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Problem-based learning in basic mathematics modules: Effects on computational thinking and mathematical resilience

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Abstract

The simultaneous development of computational thinking skills and mathematical resilience remains a challenge in basic mathematics learning in higher education, primarily due to the limited number of interventions that empirically examine the relationship between the two after learning. This study aims to analyze the effect of a project-based learning (PBL)-based basic mathematics module on students' computational thinking skills and mathematical resilience, as well as the relationship between the two constructs after the intervention. This study employed a quasi-experimental method with a single-group pretest-posttest design involving 31 students. Data were collected through a computational thinking test and a mathematical resilience questionnaire and then analyzed using descriptive statistics, normality tests, paired t-tests, effect sizes, and Pearson correlations. The results demonstrated a significant increase in computational thinking skills ($t(30) = -13.348$, $p < 0.001$, $d = 2.397$) and mathematical resilience ($t(30) = -13.338$, $p < 0.001$, $d = 2.396$), but no significant relationship was found between the two ($r = 0.053$, $p = 0.777$). These findings indicate that the PBL module is effective in improving both abilities separately, suggesting that a more integrative learning design is necessary to connect the development of both simultaneously.

Keywords: basic mathematics modules; computational thinking; mathematical resilience; problem-based learning

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Introduction

Mathematics, a fundamental subject, plays a pivotal role in cultivating students' logical and analytical thinking abilities, particularly in electrical engineering study programs. Despite its significance, challenges in mathematics learning persist, encompassing inadequate conceptual comprehension and a deficiency in computational thinking skills. Numerous studies indicate that students frequently encounter difficulties in connecting mathematical concepts to practical applications, leading to diminished motivation and suboptimal learning outcomes (Saha et al., 2024; Bengmark et al., 2017).

Computational thinking is the systematic process of comprehending problems, reasoning, and devising solutions. This skill encompasses the formulation of problems, the development of solutions, and the application of algorithms to their resolution. Computational thinking transcends the confines of computer science and finds practical applications in everyday life. Individuals who excel in this domain exhibit enhanced logical, structured, and critical thinking abilities when confronted with problem-solving challenges (Çavuş et al., 2025; Weng et al., 2024; Montuori et al., 2024; Yang et al., 2021).

Computational thinking skills are crucial for students to analyze data, develop business strategies, and solve problems systematically. These skills support data-driven decision-making, identify business trends, and implement technology and automation, thereby preparing them to face the digital and competitive workforce creatively, efficiently, and innovatively. Furthermore, computational thinking enhances problem-solving, innovation, and collaboration skills (Fitriani & Annur, 2024; Wijoyo et al., 2024; Sofyan et al., 2024). Despite the significance of computational thinking, many college students still possess weak and inadequate skills in this area (Yang et al., 2021). For instance, Kamil (2021) discovered that over 40% of students exhibit low computational thinking skills.

In addition to computational thinking skills, resilience emerges as a pivotal factor in student academic success, particularly within foundational mathematics courses. Resilience in learning encompasses the capacity to persevere in the face of academic challenges. This resilience enables students to overcome obstacles, sustain motivation, and adapt to achieve their objectives. With resilience, students possess the ability to recover from setbacks and continue their learning process successfully (Sari & Suhariadi, 2019; Reskido, 2023; Az-Zahra et al., 2024). Resilience is of paramount importance for students encountering academic challenges and navigating the competitive business landscape. This skill facilitates stress management, adaptability, and sustained motivation. With resilience, students are better equipped to tackle problems and make informed decisions in professional settings (Retno, 2021; Aula et al., 2022; Yusrin & Kurniaty, 2023; Susanti & Aprianto, 2025).

The basic mathematics module can be utilized to develop computational thinking skills and resilience among electrical engineering students. By employing structured materials, students are better equipped to analyze problems systematically, identify logical solutions, and cultivate resilience in confronting academic and professional challenges (Syahputra & Sinaga, 2024; Ariesandi et al., 2021; Fatimah & Lubis, 2021). However, existing basic mathematics modules are generally conventional and do not adequately address the needs of students in developing computational thinking skills and resilience (Fatimah & Lubis, 2021; Sausan et al., 2024). Consequently, the development of basic mathematics modules based on Problem-Based Learning (PBL) is imperative, as it is systematically designed to enhance both aspects.

Problem-Based Learning (PBL) stands as an effective pedagogical approach for enhancing conceptual comprehension and computational thinking abilities in mathematics education. Specifically, it fosters the capacity to comprehend, design, and resolve problems systematically employing computational principles (Andayani & Pratama, 2022; Perdana et al., 2023; Ndraha et al., 2024). This model places students at the forefront of learning by presenting them with real-world problems that necessitate independent or collaborative problem-solving. Notably, PBL has demonstrated its efficacy in augmenting student resilience. Through PBL, students encounter real-world challenges that compel them to exercise independent thinking, seek innovative solutions, and confront obstacles and uncertainties inherent in the learning process. In the face of difficulties, students develop resilience, adaptive problem-solving strategies, and an unwavering determination, ultimately contributing to their academic and professional success (Hutauruk, 2019; Fertikawati et al., 2024).

This study examines the development of computational thinking and mathematical resilience in basic mathematics courses through the lens of electrical engineering students as a critical case study. Electrical engineering inherently necessitates intensive engagement with mathematical modeling, algorithmic reasoning, and problem-solving in complex and often abstract contexts. These characteristics render it an appropriate setting for observing how students integrate computational thinking processes with persistence and adaptability in the face of mathematical challenges. Consequently, investigating this population serves as a meaningful testing ground for evaluating the efficacy of PBL-based interventions in fostering both constructs.

Despite the increasing interest in Project-Based Learning (PBL), empirical studies investigating its impact on computational thinking and mathematical resilience, as well as the correlation between these two constructs in higher education settings, remain limited. Based on the aforementioned considerations, this study seeks to investigate the impact of integrating Problem-Based Learning (PBL) into basic mathematics modules on students' computational thinking abilities and mathematical resilience. To attain this objective, the study is guided by the following research questions: (1) To what extent does the utilization of PBL-based basic mathematics modules enhance students' computational thinking skills? (2) To what extent does the utilization of PBL-based basic mathematics modules enhance students' mathematical resilience? and (3) Is there a statistically significant correlation between students' computational thinking skills and their mathematical resilience following participation in PBL-based learning?

Methods

This study employed a quantitative approach with a quasi-experimental design, specifically a one-group pretest–posttest design. This design was selected to investigate the impact of utilizing a basic mathematics module grounded in Problem-Based Learning (PBL) on students' computational thinking abilities and mathematical resilience, and to ascertain the correlation between these two competencies following the learning intervention. The one-group pretest–posttest design enables researchers to compare the initial and final conditions of the study participants after receiving the identical learning intervention, thereby allowing any observed changes to be attributed to the treatment (Creswell & Creswell, 2018).

The research subjects comprised second-year electrical engineering students enrolled at a private university in Medan City, North Sumatra. The selection of subjects was based on a purposive sampling technique, as these students exhibited characteristics pertinent to the research objectives, particularly in the context of cultivating higher-order thinking abilities and adaptive attitudes in mathematics education. The study was conducted during the current semester of a specific academic year, with learning durations customized to the content covered within the developed module.

In this study, the treatment employed a basic mathematics module grounded in Problem-Based Learning (PBL). The module was meticulously designed to internalize the fundamental stages of PBL, encompassing problem orientation, learning organization, independent and group investigation, solution development and presentation, and reflection on the problem-solving process. PBL was selected due to its empirical evidence demonstrating its ability to foster active student engagement, enhance problem-solving proficiency, and cultivate higher-order reasoning through meaningful contextual problems (Hmelo-Silver, 2004; Savery, 2015). Within the realm of mathematics education, PBL is also recognized for its efficacy in facilitating students' acquisition of conceptual comprehension and the development of systematic thinking strategies.

In this study, the independent variable was the utilization of a basic mathematics module grounded in Problem-Based Learning. The dependent variables encompassed students' computational thinking abilities and mathematical resilience. Furthermore, the study concentrated on examining the correlation between computational thinking skills and mathematical resilience following students' participation in the learning process facilitated by the module. Computational thinking is conceptualized as a cognitive skill set encompassing problem decomposition, pattern recognition, abstraction, and algorithm design, which are pertinent to supporting systematic mathematical problem-solving (Wing, 2006; Weintrop et al., 2016). Conversely, mathematical resilience pertains to students' positive attitudes towards mathematical challenges, encompassing perseverance, self-confidence, and the capacity to recover from learning difficulties (Johnston-Wilder & Lee, 2010).

The research instruments comprised a computational thinking ability test and a mathematical resilience questionnaire. The computational thinking test was meticulously designed using a comprehensive rubric that evaluates four key cognitive processes: decomposition, pattern recognition, abstraction, and the development of rudimentary algorithms in problem-solving. This test is an essay-based assessment comprising four distinct questions.

In contrast, the mathematical resilience questionnaire was meticulously crafted using a 1-5 Likert scale to gauge students' attitudes towards challenges and difficulties encountered during their mathematical learning journey. This questionnaire comprises 28 items, drawing inspiration from the theoretical framework developed by Johnston-Wilder & Lee (2010).

To ensure the measurement consistency of all instruments, rigorous validity and reliability testing procedures were implemented. Validity testing was conducted employing product-moment correlation, yielding valid results. Reliability testing, on the other hand, was conducted using Alpha-Cronbach's, resulting in reliable outcomes. The Cronbach's Alpha reliability coefficients for the two instruments were 0.695 and 0.478, respectively.

Data collection was conducted through pretest and posttest assessments of computational thinking skills, as well as the mathematical resilience questionnaire. These assessments were administered after students completed a series of learning sessions utilizing a PBL-based basic mathematics module. The collected data underwent descriptive analysis to elucidate the students' ability profiles, followed by a prerequisite analysis test. To ascertain the impact of module utilization on computational thinking skills and mathematical resilience, a paired sample t-test or an equivalent nonparametric test was employed to determine the disparity between pretest and posttest scores. Additionally, a correlation analysis was conducted to identify the correlation between computational thinking skills and students' mathematical resilience following the learning intervention. To augment the inferential analysis, an effect size was also calculated to determine the magnitude of the influence of the PBL-based module utilization (Field, 2018).

Results

This section presents the results of a study examining the effects of a PBL-based basic mathematics module on students' computational thinking skills and mathematical resilience. The findings are presented systematically, commencing with a descriptive analysis that provides an overview of the data distribution and central tendency. This is followed by prerequisite testing to verify statistical assumptions, parametric statistical analysis to assess the intervention's efficacy, and correlation analysis to investigate the relationship between the two measured variables. The results are subsequently interpreted and discussed in the context of relevant theoretical perspectives and previous empirical studies.

Descriptive analysis

Table 1 presents descriptive statistics on students' computational thinking skills and mathematical resilience. The table includes the mean, standard deviation, and minimum and maximum scores as indicators of data distribution.

Table 1. Descriptive statistics on pretest and posttest measurements (N = 31)

Variable	n	*M*	*SD*	Min	Max
PreTest CT	31	60.38	7.009	46.70	74.60
PostTest CT	31	70.44	7.104	60.00	88.30
PreTest MR	31	3.123	0.386	2.20	3.73
PostTest MR	31	3.729	0.488	3.00	4.80

Table 1 shows the average score for the Computational Thinking Ability (CT) variable increased from 60.38 (SD = 7.009) to 70.44 (SD = 7.104). This 10.06-point increase was supported by an increase in the group's minimum score from 46.70 to 60.00, indicating inclusive progress. Conversely, for the Mathematical Resilience (MR) variable, the average score also increased from 3.12 (SD = 0.386) to 3.73 (SD = 0.488) on a scale of 1-5. This increase suggests a shift in participants' self-perception from the 'adequate' category to the 'good' category. Notably, the data distribution exhibited a different pattern: the variation in CT scores remained stable, while the variation in MR scores tended to widen after the intervention. The visual distribution of these scores (as depicted in Distribution Plots) in Figures 1 and 2 further substantiates these numerical findings.

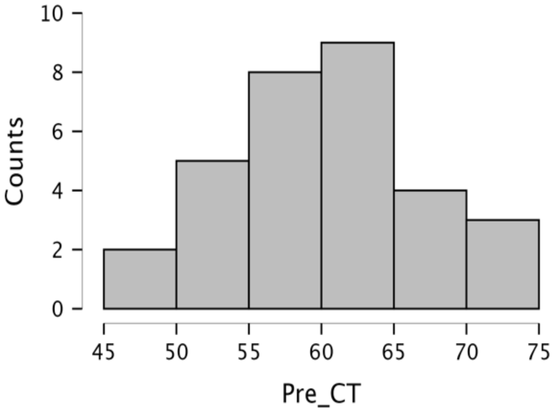

Figure 1. Pretest score for computational thinking ability

In contrast, the plot for Pre-CT exhibits a peak distribution centered around the value 60, whereas the plot for Post-CT demonstrates a distinct shift of the peak to approximately the value 70.

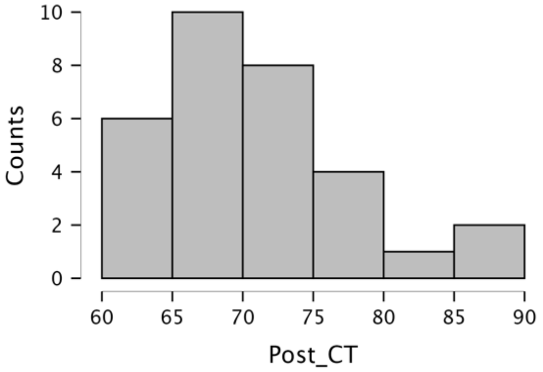

Figure 2. Posttest score for computational thinking ability

Furthermore, it can be observed that after the intervention, no participants clustered in the very low score range (below 60), visually confirming the improvement at the lower end of the group. This pattern indicates that the improvement in ability occurred evenly across all levels of participants, with the distribution maintaining its shape and relative spread but at higher levels of achievement. Distribution plots for resilience can be seen in Figures 3 and 4.

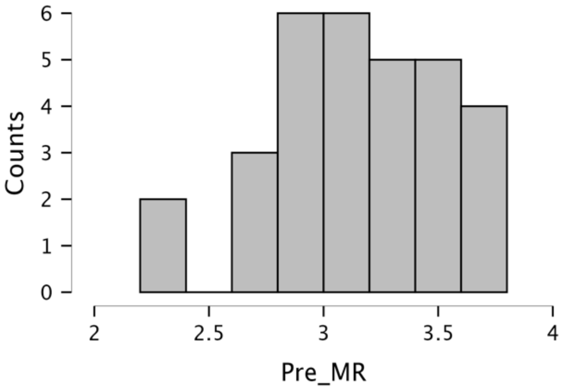

Figure 3. Pretest scores for mathematical resilience

The Pre_MR plot exhibits a distribution characterized by a relatively flat shape and a wide spread across the score range of 2.5 to 4.0.

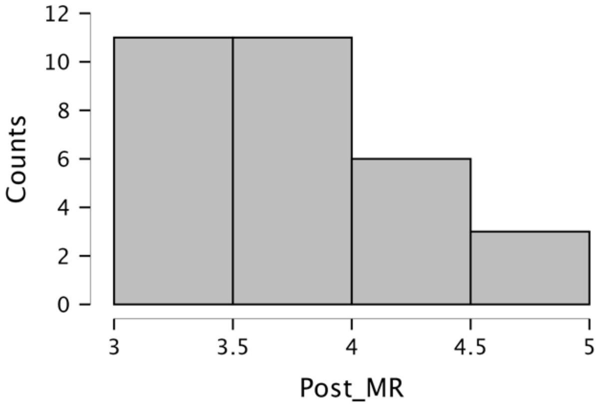

Figure 4. Posttest scores for mathematical resilience

In contrast, the Post_MR plot reveals a significant shift in the distribution's shape. The distribution exhibits a sharp rightward shift, with a prominent peak concentrated around scores of 3.7 to 4.0. Notably, the left-hand tail of the distribution, representing low scores, virtually disappears. This visual observation is attributed to the increase in the minimum score from 2.20 to 3.00. The concentration of the majority of participants within this high-score range suggests that the intervention was effective in fostering stronger and more homogeneous perceptions of resilience at the upper levels. However, it is important to note that some participants achieved exceptionally high levels, which contributed to an increase in the group variance (SD). Consequently, the intervention not only elevated the mean score but also fundamentally altered the distribution of participants' attitudes toward mathematical resilience. Initially characterized by diverse and scattered perceptions, the distribution now exhibits a concentration on positive perceptions.

Pre-requisite testing

Following the presentation of descriptive statistics, a data normality test (as depicted in Table 2) was conducted to ascertain whether the distribution of students' computational thinking ability scores adhered to a normal distribution. This assessment facilitated the suitability of employing parametric statistical tests.

Table 2. Results of the normality test of computational thinking ability and mathematical resilience

Variable	W	p
Pre_CT	0.892	0.723
Post_CT	0.988	0.971
Pre_MR	0.974	0.897
Post_MR	0.965	0.392

As a prerequisite for parametric analysis, the Shapiro-Wilk normality test was conducted on the computational thinking and mathematical resilience scores. The test results (Table 2) indicate that the data distribution in both the initial condition (Pre_CT & Pre_MR) and the final condition (Post_CT & Post_MR) did not significantly deviate from the normal distribution (all $p > .05$). Similarly, the mathematical resilience scores also met the normality assumption. Consequently, the normality assumption was satisfied for further parametric statistical analysis.

Parametric statistical tests

Additionally, the results of the paired sample t-test and the effect size of students' computational thinking skills are presented in Table 3.

Table 3. Paired samples t-test results for comparison of scores before and after intervention

Measure	Comparison	*t*	*df*	*p*	Cohen's d	SE	95% CI for Cohen's d
CT	Post – Pre	13.348	30	< .001	2.397	0.209	[1.693, 3.091]
MR	Post – Pre	13.338	30	< .001	2.396	0.188	[1.692, 3.098]

To assess the efficacy of the intervention, a Paired Samples T-Test was conducted on the pre-test and post-test scores. The analysis results (Table 3) demonstrated a statistically significant increase in both variables. In Computational Thinking Skills, the post-test score surpassed the pre-test score, $t(30) = 13.348$, $p < .001$, with a substantial effect size (Cohen's $d = 2.397$, 95% CI [1.693, 3.091]). The identical pattern was observed in Mathematical Resilience, $t(30) = 13.338$, $p < .001$, $d = 2.396$, 95% CI [1.692, 3.098]. These findings suggest that the implemented intervention not only successfully enhanced participants' cognitive competence but also effectively fostered a more positive resilient attitude towards mathematics, with comparable and highly effective levels in both domains.

Subsequently, a correlation analysis was conducted to ascertain the extent of correlation between students' computational thinking abilities and mathematical resilience following the implementation of the problem-based learning module. The findings of the correlation analysis are presented in Table 4.

Table 4. Results of pearson correlation analysis between CT and MR scores

Variable	*n*	*t*	95%CI	*t*(*df*)	*p*
Post_CT with Post_MR	31	.053	[-0.307, 0.400]	0.287(29)	.777

The Pearson correlation coefficient (r) obtained was 0.053, indicating no significant linear relationship between the two variables. The positive direction of the correlation (+ sign) suggests a tendency for increases in CT to be accompanied by increases in MR, but the strength of this relationship is weak and can be disregarded.

The resulting p-value is 0.777, which is significantly greater than the significance level of $\alpha = 0.05$. Consequently, the observed relationship is not statistically significant. In other words, there is insufficient evidence in this sample data to conclude that there is a genuine correlation (relationship) between Post_CT and Post_MR. The 95% confidence interval for the population correlation coefficient is -0.307 to 0.400, encompassing 0 within its range. This further reinforces the conclusion that the true correlation in the population is likely zero (no relationship) or very weak.

The effect size based on Fisher's z transformation is 0.053, which aligns with the very small r value. According to Cohen's (1988) criteria, an r value of approximately 0.10 is considered a small effect. This value of 0.053 is even below the threshold for a small effect, categorizing it as having no practically meaningful relationship.

Based on the data analysis, this study yielded three main findings. First, the utilization of a basic mathematics module based on Problem-Based Learning (PBL) was demonstrated to have a significant and substantial impact on enhancing students' computational thinking abilities. This was evidenced by an increase in the average score from 60.38 to 70.44, accompanied by a substantial effect size (Cohen's $d = 2.397$). This improvement was observed not only at the group average but also at the lower limit of ability, as reflected in the increase in the minimum score from 46.70 to 60.00, indicating inclusive progress.

Second, the application of a PBL-based module also had a significant and substantial impact on students' mathematical resilience. The average resilience score increased from 3.12 to 3.73 on a scale of 1–5, with an effect size equivalent to that of computational thinking skills (Cohen's $d = 2.396$). This change was accompanied by a fundamental shift in the score distribution, from a relatively dispersed distribution at the initial measurement to a concentration in the high-score range at the final measurement.

Third, no significant relationship was identified between students' computational thinking skills and mathematical resilience following the learning intervention. The very small Pearson correlation coefficient ($r = 0.053$, $p = .777$) suggests that the two variables developed relatively independently, although both significantly improved as a result of the learning intervention.

Discussion

The impact of problem-based learning modules on computational thinking abilities

The findings of this study demonstrate that the implementation of a Problem-Based Learning (PBL) module resulted in substantial enhancements in students' computational thinking (CT) abilities, evidenced by a substantial effect size (Cohen's $d = 2.397$). This discovery reinforces empirical evidence suggesting that PBL is an effective pedagogical approach for cultivating higher-order thinking skills, encompassing problem decomposition, pattern recognition, abstraction, and algorithmic thinking (Weintrop et al., 2016; Wing, 2006). As Hmelo-Silver (2004) elucidates, the core principle of PBL lies in presenting intricate problems as authentic learning catalysts, thereby engaging students in a profound cycle of inquiry, strategic planning, and evaluation.

The notable increase in the minimum CT score (from 46.70 to 60.00) signifies that this module functioned as an effective cognitive scaffold, particularly for participants with lower initial proficiency levels. This aligns with research conducted by Hmelo-Silver et al. (2007), which posits that well-structured PBL can provide the requisite support to mitigate achievement disparities among students. Furthermore, the constancy of the standard deviation (SD) from Pre-CT (7.009) to Post-CT (7.104) indicates that improvements transpired relatively uniformly across the group without exacerbating the variation in ability. This implies that the intervention successfully elevated collective achievement without exclusively benefiting high-ability students, thereby reflecting equity and inclusiveness in the learning process (Savery, 2015).

The impact of problem-based learning modules on mathematical resilience

In addition to cognitive impacts, this study demonstrated that Problem-Based Learning (PBL)-based learning significantly improved students' mathematical resilience (MR) with a very strong effect size (Cohen's d = 2.396). The increase in the average score from 3.12 to 3.73 on a scale of 1-5 reflects a shift in participants' self-perceptions from "fair" to "good." More importantly, the change in score distribution—from a relatively flat and scattered score to a high score (3.7–4.0)—indicates that the intervention successfully developed a more homogeneous and positive resilience attitude.

This improvement can be explained by the characteristics of PBL, which creates a learning environment that normalizes productive struggle, namely the productive effort to face mathematical challenges. Boaler (2016) emphasized that the experience of overcoming difficulties in a supportive context helps students view temporary failure as an integral part of the learning process, rather than as an indicator of incompetence. Thus, they develop stronger beliefs in their own ability to survive and thrive (Johnston-Wilder & Lee, 2010). However, the increase in the Post-MR standard deviation (0.488) compared to the Pre-MR (0.386) suggests that internalization of resilience is individual, possibly influenced by factors such as self-efficacy, prior learning experiences, and mathematical beliefs (Bandura, 1997). This suggests that although PBL is generally effective, each individual's affective response to the intervention may vary.

The interplay between computational thinking abilities and mathematical resilience

An intriguing finding from this study was the absence of a significant linear correlation between computational thinking skills (Post-CT) and mathematical resilience (Post-MR) following the intervention (r = 0.053, p = 0.777). This result suggests that, despite both experiencing significant and substantial improvements, their development occurred relatively independently.

This finding aligns with the perspective that the cognitive and affective domains of mathematics learning are not always directly correlated or develop linearly (Hannula, 2012). In the context of Problem-Based Learning (PBL), enhancements in CT are likely mediated through structured cognitive processes such as problem analysis and algorithm design, while improvements in MR are more influenced by emotional and reflective experiences in confronting and overcoming challenges. As Di Martino and Zan (2010) elucidated, improvements in mathematics achievement do not automatically translate into changes in attitudes, and vice versa. Consequently, the absence of correlation in this study is not a limitation, but rather contributes to our comprehension of how PBL influences various dimensions of learning through distinct mechanisms.

Nevertheless, several limitations of this study warrant acknowledgment to provide appropriate context for interpreting the findings and guiding subsequent research. Firstly, the study employed a one-group pretest-posttest design without a comparison group. Although the observed improvements were substantial and statistically significant, this design cannot fully control for external factors (such as historical or maturational effects) that may have contributed to the changes (Cook & Campbell, 1979). Secondly, the relatively small sample size (N=31) and its origin from a single institutional context restrict the generalizability of the findings. Replication with larger, more diverse samples from multiple institutions is necessary to ascertain the robustness of these findings. Thirdly, the mathematical resilience measurement relied on a self-report instrument, which, while commonly utilized, can be influenced by social desirability bias and participants' subjective perceptions (Pintrich, 2003). Future research could enhance the data by incorporating mixed methods, such as interviews or observations, to gain a more comprehensive understanding of the resilience-building process. Finally, this study exclusively measured short-term impacts immediately following the intervention. The sustainability of enhanced computational thinking skills and mathematical resilience in the long term remains an empirical question that necessitates testing through longitudinal studies.

Conclusion

Collectively, the findings of this study underscore the potential of a problem-based learning (PBL)-based module as an effective and multifaceted intervention. This module not only significantly and uniformly enhanced cognitive competence (computational thinking) but also effectively cultivated a more positive attitude towards resilience (mathematical resilience). The fact that these two improvements transpired without a strong correlation affirms that PBL can facilitate development in distinct domains simultaneously but through distinct pathways. Consequently, educators and curriculum designers can confidently utilize PBL, knowing that this approach can support students' holistic development, encompassing both cognitive skills and affective dispositions towards academic challenges.

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Declarations

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