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Evaluating Experiential Learning and AI-Supported Scaffolding in Differential Equations Courses for Engineering Students

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Abstract–This study presents the implementation and evaluation of an educational strategy based on experiential learning and the regulated use of artificial intelligence tools as support for mathematical reasoning in a Differential Equations course for engineering students. The study was conducted using a comparative quasi-experimental design, in which three groups taught by the same instructor were analyzed: one control group following a traditional instructional approach and two experimental groups that incorporated contextualized activities in real engineering scenarios and the controlled use of artificial intelligence as cognitive scaffolding. The assessment of academic performance and disciplinary competencies was designed in alignment with the learning objectives and institutional competency frameworks of the course, using instruments integrated into the regular evaluation process. The results show consistent differences in favor of the experimental groups in both final grades and criteria associated with complex problem solving, mathematical modeling, and solution interpretation. The analysis suggests that the integration of experiential learning and the regulated use of artificial intelligence promotes a more applied understanding of mathematical concepts, while maintaining students as active agents in the learning process. Overall, the study provides empirical evidence on the feasibility of pedagogical approaches aligned with Education 6.0 in foundational mathematics courses for engineering within Latin American contexts.

Keywords-- Engineering education, experiential learning, differential equations, educational innovation, education 6.0

I. INTRODUCTION

Engineering education in Latin America continues to face persistent structural challenges related to learning quality, student retention, and the effective development of disciplinary and transversal competencies, particularly during the early stages of undergraduate programs [1]-[3]. Despite sustained growth in enrollment and the progressive incorporation of digital technologies in higher education, multiple international reports indicate that learning outcomes in foundational courses, especially mathematics and basic sciences, remain heterogeneous and, in many cases, insufficient to meet contemporary professional, social, and productive demands [4]-[6]. These limitations have direct implications for academic performance, curricular progression, and the long-term formation of engineering competencies required in increasingly complex technological and societal contexts.

In response to these challenges, higher education institutions have promoted a wide range of educational innovation initiatives aimed at improving student engagement, relevance of learning experiences, and overall learning effectiveness. However, a substantial proportion of these initiatives are implemented in a fragmented manner, frequently driven by local experimentation rather than by systematically articulated pedagogical frameworks. As a result, their reported impact is often supported by limited comparative empirical evidence and exhibits weak articulation with competency-based assessment systems and quality assurance processes demanded by contemporary accreditation frameworks [7], [8]. This misalignment between innovation, evaluation, and accreditation constitutes a significant barrier to the sustainable transformation of engineering education, particularly in regions where institutional accountability and program accreditation play a central role in educational policy.

One of the most extensively documented challenges in engineering education involves bridging the gap between theoretical knowledge and its application in authentic engineering contexts, especially in foundational mathematics and science courses. Traditional instructional approaches in these subjects have historically emphasized procedural fluency and algorithmic manipulation, frequently at the expense of conceptual understanding, contextualization, and transferability of knowledge. In contrast, the engineering education literature has consistently demonstrated that inductive instructional approaches, such as experiential learning, problem-based learning, and challenge-based learning, can foster deeper and more transferable learning outcomes when supported by rigorous instructional design and aligned assessment strategies [9]-[11]. Within this perspective, constructive alignment among learning outcomes, learning activities, and assessment has been consolidated as a central principle for ensuring educational quality at the university level [12].

Foundational Sciencedies have further shown that experiential and gamification-based strategies implemented in foundational science and engineering courses can significantly enhance conceptual understanding, student motivation, and engagement, particularly when these strategies are explicitly aligned with learning objectives and competency-oriented evaluation criteria [13]. Complementarily, immersive technologies such as virtual reality have demonstrated potential to facilitate the visualization of abstract phenomena, strengthen systemic understanding, and support active learning in engineering education, provided that such technologies are employed as pedagogical resources embedded within coherent instructional designs rather than as ends in themselves [14].

More recently, the emergence of generative artificial intelligence has expanded the landscape of educational innovation in higher education. AI-based tools have opened new possibilities for cognitive scaffolding, adaptive feedback, and metacognitive support, particularly in complex problem-solving domains characteristic of engineering education. Empirical studies and recent reviews suggest that, under controlled pedagogical conditions, artificial intelligence can complement experiential learning by supporting reasoning processes and structured reflection without replacing the instructor's role or students' cognitive responsibility [15], [16]. At the same time, the literature cautions against uncritical adoption, highlighting risks such as cognitive dependency, increased extraneous cognitive load, and reduced transparency in assessment processes. These concerns reinforce the need for operational, evaluable, and pedagogically grounded frameworks that guide the responsible implementation of artificial intelligence in educational contexts [17], [18].

Within this evolving landscape, the concept of Education 6.0 has emerged as a comprehensive paradigm that extends beyond the mere integration of technology, emphasizing intentional instructional design, competency-based assessment, and human-centered learning. In engineering education, Education 6.0 promotes the development of integrated competencies that combine disciplinary knowledge, transversal skills, ethical reasoning, and adaptive problem-solving capabilities required to address ill-structured engineering challenges. From this perspective, emerging technologies, particularly artificial intelligence, are conceptualized as cognitive support mechanisms embedded within pedagogically coherent designs, rather than as autonomous problem solvers.

Importantly, Education 6.0 aligns with contemporary accreditation and quality assurance frameworks in engineering education, which emphasize outcome-based education, evidence-driven assessment, and the demonstrable achievement of competencies. Experiential learning environments, competency-aligned rubrics, and performance-based assessment generate traceable evidence of student learning that can be systematically documented and audited. When artificial intelligence is used in a regulated and transparent manner, it can further support competencies valued by accreditation bodies, such as analytical reasoning, ethical use of technology, and autonomous learning, while preserving assessment integrity and evaluability.

From an accreditation perspective, the relevance of Education 6.0 extends beyond pedagogical innovation and directly addresses the requirements of outcome-based accreditation frameworks. International models such as ABET and EUR-ACE, as well as their adaptations within Latin American accreditation systems, emphasize the systematic assessment of learning outcomes and the use of evidence-based evaluation processes to ensure educational quality and continuous improvement. Within this context, instructional innovations are expected not only to enhance learning experiences, but also to generate comparable, auditable, and institutionally relevant evidence aligned with accreditation standards.

Despite these theoretical and methodological advances, significant gaps remain in engineering education research, particularly in Latin American contexts. First, there is a limited number of comparative quasi-experimental studies that systematically analyze the impact of partially and deliberately implemented experiential strategies combined with regulated use of artificial intelligence in foundational mathematics courses. Second, many existing studies prioritize perceptual or satisfaction-based indicators, without robustly linking instructional innovation to academic performance and competency development aligned with accreditation requirements. Finally, the relationship between instructional design, competency-based assessment, and quality assurance processes remains underexplored and insufficiently systematized.

In this sense, the Differential Equations course constitutes a strategic educational context. As a core subject across multiple engineering programs, it requires high levels of abstraction, mathematical modeling, and conceptual transfer, and it is frequently associated with academic difficulties and reduced student motivation. These characteristics make it an appropriate setting to examine whether carefully designed and evaluated instructional innovations grounded in experiential learning and regulated use of artificial intelligence can generate meaningful improvements relative to traditional teaching approaches.

Building on a consolidated research trajectory in experiential learning, challenge-based education, immersive technologies, and artificial intelligence applied to engineering education [11], [13]-[15], this study presents a comparative quasi-experimental investigation conducted across three parallel groups of a Differential Equations course taught by the same instructor during a single academic period. One group operated as a control under a traditional instructional approach, while two experimental groups partially incorporated principles associated with Education 6.0, including experiential modeling contexts, regulated use of artificial intelligence as cognitive scaffolding, and competency-oriented assessment aligned with institutional frameworks. The study analyzes final grades as well as performance in disciplinary and transversal competencies, providing empirical evidence on the viability of Education 6.0-aligned pedagogical strategies in foundational mathematics courses for engineering education.

II. RELATED WORK AND RESEARCH GAP

Research in engineering education has experienced sustained growth over the last two decades, driven by increasing concerns regarding learning effectiveness, student retention, and the alignment between university training and professional practice. A substantial body of literature has documented those inductive instructional approaches, such as problem-based learning, project-based learning, and challenge-based learning, tend to promote deeper, more transferable understanding when compared to traditional, content-centered instructional models [9], [10]. These approaches emphasize active student engagement, contextualized knowledge construction, and iterative problem solving, which are particularly relevant in engineering education due to the inherently applied and integrative nature of the discipline.

Within this broader landscape, experiential learning has been consolidated as a robust theoretical and practical framework for the development of both disciplinary and transversal competencies in engineering. Experiential learning models emphasize cycles of action, reflection, conceptualization, and application, enabling students to connect abstract concepts with concrete experiences. However, the literature consistently stresses that the effectiveness of experiential learning depends critically on the constructive alignment among learning objectives, instructional activities, and assessment mechanisms [12]. Without such alignment, experiential activities risk becoming isolated experiences with limited impact on long-term learning outcomes or competency development.

A. Experiential Learning and Challenge-Based Education in Engineering

Challenge-Based Learning (CBL) represents a specific instantiation of experiential learning that has shown particular effectiveness in engineering courses related to modeling, dynamic systems, and design. In these contexts, students are required to integrate theoretical knowledge, experimentation, and decision making within open-ended, often ill-structured problem spaces. Prior research indicates that CBL contributes to the development of systems thinking, collaborative problem solving, and technical argumentation skills, while simultaneously increasing student motivation and engagement [11], [15].

Recent empirical studies have further demonstrated that CBL can lead to measurable improvements in both technical and transversal competencies implemented with explicit evaluation criteria, structured observation protocols, and performance-based assessment instruments. These findings suggest that the educational value of CBL does not reside solely in the authenticity of the challenges posed, but in the intentional design of learning trajectories that guide students from exploration to formalization and reflection. At the same time, the literature cautions that poorly structured CBL implementations may increase cognitive load or exacerbate inequities among students if adequate scaffolding and feedback mechanisms are not provided.

Interdisciplinary approaches constitute a complementary dimension of experiential and challenge-based education. Several studies have shown that early exposure to interdisciplinary problem solving reduces curricular fragmentation and enhances the transfer of learning to professional contexts. When students from different disciplinary backgrounds collaborate on authentic engineering problems, gains have been observed in conceptual understanding, technical communication, and evidence-based decision making, particularly during the initial semesters of engineering programs [15]. Nevertheless, these benefits are highly sensitive to the coherence of the instructional design and the instructor's capacity to orchestrate disciplinary integration, manage group dynamics, and align assessment with intended learning outcomes.

B. Immersive Technologies and Gamification in Foundational Courses.

Immersive technologies, including virtual reality and simulated environments, have been widely investigated as tools to support active learning and the visualization of abstract phenomena in engineering education. Empirical evidence suggests that virtual reality can enhance spatial reasoning, interaction with complex systems, and procedural safety, especially in contexts where physical experimentation is costly, risky, or impractical [14]. In foundational courses, immersive environments have been used to bridge the gap between symbolic representations and physical interpretations, supporting conceptual understanding in areas such as mechanics, electromagnetism, and mathematical modeling.

Similarly, gamification and experiential learning strategies have demonstrated positive effects on student motivation, engagement, and conceptual understanding in foundational science and mathematics courses. When designed to reinforce problem-solving processes, scientific reasoning, and iterative feedback, gamified activities can increase persistence and reduce anxiety associated with traditionally challenging subjects [13]. However, the literature consistently emphasizes that these benefits are contingent upon pedagogical integration rather than technological novelty.

Several authors warn that the educational impact of immersive and gamified technologies tends to diminish when their implementation prioritizes engagement or novelty over cognitive and instructional coherence. In such cases, technologies may increase extraneous cognitive load or distract from core learning objectives. Consequently, immersive and gamified tools are increasingly conceptualized not as universal solutions to educational challenges, but as targeted pedagogical instruments intended to support specific cognitive processes within a well-defined instructional design [17], [18].

C. Artificial Intelligence in Engineering Education

The incorporation of artificial intelligence in higher education has gained particular relevance in recent years, especially with the emergence of generative models capable of providing adaptive feedback, problem-solving support, and metacognitive scaffolding. Recent systematic reviews indicate that AI applications in education can have positive effects on academic performance and self-regulated learning, provided that their use is mediated by explicit pedagogical design and instructor supervision [16].

Within the specific domain of engineering education, recent studies have explored the use of AI as support for experiential learning and the development of complex problem-solving skills. Empirical evidence suggests that AI can function as effective cognitive scaffolding when employed in a controlled manner, avoiding the replacement of student reasoning and promoting reflective learning processes [11]. Nevertheless, the literature also highlights risks associated with unregulated use of these tools, such as cognitive dependency, superficial conceptual understanding, and lack of transparency in assessment processes, reinforcing the need for clear and evaluable operational frameworks.

D. Research Gaps and Study Justification.

Despite significant advances in these research areas, relevant gaps remain. First, there is a limited number of comparative quasi-experimental studies analyzing the impact of partial and controlled implementation of experiential strategies combined with artificial intelligence in foundational mathematics courses for engineering. Second, many studies focus on perceptual or student satisfaction indicators, without establishing robust relationships with academic performance, disciplinary competency development, and transversal competencies required by contemporary accreditation frameworks.

Additionally, most studies reported in international literature are conducted in Anglo-Saxon contexts, which limits the generalizability of their findings to institutional and cultural realities specific to Latin America. In this sense, there is a clear need for situated empirical studies that rigorously document the impact of innovative strategies in authentic teaching contexts, while controlling key variables such as instructor, course content, and assessment instruments.

The present study addresses these gaps through a comparative quasi-experimental design implemented across multiple groups of a Differential Equations course, incorporating partial and controlled principles of experiential learning and regulated use of artificial intelligence. By jointly analyzing academic performance, disciplinary competencies, and transversal competencies, this work contributes to strengthening the empirical basis required to inform evidence-based decisions on educational innovation, competency-based assessment, and quality assurance in engineering education.

III. METHODOLOGY

This study adopts a comparative quasi-experimental research design implemented within an authentic instructional context in an undergraduate Differential Equations course for engineering students. This methodological approach was selected due to institutional constraints that prevent random assignment of students to groups, while still allowing systematic comparison under controlled instructional conditions. Such designs are widely accepted in engineering education research when key instructional variables, such as instructor, course content, assessment instruments, and academic calendar, are adequately controlled.

During the academic period under analysis, five parallel sections of the Differential Equations course were taught by the same instructor. Of these, three sections participated in the educational intervention examined in this study, while the remaining two sections implemented a different instructional project focused on experimental activities using a wind tunnel and were therefore excluded from the analysis. Among the three sections considered, one functioned as a control group, following a traditional instructional approach based on lectures and conventional problem-solving exercises. The remaining two sections were defined as experimental groups, in which principles associated with Education 6.0 were partially and deliberately implemented. In this study, Education 6.0 was operationalized through three design principles: (i) experiential modeling tasks, (ii) competency-aligned analytic rubrics, and (iii) regulated AI-based cognitive scaffolding.

Language of instruction was treated as a contextual variable rather than as an independent factor in the study design; therefore, no causal claims are made regarding its effect on academic performance or competency development.

In the experimental groups, the instructional design incorporated experiential learning activities contextualized within authentic engineering scenarios. These activities required students to model, analyze, and interpret dynamic systems using differential equations, emphasizing the application of mathematical concepts to engineering-relevant problems. In addition, artificial intelligence tools were employed in a structured and limited manner as cognitive scaffolding mechanisms. Their use was intended to support student reflection, clarify intermediate modeling steps, and provide formative feedback, while explicitly avoiding the substitution of students' mathematical reasoning processes. The use of AI was regulated through explicit guidelines to ensure transparency, academic integrity, and alignment with competency-based assessment principles.

Assessment in the experimental groups emphasized both academic performance and the demonstration of disciplinary and transversal competencies. Disciplinary competencies included mathematical modeling, interpretation of solutions, and application of differential equations to engineering contexts. Transversal competencies included problem-solving, autonomy, and technical communication. The control group did not incorporate experiential or AI-supported components and followed the traditional instructional and assessment scheme of the course.

The evaluation of academic performance and competency development was designed in coherence with the learning objectives and institutional competency frameworks of the Differential Equations course. In particular, both disciplinary and transversal competencies associated with engineering problem solving, reasoning under complexity, and digital transformation were considered, in accordance with current institutional frameworks.

Regarding disciplinary competencies, assessment was aligned with the competency of Engineering Problem Solving, focusing on decision making under conditions of uncertainty and the implementation of scientific and mathematical modeling actions to address complex problems. These dimensions were operationalized through activities requiring the formulation, analysis, and interpretation of differential equations in engineering-specific contexts.

Complementarily, transversal competencies were incorporated, particularly those related to scientific thinking, reasoning for complexity, and the critical use of advanced digital technologies. These competencies were operationalized through tasks that required critical analysis of solutions, justification of assumptions, and responsible use of computational and artificial intelligence tools as support for reasoning, without replacing students' cognitive processes.

Conceptual, procedural, and attitudinal course contents served as the basis for the design of assessment instruments, ensuring coherence among learning objectives, formative activities, and evaluation criteria. This alignment enabled the evaluation not only of technical mastery of mathematical content, but also of students' ability to apply such knowledge in an integrated, reflective, and contextualized manner to engineering problems.

Data collection was conducted using instruments integrated into the regular course assessment process, thereby ensuring ecological validity. Academic performance was measured using final grades calculated according to a uniform institutional grading scheme. Disciplinary and transversal competencies were assessed using analytic rubrics aligned with institutional competency frameworks. These rubrics were developed and validated within the institutional competency framework and applied consistently across all groups to ensure reliability and comparability of competency assessment.

Data analysis included descriptive statistics (mean and standard deviation) and inferential comparisons between the control group and the experimental groups using independent-samples t-tests or one-way ANOVA, depending on data distribution. Additionally, effect sizes were calculated using Cohen's d to estimate the practical magnitude of observed differences beyond statistical significance ($\alpha = 0.05$).

All procedures complied with institutional ethical policies. Data was anonymized prior to analysis, and student participation did not involve any academic workload beyond the normal activities of the course.

From a methodological perspective, this study adopts a context-sensitive and pragmatic approach, recognizing the inherent complexity of educational phenomena involving human participants. Variables such as motivation, prior knowledge, learning strategies, and socio-cultural context cannot be fully isolated under quasi-experimental conditions. Therefore, rather than assuming strict experimental control, the design prioritizes ecological validity while maintaining alignment of key instructional variables. This approach enables meaningful comparative analysis without oversimplifying the multidimensional nature of learning processes in authentic engineering education contexts.

IV. Results

This section presents the results obtained from the comparison between the control group and the two experimental groups participating in the study. The results are organized around two main dimensions: academic performance, measured through final grades obtained in the Differential Equations course, and the development of disciplinary competencies, evaluated using instruments aligned with the institutional frameworks of the course.

For the analysis of academic performance, final grades from each group were considered. Table I presents the corresponding descriptive statistics, differentiating instructional condition and language of instruction. The results show that both experimental groups achieved higher mean scores compared to the control group.

TABLE I: DESCRIPTIVE STATISTICS OF FINAL GRADES FOR EXPERIMENTAL AND CONTROL GROUPS, INCLUDING LANGUAGE OF INSTRUCTIONAL CONDITION, SAMPLE SIZE (N), MEAN FINAL GRADE, AND STANDARD DEVIATION (SD).

Group	**Language**	**Instructional condition**	**Mean final grade**	**n**	**SD**
Group 1	English	Experimental	89.56	32	5.89
Group 2	Spanish	Experimental	87.27	26	7.72
Group 3	Spanish	Control	81.46	26	23.14

Group 1, corresponding to the experimental condition and taught in English, obtained the highest mean score ($M = 89.56$), followed by Group 2, also experimental and taught in Spanish ($M = 87.27$). In contrast, Group 3, which served as the control group under a traditional instructional approach, obtained a lower mean score ($M = 81.46$).

When results are aggregated by instructional condition, the experimental groups achieved a global mean of 88.42, whereas the control group maintained a mean score of 81.46. These descriptive differences suggest improved academic performance associated with the implementation of the experiential learning strategy supported by the regulated use of artificial intelligence. Figure 1 visually illustrates the differences in mean final grades across the analyzed groups.

To complement the comparison of mean academic performance, effect sizes were calculated using Cohen's ***d*** to estimate the practical significance of the observed differences between groups. Effect size analysis is particularly relevant in educational research, as it provides information beyond statistical significance by quantifying the magnitude of instructional impact.

The comparison between the experimental group taught in English (Group 1) and the control group (Group 3) yielded a Cohen's *d* value of 0.48, corresponding to a moderate effect size. Similarly, the comparison between the experimental group taught in Spanish (Group 2) and the control group resulted in a Cohen's *d* value of 0.31, indicating a small-to-moderate effect.

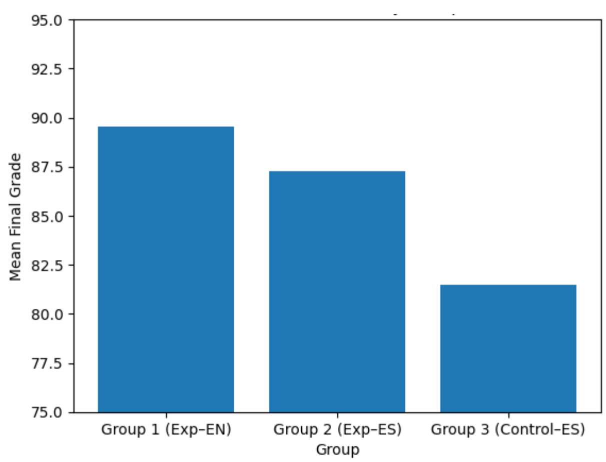

Fig. 1 Comparison of mean final grades across experimental and control groups. Groups 1 and 2 implemented the experiential and AI-supported instructional design, whereas Group 3 followed a traditional instructional approach. Language of instruction is shown for contextual reference.

To complement the comparison of mean academic performance, effect sizes were calculated using Cohen's d to estimate the practical significance of the observed differences between groups. Effect size analysis is particularly relevant in educational research, as it provides information beyond statistical significance by quantifying the magnitude of the instructional impact.

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These values suggest that the experiential and AI-supported instructional strategy produced a meaningful educational impact, with differences in effect size reported for contextual reference, as language of instruction was not isolated as an independent variable. Although language of instruction was not isolated as an independent variable in the study design, the differences in effect size point to a potential secondary influence that merits further investigation in future research (see Table II).

TABLE II. EFFECT SIZE (COHEN'S D) FOR COMPARISONS BETWEEN EXPERIMENTAL GROUPS AND THE CONTROL GROUP.

Comparison	Cohen's d	Effect magnitude
Group 1 (Experimental – English) vs. Group 3 (Control)	0.48	Moderate
Group 2 (Experimental – Spanish) vs. Group 3 (Control)	0.31	Small to moderate

Regarding disciplinary competencies, the results obtained from the analytic rubrics indicate higher performance levels in the experimental groups across criteria associated with complex problem solving, mathematical modeling, and solution interpretation. These descriptive findings support the coherence between the implemented instructional design and the observed outcomes in terms of both academic performance and competency development.

In addition to academic performance, the study examined the development of disciplinary and transversal competencies using analytic rubrics aligned with the institutional competency framework of the course. These rubrics were designed to capture qualitative differences in students' problem-solving processes, modeling strategies, solution interpretation, and technical communication, rather than to function as standalone numerical scores.

Mean rubric-level performance across disciplinary competency dimensions was systematically higher in the experimental groups than in the control group, indicating a shift toward higher-order performance descriptors in mathematical modeling, solution interpretation, and complex problem solving.

TABLE III. QUALITATIVE COMPARISON OF COMPETENCY PERFORMANCE BASED ON ANALYTIC RUBRICS

Competency dimension	Evaluation criteria (rubric-based)	Experimental groups	Control group
Mathematical modeling	Problem formulation, variable identification, model construction	Predominantly higher rubric levels	Predominantly lower rubric levels
Solution interpretation	Interpretation of results, validation of solutions, contextual reasoning	More frequent attainment of higher-level descriptors	More frequent attainment of lower-level descriptors
Complex problem solving	Strategy selection, decision making under uncertainty, iterative refinement	Greater consistency across rubric criteria	Greater variability across rubric criteria
Technical communication	Justification of assumptions, clarity of mathematical argumentation	Stronger alignment with expected competency descriptors	Partial alignment with expected competency descriptors

Table III summarizes qualitative patterns observed across analytic rubric criteria. Rather than reporting absolute differences, the table highlights comparative tendencies in the distribution of performance levels between experimental and control groups, as consistently observed across evaluated competencies.

When these competency-related results are considered alongside the academic performance outcomes, the overall pattern reinforces the consistency between the pedagogical approach applied in the experimental groups and the observed improvements across multiple dimensions of learning.

V. Analysis of results

The analysis of the results allows for an examination of the differences observed between the control group and the experimental groups in relation to academic performance, as well as their coherence with the instructional design implemented in the course. In this sense, the identified descriptive patterns provide elements to interpret the educational scope of experiential learning strategies and the regulated use of artificial intelligence tools as support for mathematical reasoning.

In terms of academic performance, final mean scores show that both experimental groups consistently outperformed the control group. This descriptive difference suggests a positive association between the implementation of the experimental pedagogical approach and improved academic performance in the Differential Equations course. The unusually high dispersion observed in the control group is largely attributable to a single extreme low-performance case corresponding to a student who remained enrolled despite failing the course. No data points were excluded from the analysis to preserve ecological validity. The fact that this trend was observed across two different groups taught in different languages reinforces the interpretation that the effect is primarily linked to the instructional design rather than to specific conditions of a single group. Although effect sizes were calculated, confidence intervals were not estimated due to sample size constraints, which should be considered when interpreting the magnitude of the observed effects.

Regarding the development of disciplinary competencies, results derived from analytic rubrics indicate more favorable performance in the experimental groups across criteria associated with complex problem solving, mathematical modeling, and solution interpretation. These descriptive findings are consistent with an instructional design that prioritized the contextualized application of mathematical knowledge in authentic engineering scenarios, in contrast to approaches predominantly centered on algorithmic practice.

A relevant aspect of the analysis is that the observed differences do not appear to stem from indiscriminate use of artificial intelligence tools, but rather from their intentional and regulated integration as support for reasoning. In this study, artificial intelligence was used as a cognitive scaffolding resource aimed at structuring processes of analysis and reflection, without substituting students' fundamental mathematical work. This suggests that the educational value of AI largely depends on the pedagogical design within which it is embedded.

From an institutional and curricular perspective, the analyzed results are consistent with competency-based assessment frameworks and the learning objectives of the course. The alignment among formative activities, assessment instruments, and institutional competencies contributed to the internal coherence of the study and supports the interpretation of the results within a quality assurance context. This aspect is particularly relevant in Latin American contexts, where educational innovations must be viable, evaluable, and compatible with accreditation processes.

Overall, the analysis of results suggests that the combination of experiential learning, competency-aligned assessment, and regulated use of digital technologies constitutes a promising strategy for strengthening learning in foundational mathematics courses for engineering. Rather than promoting the indiscriminate adoption of technological tools, the findings emphasize the importance of coherent instructional designs that integrate experience, reflection, and evaluation, while maintaining students as active agents in the learning process.

It is important to acknowledge that the observed differences cannot be exclusively attributed to isolated instructional variables. Student performance is influenced by multiple interacting factors intrinsic to human learning processes, including motivation, prior knowledge, and individual learning trajectories. These elements are inherent to educational contexts and should be considered when interpreting the results of quasi-experimental designs.

VI. Conclusions

This study analyzed the implementation of an educational strategy based on experiential learning and the regulated use of artificial intelligence tools as support for mathematical reasoning in a Differential Equations course for engineering students. Through a comparative quasi-experimental design, the study examined academic performance and the development of disciplinary competencies within an authentic instructional context, while maintaining coherence with the course learning objectives and institutional competency-based assessment frameworks.

The results indicate that the incorporation of contextualized activities grounded in engineering scenarios is associated with a more functional and applied understanding of mathematical concepts, particularly in processes related to mathematical modeling, solution interpretation, and complex problem solving. These findings reinforce the notion that the difficulties traditionally associated with foundational mathematics courses are not solely attributable to the level of abstraction of the content, but also to the extent to which such content is meaningfully connected to situations that are relevant and significant for students.

Additionally, the controlled and explicitly regulated use of artificial intelligence tools emerged as a relevant complementary element when integrated as cognitive scaffolding within a coherent pedagogical design. Rather than replacing mathematical reasoning, artificial intelligence supported the structuring of thought processes, clarification of intermediate steps, and reflection on decision making during problem solving. This approach contributes to a balanced view of the role of artificial intelligence in engineering education, moving away from both technophilic positions and overly restrictive perspectives that limit its formative potential.

From a methodological standpoint, the study demonstrates that it is possible to generate relevant empirical evidence in real classroom contexts, even under institutional constraints that prevent random assignment of students. The alignment among instructional design, assessment instruments, institutional competencies, and data analysis strengthened the internal coherence of the study and enabled consistent interpretation of the findings. In this sense, the proposed instructional architecture is transferable to other foundational STEM courses where abstraction and mathematical modeling represent major learning barriers. This aspect is particularly significant in Latin American contexts, where educational innovations must be viable, evaluable, and compatible with quality assurance and accreditation processes.

In terms of educational contribution, this work adds to ongoing discussions on the effective implementation of Education 6.0–oriented approaches in foundational mathematics courses for engineering. Rather than advocating for the indiscriminate adoption of emerging technologies, the results underscore the importance of intentional instructional designs that integrate experience, reflection, and competency-based assessment, while maintaining students as active agents in the construction of applied mathematical knowledge.

Although the quasi-experimental design limits the establishment of strict causal relationships, the consistency of the observed patterns suggests that the implemented strategies hold meaningful educational potential. Future research should extend this study through larger samples, longitudinal designs, and the incorporation of mixed-methods approaches to better capture the complexity of learning processes in engineering education. Qualitative techniques such as interviews, classroom observations, and think-aloud protocols could provide deeper insights into students' cognitive and metacognitive processes, as well as their interaction with AI-supported scaffolding. Additionally, incorporating variables such as motivation, self-regulated learning, prior knowledge, and socio-cultural context would contribute to a more comprehensive understanding of the observed effects and strengthen the interpretation of quasi-experimental findings in human-centered educational environments.

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