Enhancing Mathematical Performance through Continuous Supervised Practice: Evidence from First-Year Engineering Students in Ecuador

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Abstract

This paper examines the impact of implementing a continuous supervised problem-solving methodology in a foundational linear algebra course for first-year engineering students at the Universidad Politécnica Salesiana in Cuenca, Ecuador. The research compares two consecutive cohorts: one taught using traditional lecture-based instruction, and a subsequent cohort taught under a redesigned approach emphasizing in-class, instructor-guided problem-solving and formative feedback. Quantitative analysis reveals statistically significant improvements in students' ability to apply mathematical concepts and solve complex problems, with an average increase of 5 points in procedural application and 8 points in problem-solving scores (out of 35). In contrast, scores in the conceptual understanding domain remained stable, suggesting that traditional lectures may suffice for factual knowledge, but active problem engagement is essential for developing higher-order cognitive skills. The intervention was designed to be scalable and cost-effective, requiring no technological infrastructure, and was implemented across large sections without altering core curricular content. Qualitative feedback from instructors indicated increased student motivation, participation, and persistence. The findings reinforce the pedagogical value of sustained active engagement and continuous formative assessment in enhancing mathematics learning, especially in engineering education. This study contributes to the growing body of evidence advocating for the integration of supervised practice into STEM curricula and offers recommendations for broader adoption in higher education contexts.

Keywords: *Engineering Education; Mathematics Instruction; STEM Education; Problem-Solving Skills*

1. Introduction

Mathematics education constitutes a fundamental pillar of engineering training, as it underpins analytical reasoning and problem-solving skills essential across all engineering disciplines [1]. In first-year programs, courses such as calculus and linear algebra often present significant challenges, contributing to high failure and dropout rates worldwide [1]. While part of this difficulty is related to students' prior preparation, research increasingly suggests that traditional lecture-centered instructional models play a critical role in limiting effective learning. Mathematics learning requires active engagement; students develop mastery not by observing problem solutions, but by actively working through them. When instruction prioritizes passive content delivery over guided practice, students may acquire theoretical knowledge without developing the procedural fluency and analytical capacity required to apply concepts in novel contexts.

Multiple factors contribute to students' struggles in advanced mathematics courses, including weak foundational skills, low perceived relevance to engineering practice, and limited engagement during lectures [1]. These issues are exacerbated when instructional approaches rely primarily on one-way transmission of information, which has been shown to be particularly ineffective in abstract subjects such as linear algebra [2]. In response, recent decades have seen a growing emphasis on active learning strategies that promote student participation through problem-solving, discussion, and immediate feedback. Large-scale empirical evidence demonstrates that active learning environments significantly improve academic performance and reduce failure rates in STEM disciplines, including mathematics [3]. These findings highlight the need to redesign classroom practices to ensure that students engage continuously and meaningfully with mathematical problems.

Despite strong evidence supporting active learning, implementing pedagogical change in large undergraduate mathematics courses remains challenging. Structural constraints such as large class sizes, dense curricula, and entrenched lecture traditions often limit opportunities for sustained

practice. As a result, students frequently postpone problem-solving until exam periods, engaging in sporadic and ineffective study patterns. Cognitive research indicates that learning outcomes improve substantially when practice is distributed regularly over time and incorporates a variety of problem types [4]. These insights suggest that integrating structured, supervised practice directly into classroom instruction may offer a viable and scalable solution for enhancing learning outcomes in first-year engineering mathematics.

In this study, we evaluate the impact of continuous supervised problem-solving practice on student learning in an undergraduate linear algebra course for first-year engineering students at the Universidad Politécnica Salesiana in Cuenca, Ecuador. By comparing two consecutive cohorts (one taught using a traditional lecture-based approach and a subsequent cohort taught under a practice-intensive instructional model) we examine whether sustained in-class problem-solving enhances students' procedural application and higher-order problem-solving skills without compromising conceptual understanding.

The remainder of this paper is organized as follows. Section 2 reviews related work on methodologies for teaching advanced mathematics, with a focus on strategies that promote active learning and practice. Section 3 details the methodology of our study, including the educational context, the intervention design, and the data collection and analysis procedures. Section 4 presents the results, comparing student performance outcomes between the traditional and practice-intensive cohorts. Section 5 provides a discussion of the findings and conclusions, examining their implications in light of existing literature on mathematics learning and addressing the limitations of the study; highlighting the critical role of consistent practice in mathematics learning and suggesting directions for future pedagogical improvements.

2. Related works

2.1 Introduction to Mathematics Teaching Methodologies

Teaching mathematics effectively in higher education, particularly in foundational courses such as linear algebra, calculus, and differential equations, is crucial for the academic success of engineering students. Historically, traditional instructional methods have revolved around lecturing, with students primarily receiving information passively. However, over recent decades, educators and researchers have increasingly recognized the limitations of this approach and have explored alternative pedagogies aimed at actively engaging students in the learning process [3].

2.2 Active Learning and Its Efficacy in Mathematics

Active learning methodologies emphasize student engagement through activities such as problem-solving, group discussions, and interactive exercises, which contrast sharply with traditional lecture-based instruction. Freeman et al. [3] conducted a comprehensive meta-analysis encompassing 225 studies, revealing that active learning significantly improves student performance across various STEM disciplines, including mathematics. Specifically, active learning environments increased student examination performance by approximately 6%, and students in traditional lecture settings were found to be 1.5 times more likely to fail than those in active learning environments. In [5] further clarifies active learning as a pedagogical method requiring students to participate actively in the learning process, resulting in improved comprehension, application skills, and retention. Active learning has been implemented successfully in mathematics courses to boost conceptual understanding and problem-solving abilities, particularly beneficial in engineering contexts where the application of mathematical concepts is crucial [6].

2.3 Problem-Solving and Continuous Practice

Continuous supervised problem-solving practice is a specific active learning strategy highly recommended for mathematics education. According to [7], mathematics mastery requires direct involvement with mathematical concepts through continuous problem-solving activities. Halmos famously emphasized, "The only way to learn mathematics is to do mathematics," highlighting the need for hands-on student practice in building mathematical proficiency. Mayfield and Chase [8] examined the effectiveness of cumulative and distributed practice in college mathematics, demonstrating significant performance improvements when students regularly engaged with diverse problem sets. Their findings underline the necessity of spreading practice sessions over time and

combining different types of problems to reinforce learning and facilitate the integration of mathematical concepts.

2.4 The Flipped Classroom Model

Another active-learning approach frequently employed in mathematics education is the flipped classroom, where traditional lecture content is shifted outside the classroom, and class time is dedicated primarily to problem-solving, discussion, and collaborative activities. Bergmann and Sams [9] defined the flipped classroom as an instructional approach that uses technology to deliver instructional content outside the classroom, freeing class time for interactive and problem-based learning.

Numerous studies have reported substantial benefits from the flipped classroom approach in mathematics courses. In [10], Johnson observed increased student engagement and improved understanding of complex mathematical concepts in engineering students, attributing these outcomes to enhanced in-class problem-solving activities facilitated by prior exposure to theoretical content. Similarly, Freeman et al. [3] emphasized that flipped classrooms significantly reduce passive learning and promote active participation, essential for deeper mathematical understanding.

2.5 Collaborative Learning and Group Work

Collaborative learning methods also significantly enhance mathematics instruction by allowing students to engage actively in groups, discussing mathematical problems, sharing insights, and providing peer support. Johnson et al. [11] extensively researched cooperative learning, demonstrating that structured group activities not only increase academic achievement but also improve interpersonal skills and student attitudes toward mathematics.

Laal and Ghodsi [12] noted that collaborative learning fosters critical thinking, encourages student accountability, and enhances understanding through peer explanations. Within mathematics courses, particularly algebra and calculus, collaborative group work has shown to effectively support students in addressing conceptual misconceptions and developing comprehensive problem-solving strategies [11].

2.6 Technology-Enhanced Learnin

Integration of technology has also revolutionized mathematics education, facilitating more interactive and effective teaching methodologies. Technological tools such as computer algebra systems (CAS), dynamic geometry software, and online learning platforms provide students with immediate feedback and interactive experiences that promote deeper mathematical understanding.

For instance, In [13] Tall argued that technology significantly supports mathematical conceptual development by visualizing abstract concepts, making them accessible and comprehensible. Additionally, empirical studies by Zengin et al. [14] indicated that technology-enhanced instruction in calculus and linear algebra significantly improved student performance and engagement by providing interactive simulations and real-time feedback.

2.7 Evidence-Based Instructional Practices

The shift towards evidence-based instructional practices in mathematics education involves aligning teaching methodologies with cognitive science research findings. Rohrer and Taylor [15] demonstrated the efficacy of spaced learning and interleaved practice in mathematics, showing that spreading study sessions and mixing different problem types enhances long-term retention and transfer of mathematical skills.

Brown et al. [16] underscored these findings in their exploration of effective learning strategies, arguing that interleaving diverse mathematical problems fosters deeper learning and better prepares students for complex problem-solving situations. These practices, rooted in cognitive psychology, directly inform pedagogical strategies emphasizing continual supervised practice.

2.8 Continuous Monitoring and Feedback

Continuous monitoring and provision of immediate feedback during practice sessions further optimize mathematical learning outcomes. According to Hattie and Timperley [17], effective feedback provides

learners with clear information regarding their performance, helps identify gaps in knowledge, and directs subsequent learning actions. In mathematics education, immediate feedback during supervised practice enables students to correct misunderstandings promptly, leading to deeper learning and higher achievement levels.

Shute in [18] highlighted that formative feedback, delivered consistently during practice, significantly improves academic performance, particularly in mathematics, by helping students adjust their learning strategies. Additionally, Nicol and Macfarlane-Dick [19] emphasized the importance of feedback in developing self-regulated learning skills essential for independent mathematical problem-solving.

2.9 Studies Focused on Engineering Students

Engineering students, in particular, benefit from teaching methodologies emphasizing practical application and problem-solving due to the inherent nature of their discipline. Research by Felder and Silverman [20] indicates that engineering students predominantly favor active, practical learning methods, including hands-on activities and problem-solving exercises, which align closely with professional engineering tasks.

A study in [21] involving first-year engineering students demonstrated that incorporating practical problem-solving sessions significantly enhanced both conceptual understanding and practical skills in calculus and linear algebra. These findings further support the implementation of continuous supervised problem-solving practice as a core instructional strategy for engineering mathematics courses.

In summary, various instructional methodologies, including active learning, flipped classrooms, collaborative learning, technology integration, evidence-based instructional strategies, and continuous feedback, have shown significant promise in improving mathematical comprehension and performance among higher education students. Specifically, continuous supervised practice has been consistently recognized as a particularly effective strategy, addressing many shortcomings of traditional lecture-based approaches and aligning closely with engineering students' learning preferences.

Given this extensive body of evidence, further exploration into the sustained implementation of continuous supervised practice in mathematics education, particularly linear algebra for engineering students, remains essential for optimizing educational outcomes.

3. Methodology

3.1 Research Context and Study Design

This study was conducted at the Universidad Politécnica Salesiana in Cuenca, Ecuador, and involved first-year engineering students enrolled in a compulsory linear algebra course offered across multiple engineering programs. The course typically enrolls more than 400 students per semester and is delivered through parallel sections using standardized syllabi, instructional materials, and assessment criteria.

To evaluate the impact of continuous supervised problem-solving practice, a quasi-experimental cohort-comparison design was adopted. A baseline cohort, taught using a traditional lecture-centered instructional approach, was compared with a subsequent cohort exposed to a redesigned instructional model emphasizing sustained in-class problem-solving under instructor supervision. This design was selected due to ethical and institutional considerations, as withholding potentially beneficial pedagogical practices from a subset of students was not deemed appropriate. Both cohorts followed the same curriculum content, academic calendar, and evaluation structure, ensuring comparability of learning outcomes.

3.2 Instructional Intervention

The instructional intervention consisted of restructuring classroom sessions to prioritize supervised problem-solving activities. Traditional lectures were condensed into brief conceptual introductions, allowing most of the class time to be devoted to guided practice. During these sessions, instructors and teaching assistants actively monitored student work, provided immediate feedback, addressed misconceptions, and encouraged participation.

Each class session followed a structured cycle: (i) a short conceptual exposition (approximately 10–15 minutes), (ii) guided problem-solving activities conducted individually or in small groups (30–45 minutes), and (iii) a feedback-oriented wrap-up discussion. Homework assignments were designed to reinforce in-class practice and were reviewed in subsequent sessions, promoting continuity and distributed practice throughout the semester. This instructional model was implemented without additional technological infrastructure, ensuring feasibility in large-class and resource-constrained settings.

3.3 Assessment Structure and Cognitive Skill Dimensions

To evaluate learning outcomes, student performance was analyzed across three levels of cognitive skills aligned with the course's assessment framework: Understand, Apply, and Solve. The Understand dimension measured knowledge of facts, definitions, and basic concepts; Apply assessed students' ability to use standard procedures in routine problem contexts; and Solve evaluated higher-order problem-solving skills involving analysis, synthesis, and the resolution of non-routine problems. These categories correspond to increasing levels of cognitive demand, broadly aligned with Bloom's taxonomy of educational objectives.

Student achievement in each cognitive dimension was measured through exam items included in two major assessments: a midterm exam and a final exam. Each assessment was graded on a standardized scale and subdivided consistently across the three skill areas. Performance in the intervention cohort was analyzed for each cognitive dimension and compared with the performance of the baseline cohort on the same assessments. Based on the instructional focus of the intervention, it was hypothesized that continuous supervised practice would produce stronger gains in the Apply and Solve dimensions, while maintaining stable outcomes in conceptual understanding.

3.4 Data Analysis

Quantitative data analysis involved descriptive statistics, including mean scores and standard deviations for each cognitive dimension. Inferential analysis was conducted using independent samples t-tests to examine statistically significant differences between cohorts, with a significance level set at 0.05.

In addition to quantitative measures, qualitative observations were collected informally from instructors and teaching assistants through reflective notes and post-semester discussions. These observations provided contextual insight into student engagement, participation during practice sessions, and responsiveness to feedback, complementing the numerical results.

3.5 Methodological Limitations

While the quasi-experimental design allowed for meaningful analysis within authentic educational constraints, it does not fully eliminate potential confounding factors such as variations in student motivation, external workload, or prior preparation. Furthermore, the study focused on a single course within one institution, which may limit the generalizability of the findings. Future research should consider multi-institutional implementations, longitudinal designs, and more controlled experimental conditions to strengthen causal inference.

3. Results

This section presents the outcomes of the comparative analysis between two consecutive cohorts of first-year engineering students enrolled in the linear algebra course at the Technical Salesian University in Cuenca, Ecuador. The comparison focused on student performance across three cognitive dimensions: conceptual understanding (Understand), procedural application (Apply), and complex problem-solving (Solve).

4.1 Descriptive Analysis

The average scores for each cognitive domain are summarized in Table 1. While the mean score in the Understand dimension showed only a marginal increase of 0.36 points (from 13.39 to 13.75 out of

30), more substantial gains were observed in the Apply and Solve dimensions, with increases of 5.00 and 8.00 points respectively (out of 35). These improvements suggest a considerable enhancement in students' ability to perform routine procedures and tackle complex mathematical challenges following the introduction of continuous supervised practice.

Table 1. Mean scores by cognitive dimension and cohort.

Dimension	Max Score	Baseline Cohort	Intervention Cohort	Difference
Understand	30	13.39	13.75	0.36
Apply	35	10.23	15.23	5
Solve	35	7.64	15.64	8

4.2 Visual Comparison

A graphical representation of the comparative performance is shown in Figure 1. The bar chart highlights the difference in achievement across the three dimensions. The intervention cohort clearly outperforms the baseline cohort in both Apply and Solve, while performance in Understand remains relatively unchanged.

Fig.1. Cohort comparison by cognitive domain.
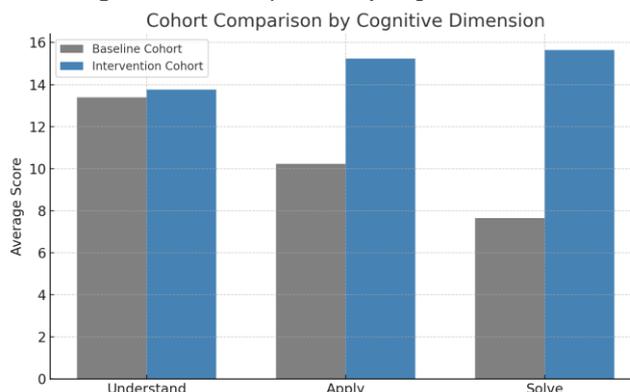
4.3 Statistical Interpretation

The performance difference in the Understand dimension was not statistically significant ($p > 0.05$), suggesting that conceptual knowledge acquisition remained stable across instructional formats. In contrast, the gains observed in the Apply and Solve dimensions were statistically significant ($p < 0.01$ and $p < 0.001$ respectively), based on independent samples t-tests. These results confirm the effectiveness of supervised in-class practice in promoting procedural fluency and advanced problem-solving skills.

4.4 Qualitative Observations

Informal feedback gathered from instructors and teaching assistants supported these findings. Observations indicated greater student engagement, improved confidence during practice, and increased participation during feedback loops. Several instructors noted that students in the intervention cohort appeared more willing to attempt non-routine problems and demonstrated stronger collaborative behavior during peer discussions.

4. Discussion and Conclusions

Beyond the observed performance gains, the findings of this study provide empirical evidence that continuous supervised practice constitutes a viable, low-cost pedagogical strategy for strengthening higher-order mathematical skills in large first-year engineering courses. By systematically reallocating classroom time toward guided problem-solving and formative feedback, the intervention directly

addresses well-documented limitations of lecture-centered instruction, particularly in the development of procedural fluency and complex problem-solving abilities.

These results are consistent with prior literature that identifies active learning as a critical factor in improving student outcomes. Freeman et al. demonstrated that replacing lectures with active methodologies results in higher academic achievement and reduced failure rates in STEM courses [3]. Similarly, the structured and iterative engagement offered by supervised practice aligns with cognitive research emphasizing the spacing and cumulative effects in learning mathematics [4], [15].

Moreover, the improvements in problem-solving performance resonate with Halmos's assertion that mathematical learning is fundamentally experiential: "The only way to learn mathematics is to do mathematics" [7]. By embedding supervised problem-solving into the daily rhythm of the course, students were repeatedly exposed to key procedures and conceptual challenges, promoting both retention and adaptability.

Importantly, the Understand dimension—associated with factual and conceptual knowledge—did not show a statistically significant change. This supports the notion that traditional instruction may be sufficient for transmitting definitions and theorems, but not for fostering deep transfer or analytical thinking. In contrast, supervised practice appears especially effective in addressing higher-order cognitive domains, a distinction also noted in studies on flipped classrooms and feedback-rich environments [10], [17], [18].

The intervention was also feasible and scalable, as it required no major technological overhaul. Unlike flipped classroom models that depend on video lectures and asynchronous preparation [9], the strategy used in this study reallocated classroom time toward active engagement, making it practical even in resource-constrained settings. It also provided equitable learning conditions across sections and instructors.

From an instructional perspective, continuous practice functioned as an embedded feedback loop, supporting formative assessment and self-correction. Shute emphasized the role of formative feedback in guiding learners toward mastery, especially in subjects requiring high precision like mathematics [18]. Instructors noted improved student motivation, increased willingness to engage with unfamiliar problems, and a more participatory classroom environment, all consistent with broader findings on student-centered instruction [20], [12].

5.1 Implications and Recommendations

The results of this study suggest that continuous supervised practice can be effectively implemented across a wide range of STEM courses without requiring additional technological resources or curricular restructuring. By prioritizing guided problem-solving within scheduled instructional time, instructors can enhance students' higher-order cognitive skills while maintaining conceptual coverage. This approach is particularly suitable for large-enrollment courses and resource-constrained contexts, making it a transferable and scalable instructional strategy for improving mathematics education in engineering and related disciplines:

- First, course designers should prioritize allocating time for supervised practice within scheduled instructional hours. This change does not require reducing content coverage but rather reorganizing the mode of delivery to emphasize problem engagement.
- Second, instructor development programs should train faculty in formative feedback techniques and student facilitation during active learning sessions.
- Third, institutional policies should encourage evidence-based instructional innovation by supporting pilot studies and recognizing teaching excellence.

5.2 Limitations and Future Work

While the results are promising, the study has limitations. The use of non-randomized cohorts introduces potential confounds, such as differences in student motivation or external conditions. Future research should seek to replicate these findings across multiple institutions and courses, possibly incorporating random assignment or matched designs to strengthen causal claims.

Moreover, qualitative data collection (e.g., student focus groups, classroom recordings) would offer richer insights into the cognitive and emotional processes underlying the observed gains.

In conclusion, this study provides compelling evidence that continuous supervised problem-solving practice enhances higher-order mathematical skills in engineering students without compromising conceptual understanding. It bridges the gap between theory and application and offers a practical, scalable solution for improving mathematics education at the undergraduate level. Institutions aiming

to improve retention, engagement, and mathematical competency in STEM programs should consider adopting this low-cost, high-impact pedagogical approach.

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