sample t-test or Wilcoxon Signed Rank Test, effect size analysis, and N-Gain evaluation, providing a comprehensive assessment of both statistical significance and practical learning impact.

3 Result and Discussion

The effectiveness of the Ethno-STEAM–based digital mathematics learning model was examined based on students' cognitive learning outcomes, with a specific focus on their mathematical problem-solving abilities in integral calculus. The study employed a one-group pretest–posttest design with 40 civil engineering students who participated in the learning intervention across eight instructional sessions.

Descriptive statistical analysis of the pre-test data shows that students' initial mathematical problem-solving abilities were relatively low and varied considerably. The pre-test scores ranged from 20 to 75, with a mean score of 47.13 and a standard deviation of 11.32. The wide score range (55 points) and relatively high standard deviation indicate substantial heterogeneity in students' initial understanding of integral concepts. This suggests that prior to the intervention, many students experienced difficulties in interpreting problems, selecting appropriate solution strategies, and applying integration techniques in engineering-related contexts.

Following the implementation of an Ethno-STEAM–based digital mathematics learning approach, a substantial improvement in students' learning outcomes was observed. The post-test scores ranged from 65 to 100, with a mean score of 84.25 and a standard deviation of **8.21**. The increase in the minimum score from 20 (pre-test**)** to 65 (post-test) reflects a notable improvement among students who initially demonstrated low achievement. At the same time, the reduction in standard deviation indicates that students' performance became more evenly distributed, suggesting that the learning model supported more equitable learning outcomes across the class.

Overall, the mean score increased by 37.12 points, representing a substantial gain in students' mathematical problem-solving performance. This descriptive evidence indicates that the Ethno-STEAM–based digital mathematics learning model was effective in enhancing both students' conceptual understanding and procedural competence in integral calculus.

Before conducting hypothesis testing, data normality was examined using the Shapiro–Wilk test. The results indicated that the pre-test and post-test data did not fully meet the assumption of normal distribution. Consequently, effectiveness testing was conducted using appropriate statistical procedures. The hypothesis testing results showed a statistically significant difference between students' pre-test and post-test scores ($p < 0.05$), indicating that the observed improvement in learning outcomes was not due to chance.

This statistically significant difference confirms that the Ethno-STEAM–based digital mathematics learning intervention had a real and measurable impact on students' cognitive achievement. The findings provide strong empirical support for the effectiveness of the learning model in improving students' mathematical problem-solving abilities.

To further examine the strength of the learning intervention, effect size analysis was conducted using Cohen's d. The resulting Cohen's d value of 2.65 falls into the huge effect category. This indicates that the learning intervention had a strong, practically meaningful impact on students' learning outcomes.

A huge effect size suggests that the observed improvement was not only statistically significant but also educationally substantial. In practical terms, this means that the Ethno-STEAM–based digital mathematics learning model significantly improved students' ability to understand

problems, plan solution strategies, perform calculations, and evaluate results. Such a large effect size is rarely achieved in educational interventions, highlighting the strength of the developed learning model.

In addition to effect size analysis, learning improvement was evaluated using the normalized gain (N-Gain) score to assess students' progress relative to their initial ability levels. The analysis revealed an average N-Gain value of 70.21%, which is classified in the high category according to Hake's criteria.

A high N-Gain score indicates that students achieved a substantial proportion of the maximum possible improvement after the learning intervention. This result suggests that the learning model was effective not only in increasing absolute scores but also in facilitating meaningful learning progress for students with varying initial abilities. Students moved closer to the highest level of mastery possible, particularly in solving integrals in engineering contexts.

The strong learning outcomes observed in this study can be attributed to several key characteristics of the Ethno-STEAM–based digital mathematics learning model. First, integrating Ethno-STEAM principles enabled the presentation of mathematical concepts in culturally relevant, interdisciplinary contexts. This contextualization reduced the abstract nature of integral calculus and helped students relate mathematical procedures to real-world engineering applications.

Second, the use of digital learning media supported visualization, interactive learning, and self-paced study. These features enabled students to revisit complex concepts, practice problem-solving steps repeatedly, and engage more actively with learning materials. This is particularly important for integral calculus, which often requires strong conceptual understanding and procedural accuracy.

Third, the structured incorporation of problem-solving stages, such as understanding the problem, planning a solution, executing the plan, and evaluating the result, supported the development of systematic and reflective thinking. This approach helped students move beyond rote computation toward deeper analytical reasoning, an essential skill for engineering problem-solving.

Overall, the combined results and discussion demonstrate that Ethno-STEAM–based digital mathematics learning is highly effective in improving civil engineering students' mathematical problem-solving abilities. The convergence of descriptive statistics, statistical significance testing, effect size analysis, and N-Gain results provides robust evidence of the learning model's effectiveness. These findings highlight the potential of Ethno-STEAM–based digital learning as an innovative and powerful approach for enhancing mathematics education in engineering contexts.

4 Conclusion

This study contributes a novel instructional model that integrates Ethno-STEAM principles into a digital mathematics learning environment to enhance civil engineering students' mathematical problem-solving abilities. Unlike conventional digital or STEAM-based approaches, this model systematically combines local cultural contexts, engineering applications, and structured problem-solving stages into an interactive digital format, providing a more contextual and meaningful learning experience.

The empirical findings demonstrate that the developed Ethno-STEAM–based digital learning model produces significant and substantial improvements in students' cognitive performance, supported by strong statistical evidence, a very large effect size, and high learning gains. These results confirm that integrating culture, technology, and interdisciplinary learning is not only pedagogically sound but also highly effective in strengthening higher-order mathematical thinking.

This research extends existing studies on digital and STEAM-based learning by offering validated design procedures and evidence of effectiveness specifically tailored to higher education engineering mathematics. The proposed model serves as a practical, scalable reference for educators seeking to implement culturally responsive, technology-enhanced mathematics instruction. Future studies may further explore the adaptability of this model across different mathematical topics, disciplines, and educational contexts to broaden its impact.

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