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Comparative Efficacy of Collaborative, Cooperative, and Traditional Learning on Linier Algebra Problem-Solving Ability in Higher Education

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Abstrak

Tantangan yang dihadapi siswa dalam memahami sistem persamaan linear berasal dari sifat abstrak subjek dan perhitungan ekstensif yang diperlukan untuk matriks berordo lebih dari tiga. Studi kuasi-eksperimental ini meneliti efektivitas komparatif model pembelajaran kolaboratif dan kooperatif dalam meningkatkan kemampuan pemecahan masalah matematika mahasiswa S1 pada sistem persamaan linear. Partisipan terdiri dari tiga kelas utuh: dua kelompok eksperimen mahasiswa Ilmu Komputer (tahun akademik 2024/2025) yang diajar menggunakan model pembelajaran kolaboratif dan model pembelajaran kooperatif, dan satu kelompok kontrol mahasiswa Pendidikan Matematika (tahun akademik 2021/2022) yang menerima pengajaran tradisional. Sebelum intervensi, tes pendahuluan diberikan untuk memeriksa kemampuan pemecahan masalah dasar. ANOVA satu arah kemampuan awal yang tidak sama. Oleh karena itu, efektivitas pembelajaran dievaluasi menggunakan skor normalized gain. Kelompok pembelajaran kolaboratif mencapai rata-rata N-Gain tertinggi, diikuti oleh kelompok pembelajaran kooperatif, sedangkan kelompok pembelajaran tradisional menunjukkan peningkatan terendah. Hasil ini menunjukkan bahwa pembelajaran kolaboratif terstruktur lebih efektif dalam meningkatkan kemampuan pemecahan masalah siswa dalam sistem persamaan linear dibandingkan dengan pendekatan kooperatif dan tradisional.
***Kata kunci**: Pembelajaran Berbasis Tim; Think-Pair-Share; Pembelajaran Tradisional; Model Pembelajaran; Kemampuan Pemecahan Masalah.*

Abstract

The challenges students face in comprehending systems of linear equations originate from the abstract character of the subject and the extensive calculations required for matrices of order more than three. This quasi-experimental study investigated the comparative effectiveness of collaborative and cooperative learning models in improving undergraduate students' mathematical problem-solving ability on systems of linear equations. The participants consisted of three intact classes: two experimental groups of Computer Science students (academic year 2024/2025) taught using a collaborative learning model and a cooperative learning model, respectively, and one control group of Mathematics Education students (academic year 2021/2022) receiving traditional instruction. Prior to the intervention, a pre-test was administered to examine baseline problem-solving ability. One-way ANOVA indicating unequal initial ability. Therefore, learning effectiveness was evaluated using normalized gain. Post-test scores were analyzed descriptively, as their distribution violated normality assumptions. The collaborative learning group achieved the highest mean N-Gain, followed by the cooperative learning group, while the traditional learning group demonstrated the lowest improvement. These results suggest that structured collaborative learning is more effective in enhancing students' problem-solving improvement in systems of linear equations than cooperative and traditional approaches.
Keywords: Team Based Learning; Think-Pair-Share; Traditional Learning; Learning Model; Problem-Solving Ability.

I. INTRODUCTION

Mathematics is a requisite discipline in higher education, as demonstrated by its inclusion in the fields of Science, Technology, Engineering, and Mathematics (STEM) (Warsito et al., 2023). Research by (Sanabria et al., 2020) indicates that prospective students with inadequate mathematical preparation tend to achieve lower scores on college placement tests and are typically assigned to developmental or remedial education programs. Consequently, the research indicates that mathematics is a fundamental competence in higher education. Algebra is a fundamental discipline in mathematics, alongside arithmetic and geometry. Elementary linear algebra is a key subject that students in education, science, and engineering, particularly those in computer science programs, must study. This subject is essential for computer science students, as the fundamental skill of developing a coding-based application necessitates accuracy in computations and matrix size evaluation (Paper, 2018; Sari & Afriansyah, 2020; Sarumaha et al., 2024).

The challenges students face in comprehending linear equations stem from the abstract characteristics of the subject and the complex calculations requiring matrices of rank beyond three. Research by (Angraini & Wahyuni, 2021) elucidates that mathematics education students encounter learning barriers in the elementary linear algebra course. Consequently, the researchers created instructional materials by analysing the learning challenges encountered by mathematics education students in their third semester at Islamic University of Riau. The conventional educational approach primarily focuses on the instructor, resulting in minimal student engagement in the discovery of concepts (Stewart et al., 2018; Arwadi et al., 2024). Consequently, there is a necessity for tactics and pedagogical approaches that can augment active student engagement, facilitate profound comprehension, and strengthen students' abilities in systematic problem-solving.

Empirical studies of linear algebra courses consistently report that students struggle with systems of linear equations due to the abstract nature of the concepts and the cognitive load required in matrix computations (Astutik & Purwasih, 2023; Guna, Firdausy, & Sumartini, 2025). However, despite the growing research on peer-assisted learning, comparative studies directly evaluating various learning models, particularly collaborative, cooperative, and traditional learning, within the same course context are limited. Prior research typically compares only one innovative model with traditional learning, resulting in fragmented evidence and limiting cross-model generalizability. Furthermore, studies explicitly focusing on higher education linear algebra, particularly in the domain of problem-solving performance are rare, with most studies conducted in school-level mathematics, even comparing the two courses within two different study programs, such as in this case, mathematics education and computer science, despite known differences in students' prior knowledge structures and learning orientations. These gaps collectively underscore the need for rigorous comparative evidence across learning models in the context of linear algebra problem solving.

Problem solving is a method for identifying solutions to previously unrecognized issues (Talia, Afriansyah, & Sumartini, 2024). The methodical stages in problem-solving as outlined by (Polya, 1973)include comprehending the problem, devising a solution, implementing the plan, and evaluating the outcome. Several challenges are faced in the use of Polya's problem-solving method, specifically (1) insufficient conceptual knowledge, (2) restricted tactics, (3) inadequate reflection, and (4) the effect of traditional learning models. Constructivism priorities problem-solving as the primary objective of learning. (Kanselaar, 2002; Murphy, 1997). One strategy to boost students' problem-solving skills is the implementation of collaborative and cooperative learning.

Elementary linear algebra requires students to integrate procedural fluency with conceptual understanding. Prior studies have shown that students often struggle with selecting appropriate solution strategies, interpreting the meaning of solutions, and justifying their reasoning. These characteristics make systems of linear equations particularly suitable for social learning approaches. Collaborative learning, which emphasizes shared knowledge construction and open-ended problem solving, supports students in negotiating meaning and resolving conceptual conflicts. In contrast, cooperative learning provides structured interaction and individual accountability, which are essential for mastering algebraic procedures and reducing computational errors. Therefore, both collaborative (Team-Based Learning) and cooperative (Think–Pair–Share) approaches were intentionally employed to address complementary dimensions of students' difficulties in learning systems of linear equations.

Collaborative learning is a pedagogical approach in which individuals engage in group work to attain shared objectives, focusing on debate, negotiation, and problem-solving processes (Salsabila, Rahmi, & Delyana, 2023). In this environment, each group member is accountable for their own contributions and the collective success of the group. Collaborative learning highlights mutual authority and productive discourse among participants (Dillenbourg, 1999). Cooperative learning is a structured learning technique that entails group activity, distinguishing it from collaborative learning. In cooperative learning, tasks are distinctly allocated among group members, with well-defined responsibilities and individual responsibility. This technique frequently employs models such as jigsaw, think-pair-share, and collaborative learning (Slavin, 1995). Strategies for collaborative and cooperative learning address challenges through the application of models such as Team-Based Learning (TBL) and cooperative learning frameworks like Think-Pair-Share (TPS) and Learning Together (LT), which are intended to augment student engagement and facilitate learning from peers' viewpoints (Yang, 2023).

Team-Based Learning (TBL) is a collaborative educational method aimed at increasing active student engagement (Siregar et al., 2023). The material on linear equations enables students to collaboratively solve problems, exchange strategies, and assess the generated answers (Michaelsen et al., 2023). TPS is a cooperative learning approach comprising three phases: private contemplation, paired dialogue, and collective sharing in a larger group. This approach is efficacious for instructing students in critical thinking and systematic problem-solving (Lyman et al., 2023). The study conducted by (Yeung et al., 2023) demonstrates that team-based learning effectively enhances problem-solving abilities and critical thinking skills in nursing students, utilizing a quasi-experimental research methodology. The integration of team-based learning with flipped classroom methodologies positively influenced learning outcomes, including knowledge acquisition, problem-solving skills, and student happiness, hence enhancing students' problem-solving abilities and overall learning satisfaction (Kang & Kim, 2021).

The Think-Pair-Share (TPS) technique fosters an interactive, collaborative, and democratic learning environment. This enables students to engage, acquire information, collectively enhance conversation abilities, and refine each other's ideas through active classroom engagement (Alsmadi et al., 2023). The implementation of cooperative learning through the RoundTable and Think-Pair-Share techniques effectively cultivates critical thinking skills, including observation, inference, interpretation, analysis, and argumentation, among fourth-grade elementary children (Hidayati et al., 2023).

Systems of Linear Equations (SPL) was selected because it is a core topic in elementary linear algebra that requires students to integrate procedural accuracy, conceptual understanding, and mathematical reasoning. Students commonly experience difficulties in selecting appropriate solution strategies, coordinating multiple equations, and interpreting the meaning of solutions, indicating that SPL learning benefits from structured social interaction. Cooperative learning, which emphasizes positive interdependence, individual accountability, and a clear division of labor (Johnson, D. W., & Johnson, 2020; Panitz, 1997) is particularly effective for supporting procedural fluency and reducing computational errors in SPL through techniques such as Think-Pair-Share. In contrast, collaborative learning focuses on joint knowledge construction and negotiation of meaning without rigid role assignments (Davidson, 2021; Roschelle & Teasley, 1995), making it well suited for SPL tasks that require justification of solution methods and conceptual interpretation. Therefore, SPL provides an appropriate instructional context to examine the complementary roles of cooperative and collaborative learning in enhancing students' problem-solving abilities.

The novelty of this study lies in its direct three-way comparison of a Collaborative learning model (Team-Based Learning), a Cooperative learning model (Think-Pair-Share), and traditional instruction within a unified quasi-experimental framework, providing empirical clarity on the relative effectiveness of these pedagogical approaches in higher education linear algebra. Unlike previous studies that evaluate only single instructional innovations, this research simultaneously contrasts multiple student-centered models while maintaining consistency in course content, assessment, and learning environment, thereby generating more robust comparative findings. Additionally, the study contributes new evidence by examining effectiveness across two distinct academic programs (Computer Science and Mathematics Education), offering insights into how disciplinary contexts influence the success of different learning models. Beyond comparing instructional approaches, this study introduces a contextual novelty by examining the effectiveness of collaborative and cooperative learning across different academic programs. Computer Science and Mathematics Education students represent distinct disciplinary cultures with different learning habits and cognitive orientations. Investigating how these pedagogical approaches function within such heterogeneous academic contexts provides insights that extend beyond homogeneous samples commonly used in prior studies.

Based on the gaps identified in the literature and the need to evaluate the comparative effectiveness of distinct instructional approaches, this study seeks to examine the extent to which Team-Based Learning (TBL) and Think-Pair-Share (TPS) influence students' problem-solving capabilities in elementary linear algebra. In addition, the study investigates whether TBL, TPS, and traditional instructional approaches yield differential effects on students' problem-solving ability. Finally, the research aims to determine the relative sequence of effectiveness criteria among these three learning methodologies in enhancing students' problem-solving skills.

II. METHOD

This research method is quantitative and employs a quasi-experimental model with non-equivalent control groups, as the participants were drawn from intact classes that could not be randomly assigned. This research employs a set of test questions focused on problem-solving in elementary linear algebra courses concerning systems of three-variable linear equations. The instrument was administered as a pretest and posttest to the third group, consisting of two experimental groups and one control group. The pretest and posttest assessments are calibrated to problem-solving indicators. Total students are 72 such as: The study sample comprised 2 classes from the elementary linear algebra course at PGRI Wiranegara University's computer science programme for the 2024/2025 academic year, part of a total of 48 students divided into 2 experimental groups and dditionally, 24 students from the mathematics education programme for the 2021/2022 academic year served as the control group. All participants were informed about the purpose, procedures, potential risks, and voluntary nature of the study, and written informed consent was obtained prior to participation. Participants were assured that their involvement would not affect their academic standing and that they could withdraw from the study at any time without penalty.

The selection of participants from various academic programs was purposeful and aligned with the research goal of testing the robustness of collaborative and cooperative learning across heterogeneous learner profiles. Although this design introduces variability in initial mathematics ability, it reflects authentic learning settings in higher education. Consequently, baseline differences were statistically examined, and learning gains were analyzed using normalized gain scores to control for baseline differences.

The collaborative learning group was implemented using the Team-Based Learning (TBL) model, which emphasizes collective responsibility, peer discussion, and consensus-based problem solving. Students worked in permanent teams to analyze and solve systems of linear equations, justify their strategies, and evaluate alternative solutions. The cooperative learning group employed the Think-Pair-Share (TPS) strategy, which involves structured phases of individual thinking, peer discussion, and class-level sharing. This model was designed to promote individual accountability while supporting procedural accuracy in solving linear systems. The last group, the control group received traditional instruction dominated by lecturer explanations and individual problem-solving exercises.

The investigation conducted in three courses occurred during elementary linear algebra lectures, spanning 15 sessions over one semester, equivalent to six months of instruction. The exam questions are changed according to Polya's problem-solving indicators and have been evaluated by five experts (R. Burke Johnson dan Larry Christensen, 2019). The instrument from the questions has been examined for reliability using Cronbach Alpha (Leavy & Patricia, n.d.), with the criterion that if the value is more than 0.70, it is characterised as reliable.

The reliability analysis based on data from 72 participants showed that all four indicators of mathematical problem-solving ability demonstrated satisfactory internal consistency, with Cronbach's alpha values of 0.711 for comprehending the problem, 0.705 for formulating a strategy, 0.811 for executing the strategy, and 0.740 for reflecting on the solution process, all exceeding the minimum acceptable threshold of 0.70. Construct validity analysis using item–total Pearson correlations indicated positive correlations for all items, with correlation coefficients ranging from 0.499 to 0.885; most items were statistically significant ($p < 0.05$), supporting the adequacy of the instrument for subsequent analysis.

III. RESULT AND DISCUSSION

A. Results

Given the non-normal distribution of post test scores within the TBL and TPS groups, improvements within each group were examined using the Wilcoxon Signed-Rank Test, which is recommended for paired nonparametric data (Field, 2013; Pallant, 2016). Furthermore to compare posttest performance across the three such as TBL, TPS, and Traditional learning models, the Kruskal Wallis H test was employed, as it is appropriate for comparing three or more independent

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groups when the assumptions of ANOVA and T-test are not met (Coakley & Conover, 2000; Frey, 2023). Post hoc comparisons were conducted using Dunn's procedure with Bonferroni adjustment to determine the specific ordering and significance of differences between learning models.

Initial analysis of pre-test scores use ANOVA showed a statistically significant difference in students' initial problem-solving abilities across the three learning groups, namely <0.01 ($p < 0.05$), which indicates unequal baseline conditions. Given these baseline differences, direct comparisons of post-test scores were considered insufficient to determine instructional effectiveness. Therefore, learning improvement was primarily evaluated using normalized gain (N-Gain) scores to account for initial disparities. The pre-test analysis revealed a statistically significant difference in students' initial problem-solving abilities across the groups. The significant difference in pre-test scores further supports the notion that students from different academic programs enter the course with distinct prior knowledge structures, reinforcing the importance of examining instructional effectiveness across disciplinary contexts rather than assuming homogeneous learners. However, this baseline disparity also necessitates cautious interpretation of comparative outcomes and underscores the need for analytical approaches that account for initial differences.

Given the significant baseline differences among groups, learning improvement was evaluated using normalized gain (N-Gain) scores. The mean N-Gain values were 0.57 for TBL, 0.59 for TPS, and 0.40 for traditional learning. The Wilcoxon Signed-Rank Test was conducted to examine within-group changes in students' problem-solving ability between the pre-test and post-test. The results indicated a statistically significant improvement in students' problem-solving scores after the instructional intervention ($Z = -7.300$, $p < 0.001$). Higher post-test scores than pre-test scores, while no cases showed a decrease and only two cases remained unchanged, and the dominance of positive ranks (mean rank = 35.50) confirms that the instructional interventions collectively led to substantial gains in students' problem-solving performance in elementary linear algebra.

A Kruskal-Walli's test revealed a statistically significant difference in N-Gain among the instructional approaches ($p < 0.05$). Post hoc Mann–Whitney tests with Bonferroni correction indicated that TBL resulted in significantly higher learning gains than traditional learning ($p < 0.0167$), whereas differences between TBL and TPS and between TPS and traditional learning were not statistically significant. The significant differences in students' initial abilities across groups, normalized gain (N-Gain) scores were calculated to evaluate relative learning improvement. To examine differences in learning effectiveness among Team-Based Learning, Think-Pair-Share, and traditional instruction, a Kruskal-Walli's test was applied to N-Gain scores, followed by post hoc Mann-Whitney tests with Bonferroni adjustment. This approach allowed for a fair comparison of instructional effectiveness by accounting for unequal baseline performance, consistent with recommendations for quasi-experimental educational research.

To examine whether the instructional approaches yielded differential effects on students' problem-solving improvement, normalized gain (N-Gain) scores were analysed. Normality testing using the Shapiro-Wilk test indicated that the N-Gain distribution violated the normality assumption in at least one group (TPS, $p < .05$), thereby justifying the use of a nonparametric approach. A Kruskal-Wallis H test revealed a statistically significant difference in N-Gain scores among the three instructional methods, $\chi^2(2) = 10.626$, $p = 0.005$. The mean rank values indicated that Team-Based Learning (TBL) produced the highest relative learning gain (mean rank = 44.04), followed by Think-Pair-Share (TPS; mean rank = 40.04), while traditional learning showed the lowest improvement (mean rank = 25.42). These findings demonstrate that the instructional approach significantly influenced students' relative gains in problem-solving ability after controlling for unequal initial performance.

The relative effectiveness of the instructional approaches was further examined using pairwise comparisons of normalized gain (N-gain) scores through the Mann–Whitney U test with Bonferroni adjustment ($\alpha = 0.0167$), due to the non-normal distribution of the data. The results indicated that Team-Based Learning (TBL) yielded significantly higher N-gain scores than traditional learning ($U = 137.000$, $Z = -3.128$, $p = 0.002$), demonstrating a robust advantage of structured team-based instruction. In contrast, although the Think-Pair-Share (TPS) group exhibited higher N-gain scores than the traditional learning group, this difference did not reach statistical significance after Bonferroni correction ($U = 173.000$, $Z = -2.381$, $p = 0.017$). Furthermore, no statistically significant difference was observed between the TBL and TPS groups ($U = 258.000$, $Z = -0.623$, $p = 0.534$). Based on the distribution of mean ranks, the overall sequence of instructional effectiveness was TBL, followed by TPS, and then traditional learning, indicating that collaborative and cooperative strategies tend to promote greater learning gains than conventional instruction, with TBL demonstrating the most consistent impact.

B. Discussion

The initial analysis of pre-test scores revealed statistically significant differences in students' initial problem-solving abilities across the three instructional groups ($p < 0.01$), indicating unequal baseline conditions. This finding is not uncommon in quasi-experimental research involving intact classes from different academic programs (Neitzel et al., 2022), where random assignment is not feasible. Such baseline disparities pose a threat to internal validity if instructional effectiveness is inferred solely from post-test comparisons, as higher post-test performance may partially reflect stronger prior knowledge rather than instructional impact. To address this issue, learning improvement was evaluated using normalized gain (N-Gain) scores, which measure students' relative progress in relation to their initial performance. The use of N-Gain has been widely recommended in educational research as an appropriate metric for comparing learning outcomes across groups with unequal starting points, as it allows instructional effectiveness to be interpreted in terms of proportional improvement rather than absolute achievement (Bao, 2006; Meltzer, 2002; R. Hake, 1998). By normalizing learning gains, this approach mitigates the confounding effect of baseline differences and provides a fairer basis for cross-group comparison.

The results of the Wilcoxon Signed-Rank Test demonstrate a robust and consistent improvement in students' problem-solving ability following the instructional interventions. The overwhelming dominance of positive ranks, indicates that learning occurred across all instructional conditions. This pattern suggests that engagement with elementary linear algebra content regardless of instructional format supported students' cognitive development, particularly in procedural fluency and conceptual understanding. Such improvement is theoretically consistent with Team Based Learning employs small groups that intensively restructure the course to cultivate and leverage the distinct capabilities of high performing learning teams (Huggett & Jeffries, 2014). This team possesses two attributes that provide substantial benefits in educational contexts: the willingness of each member to diligently engage in their learning or tasks, and the team's capacity to address challenges that exceed the abilities of its most skilled members (L. K. Michaelsen et al., 2023). The same thing as research by (Alizadeh et al., 2024; L. K. Michaelsen & Sweet, 2011) which shows that TBL has a positive impact than other active learning on independent learning, learning ability, decision making, emotional intelligence and emphasizes readiness assurance, team accountability and aplication focused problem tasks. Such findings are consistent with prior research showing that structured exposure to problem-solving tasks, feedback, and guided practice can yield significant learning gains (George Polya, 1962; Schoenfeld, 2016). The pairwise comparison of normalized gain scores provides a more nuanced understanding of the relative effectiveness of the instructional approaches after controlling for unequal baseline abilities.

The Kruskal-Walli's test confirmed a statistically significant difference in N-Gain scores among the three instructional approaches ($p < 0.05$), indicating that the type of instructional method significantly influenced students' learning progress after controlling for initial disparities. Subsequent post hoc analyses using Mann-Whitney tests with Bonferroni adjustment revealed that TBL produced significantly higher learning gains than traditional instruction ($p < 0.0167$). In contrast, the differences between TBL and TPS, as well as between TPS and traditional learning, did not reach statistical significance after correction. These findings suggest that while both collaborative approaches support greater learning gains than conventional instruction, the advantage of TBL over traditional learning is the most robust under stringent statistical control. These results suggest that while conventional or traditional instruction can enhance procedural and conceptual understanding, structured collaborative learning environments offer stronger cognitive gains by engaging students in collective reasoning and shared accountability core principles supported by social constructivist learning theory (Vygotsky, 1978).

The pairwise comparison of normalized gain scores provides a more nuanced understanding of the relative effectiveness of the instructional approaches after controlling for unequal baseline abilities. The significantly higher N-gain achieved by the Team-Based Learning (TBL) group compared to traditional instruction indicates that highly structured TBL offers a clear advantage in promoting problem-solving development. This finding aligns with prior research suggesting that TBL's emphasis on permanent teams, individual accountability, and application-focused problem tasks facilitates deeper cognitive processing and sustained engagement (Michaelsen & Sweet, 2011; Hrynchak & Batty, 2012). Think-Pair-Share is a pedagogical approach that promotes active engagement and interaction among students (Rohim & Umam, 2019). This learning enables students to engage in critical thinking, problem-solving, and idea exchange, thereby cultivating diverse mathematical skills and improving collaborative tactics through "pairing" for solution discussions (Alsmadi et al., 2023). Consequently, this learning corresponds with the researchers' findings, which suggest that it can enhance students' problem-solving skills, especially in addressing systems of linear equations. Various active learning strategies employed to improve problem-solving abilities and student engagement encompass roleplay, think-pair-share, and buzz groups, which facilitate students in proposing solutions, articulating ideas through writing and discussion, and addressing problems (Srivatanakul & Annansingh, 2022). Although the Think-Pair-Share (TPS) group demonstrated higher learning gains than the traditional group, the absence of statistical significance after Bonferroni correction suggests that TPS may yield more variable outcomes depending on the depth and consistency of peer interaction. The lack of a significant difference between TBL and TPS further implies that both approaches are pedagogically effective, yet TBL exhibits a more stable and robust impact on learning gains. The superior performance of TBL aligns with prior research indicating that highly structured collaborative frameworks generate stronger higher-order thinking and problem-solving outcomes compared to loosely structured cooperative learning models (Hrynchak & Batty, 2012; L. K. Michaelsen & Sweet, 2011). The significantly higher N-gain achieved by the Team-Based Learning (TBL) group compared to traditional instruction indicates that highly structured team-based learning offers a clear advantage in promoting problem-solving development.

Overall, the observed ranking such as: TBL, followed by TPS, and then traditional learning supports the view that instructional designs incorporating structured collaboration and shared responsibility are more effective for enhancing problem-solving skills than conventional lecture-based approaches. In team-based learning, the presence of an academic superstar is not required for accomplishing tasks or resolving complex team issues. The team members assist one another in comprehending the topic, enabling the team to tackle very tough and intricate challenges that surpass the capabilities of the most proficient pupils in their discipline while working alone (L. K. Michaelsen et al., 1989). Numerous research indicates that the implementation of Team-Based Learning, supported by evidence, yields favourable outcomes for students (Baty & Bruns, 2024; Bruns & Baty, 2023; Carrasco et al., 2021; Chueh & Kao, 2024; Sin, 2022). Team-based learning has four primary components: Team-based learning is conducive to enhancing students' problem-solving capabilities through (1) meticulously structured and administered teams, (2) regular and prompt feedback, (3) problem-solving activities, and (4) peer evaluation among students, (A. W. Burgess et al., 2014; Farland et al., 2013; L. Michaelsen & Richards, 2005; Ofstad & Brunner, 2013) which encompasses a dedicated problem-solving phase. Team-based learning enhances pedagogy in health education (Abdelkhalek et al., 2010), supported by research indicating that students favour active and collaborative learning methods. Additionally, educators are drawn to the integrated approach of team-based learning for fostering students' professional skills, such as leadership, communication, and teamwork. Implementing team-based learning methodologies will produce superior outcomes for educators, learners, and the institution (A. Burgess et al., 2020).

Developing students’ problem-solving ability in higher education is not solely dependent on cognitive mastery of mathematical concepts, but also on the instructional approaches through which learning experiences are structured. Learning models that promote collaboration, interaction, and shared responsibility are increasingly regarded as essential because they shape students’ engagement, persistence, and attitudes toward complex tasks elements that traditional teacher-centered instruction often fails to cultivate effectively. Within this perspective, the improvement of problem-solving skills is understood not only as a product of mental processing, but also as a dynamic outcome influenced by instructional design, emotional engagement, and the social learning environment that supports reflective thinking and active participation. Certain research indicate that cognitive skills diverge from the inclination of instructional attitudes in the classroom; reflection and the advancement of prior learning as essential competencies constitute a gradual accumulation process, whereas the latter, as an attitude, is shaped by the circumstances of the educational setting, such as innovative teaching methods and demanding yet advantageous assignments (Halpern, 2001; Miterianifa et al., 2021).

Differences in disciplinary learning cultures may help explain the observed variation in learning gains between Computer Science students in the experimental groups and Mathematics

Education students in the control group. Computer science students are commonly accustomed to individualised problem-solving practices such as coding and algorithmic reasoning, which emphasise solitary cognitive work rather than sustained peer interaction (Angeli & Giannakos, 2020). The introduction of structured collaborative and cooperative learning therefore may have generated a novelty effect, whereby is grounded in social constructivism and emphasizes knowledge construction through dialogue, negotiation of meaning, and shared intellectual authority within communities of learners. This orientation aligns closely with the learning culture of Computer Science students, who are often trained in individual problem-solving and algorithmic reasoning; when introduced to collaborative environments, these students may experience heightened cognitive engagement through the externalization and negotiation of reasoning, producing a strong instructional impact (Bruffee, 1973, 1984, 1995a, 1995b; Yang, 2023). Cooperative learning characterized by structured group roles, division of labor, individual accountability, and clearly defined outcomes (Johnson & Johnson, 1998; Slavin, 1995; Yang, 2023) resonates with the pedagogical traditions of Mathematics Education programs, where students are typically accustomed to guided discussion, scaffolded group work, and instructional routines emphasizing shared responsibility. Consequently, while both approaches support problem-solving development, collaborative learning may generate stronger novelty and engagement effects for Computer Science students, whereas cooperative learning may reinforce and extend existing learning practices among Mathematics Education students.

In contrast, Mathematics Education students in the traditional learning condition experienced more instructor-centered approaches that emphasize transmission of formal procedures and worked examples, potentially limiting opportunities for sustained peer interaction and collective reasoning. Consequently, the superior learning gains observed in the Computer Science groups suggest that collaborative and cooperative learning models are especially effective in fostering problem-solving development when students are systematically engaged in social interaction and shared cognitive responsibility, highlighting the pedagogical advantage of interactive learning designs over traditional instruction in elementary linear algebra.

IV. Conclusion

This study investigated the effectiveness of Team-Based Learning (TBL), Think-Pair-Share (TPS), and Traditional Learning in enhancing students' problem-solving abilities in elementary linear algebra, while accounting for unequal baseline abilities across instructional groups. The findings demonstrate that all three instructional approaches contributed to significant improvements in students' problem-solving performance; however, the magnitude of learning gains differed across methods. After controlling for initial disparities using normalized gain (N-Gain) analysis, Team-Based Learning consistently produced the highest relative learning gains, followed by

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Think-Pair-Share, while traditional instruction yielded the lowest improvement. Thus, in terms of relative effectiveness, the instructional sequence can be concluded as TBL > TPS > Traditional Learning.

From a practical perspective, these results suggest that lecturers teaching elementary linear algebra particularly in Computer Science programs should prioritize structured collaborative approaches such as Team-Based Learning, as its emphasis on permanent teams, individual accountability, and application-focused problem tasks appears to foster deeper problem-solving development. Think-Pair-Share remains a viable alternative for promoting active engagement and peer discussion, especially in settings with limited instructional resources or time constraints, while traditional lecture-based instruction may be more suitable for introducing foundational concepts but should be complemented with interactive elements to maximize learning gains.

Several limitations should be acknowledged. The study employed a quasi-experimental design with intact classes from different academic programs and cohorts, resulting in significant baseline differences that limit causal generalization. Although N-Gain analysis mitigated this issue, the findings reflect relative rather than absolute instructional effectiveness. In addition, the sample size was modest, the intervention duration was relatively short, and the exclusive reliance on quantitative measures constrained insight into the underlying learning processes.

Despite these limitations, this study contributes to mathematics education research by providing empirical evidence on the comparative effectiveness of collaborative and cooperative learning models in higher education contexts with heterogeneous learners. The findings underscore the importance of aligning instructional design with students' disciplinary learning cultures and prior experiences. Future research is recommended to employ randomized or matched-group designs within comparable cohorts, incorporate longitudinal assessments to examine retention and transfer of problem-solving skills, and integrate qualitative data to better elucidate how collaborative learning mechanisms influence students' cognitive development.

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