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Participatory Action Research on the Implementation of STEAM-Integrated Problem-Based Learning

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Abstract

This study aimed to examine the implementation of a STEAM-based Problem-Based Learning (PBL) approach in mathematics learning to enhance students' engagement, creativity, and problem-solving abilities. The research was conducted at SMP Negeri 26 Makassar using a Participatory Action Research (PAR) framework involving collaboration between university researchers, pre-service teachers, and the classroom teacher. The learning activities focused on the topic of arithmetic sequences and were designed following the stages of the PBL model integrated with STEAM elements (Science, Technology, Engineering, Arts, and Mathematics). Students worked collaboratively in small groups to analyze contextual problems, formulate hypotheses, conduct investigations using digital tools, and communicate their findings through digital presentations. Data were collected through classroom observations, learning artifacts, student presentations, and formative assessment results. Descriptive statistical analysis of the formative test scores showed that the average student score reached 92.5, with a median and mode of 90, indicating strong academic performance and relatively consistent achievement among students. The findings revealed that the STEAM-based PBL approach effectively promoted active participation, collaborative inquiry, and deeper conceptual understanding of arithmetic sequences. The integration of digital tools and interdisciplinary learning activities also supported the development of students' critical thinking and communication skills. These results suggest that integrating STEAM within a PBL framework can provide meaningful and engaging mathematics learning experiences while improving students' problem-solving abilities and overall learning outcomes.

INTRODUCTION

Mathematics education seeks to provide learners with meaningful learning experiences that promote conceptual understanding, relational thinking, and the ability to apply mathematical knowledge in authentic real-life contexts. Nevertheless, mathematics continues to be perceived by many students as a challenging subject, often leading to misconceptions and difficulties in problem-solving processes (Aguilera & Ortiz-Revilla, 2021; Li et al., 2023). Recent studies indicate that students frequently struggle to connect abstract mathematical concepts with practical applications, limiting their ability to transfer knowledge beyond classroom settings. Furthermore, insufficient integration of digital technologies within mathematics instruction reduces opportunities for students to experience contextualized and interactive learning environments aligned with contemporary educational demands (Bond et al., 2020; OECD, 2023). These challenges are largely attributed to instructional practices that remain teacher-centered and lack innovative pedagogical designs capable of fostering engagement, conceptual understanding, and higher-order thinking skills among learners (Chiu et al., 2022; Rasheed et al., 2020).

In response to these persistent challenges, contemporary education has increasingly emphasized the adoption of innovative pedagogical approaches designed to cultivate creativity, critical thinking, collaboration, and problem-solving competencies required in the 21st century. Among these approaches, Problem-Based Learning (PBL) has gained significant attention as a student-centered instructional model that engages learners in solving authentic and context-based problems through inquiry and collaborative investigation. Recent studies highlight that integrating PBL with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach provides meaningful interdisciplinary learning experiences that promote deeper conceptual understanding and real-world application of knowledge (Li et al., 2023; Perignat & Katz-Buonincontro, 2021). STEAM-integrated learning environments enable students to connect mathematical concepts with scientific reasoning, technological tools, engineering design processes, and creative thinking practices, thereby strengthening higher-order thinking and collaborative learning skills (Herro et al., 2022; Quigley et al., 2020). Consequently, the integration of PBL and STEAM is increasingly recognized as an effective framework for supporting holistic learning experiences that prepare students to address complex and interdisciplinary problems in modern educational contexts.

Furthermore, STEAM-based learning environments have been widely recognized for supporting the development of essential 21st-century competencies, including creativity, critical thinking, collaboration, and communication skills (Djam'an, 2025). Through interdisciplinary exploration integrating science, technology, engineering, arts, and mathematics, students actively construct knowledge while engaging in authentic and innovative learning experiences that enhance motivation and participation (Djam'an et al., 2024). Recent studies emphasize that STEAM learning promotes learner autonomy and meaningful engagement by connecting disciplinary knowledge with real-world contexts and technological applications (Herro et al., 2022; Li et al., 2023; Thibaut et al., 2021). Within this interdisciplinary framework, Problem-Based Learning (PBL) plays a crucial role by positioning students as active problem solvers who collaboratively investigate contextual problems, communicate ideas, and apply analytical reasoning to develop feasible solutions. Empirical evidence suggests that integrating PBL with STEAM significantly improves mathematical problem-solving performance and creative thinking through inquiry-oriented and collaborative learning processes (Cheng et al., 2023; Perignat & Katz-Buonincontro, 2021).

Recent empirical investigations have demonstrated the positive impact of STEAM-integrated Problem-Based Learning (PBL) on students' higher-order thinking skills and adaptive learning capacities. For instance, Kwon et al. (2022) found that STEAM–PBL enhances students' creativity and collaborative problem-solving through project-based and experiential learning activities. Similarly, Margot and Kettler (2022) reported that interdisciplinary STEAM instruction strengthens students' resilience and adaptive responses when addressing complex mathematical challenges.

However, most of these studies primarily focus on general outcomes and are often conducted in well-resourced or higher education settings, with limited attention to how STEAM-integrated PBL is implemented in actual classroom practices at the junior secondary level. In particular, there is a lack of empirical evidence that documents the *process of implementation*, including how teachers and students engage in STEAM-integrated PBL activities and how such practices are adapted within developing educational contexts.

Furthermore, studies employing a Participatory Action Research (PAR) approach to systematically examine the iterative implementation, reflection, and improvement of STEAM-integrated PBL in mathematics classrooms are still scarce. This gap highlights the need for context-specific and process-oriented investigations that not only examine learning outcomes but also capture how STEAM-integrated PBL is enacted in real classroom settings.

In this regard, SMP Negeri 26 Makassar was selected as the research setting due to its growing commitment to implementing innovative instructional practices in mathematics education. While prior research has largely concentrated on STEAM applications in higher education or specialized programs, evidence concerning its implementation in junior secondary mathematics classrooms is still relatively scarce. Therefore, this study investigates how the integration of Problem-Based Learning with the STEAM approach can enhance students' creative thinking and mathematical problem-solving abilities while identifying challenges encountered during classroom implementation.

Accordingly, this study aims to explore the implementation of STEAM-based Problem-Based Learning in junior secondary mathematics education and examine its benefits and challenges in promoting students' creativity and problem-solving skills. The findings are expected to provide practical insights into effective STEAM–PBL integration and offer evidence-based recommendations for educators seeking to implement innovative, student-centered instructional approaches that improve engagement and learning outcomes in mathematics classrooms.

Based on the research objectives and the identified gap, this study addresses the following research question: How is STEAM-integrated Problem-Based Learning (PBL) implemented in mathematics classrooms through a Participatory Action Research (PAR) approach to support students' learning of arithmetic sequences?

METHODS

1. Research Design

This study adopted a descriptive qualitative approach within a Participatory Action Research (PAR) framework following Kemmis and Wilkinson (Atweh, Kemmis, & Weeks, 1998), which emphasizes collaborative inquiry through iterative cycles of planning, action, observation, and reflection (Figure 1). The study aimed to examine the implementation of a Problem-Based Learning (PBL) model integrated with the STEAM approach (Science, Technology, Engineering, Arts, and Mathematics) in mathematics learning at SMP Negeri 26 Makassar, with a focus on fostering students' creative thinking and problem-solving skills.

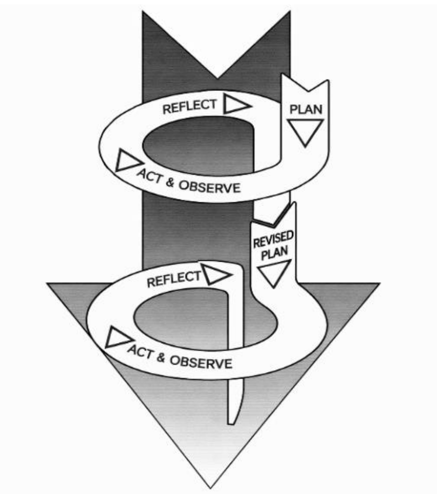

Figure 1. The Kemmis and Wilkinson Action Research Cycle

Prior to implementation, pre-service teachers collaboratively worked with the research team, consisting of two university lecturers and the classroom teacher, to design STEAM-oriented learning activities. This preparatory phase included classroom observations, analysis of the mathematics content, and identification of students' learning needs, which informed the joint development of lesson plans and student worksheets aligned with the PBL–STEAM framework. The study was conducted through one action research cycle consisting of planning, action, observation, and reflection. Consistent with the participatory principles of PAR, ongoing dialogue and reflective discussions among university researchers, pre-service teachers, and the classroom teacher were maintained throughout the cycle to refine the instructional design and evaluate the learning process.

2. Participants

The participants in this study were 26 students from a selected class at SMP Negeri 26 Makassar who took part in mathematics learning implemented through the PBL–STEAM model during the second semester of the 2024/2025 academic year. The class was selected because its learning schedule corresponded with the topic targeted for the intervention. The specific mathematics topic addressed during the learning session was the general formula of arithmetic sequences. In addition, one mathematics teacher from the school participated in the study, contributing to the implementation of the lesson and the reflective discussions conducted during the action research process.

3. Data Collection

The research procedure was conducted through several systematic stages beginning with the preparation phase, during which STEAM-based instructional materials and contextual problem scenarios relevant to students' daily experiences were developed alongside formative assessment instruments to evaluate learning effectiveness and student achievement. This was followed by the implementation phase, where students participated in collaborative learning activities organized in small groups to solve authentic problems designed to foster critical and creative thinking skills. Throughout the learning process, observations and documentation were carried out to capture students' interactions, engagement in collaborative activities, and the development of their problem-solving and creative thinking abilities, supported by evidence such as photographs, video recordings, and students' learning outputs, including reports and presentations. Upon completion of the learning sessions, students undertook a formative assessment to measure their conceptual understanding and to evaluate the effectiveness of the STEAM-integrated Problem-Based Learning (PBL) model. The research instruments employed in this study consisted of observation sheets, formative tests, and documentation records.

4. Data Analysis

The data obtained from observation sheets, formative tests, and documentation are analyzed both qualitatively and quantitatively.

Observation data are analyzed to identify patterns that reflect improvement in students' creative thinking and problem-solving skills, while the formative test data are analyzed to assess how well students understand mathematical concepts and apply them in the context of real-world problems.

RESULTS AND DISCUSSION

1. Result

The results of this study indicate that the learning process was implemented using a Problem-Based Learning (PBL) model integrated with STEAM principles. In this study, the PBL model was applied through a series of structured learning activities in which students were actively engaged in identifying problems, exploring relevant information, and developing solutions collaboratively. During the implementation, students participated in various stages of the learning process, including understanding the given problem, gathering information, formulating initial ideas, and refining their solutions based on discussion and investigation. These activities were observed directly during classroom interactions and documented through learning artifacts and observations. The findings show that the application of the PBL model in this context facilitated active student participation and supported the learning process through contextual and collaborative problem-solving activities.

The Problem-Based Learning (PBL) process involves eight key steps that students follow. These include: (1) identifying a problem, (2) clearly defining the issue, (3) collecting relevant information, (4) forming an initial hypothesis, (5) conducting an investigation, (6) refining the problem definition based on findings, (7) developing a collaborative conclusion or solution, and (8) testing the proposed solution to address the problem (Fogarty, 1997). Problem-Based Learning consists of five primary stages. It begins with the teacher presenting the learning goals and encouraging students to actively engage in solving the given problem. According to Ibrahim and Nur (2000), the process of problem-based learning includes the following steps.

Table 1. Steps in Problem Based Learning Model

Stage / Phase	Teacher Behavior
Stage-1 Student orientation to the problem	The teacher outlines the intended learning goals, provides an overview of the necessary materials or resources, and presents a phenomenon, demonstration, or narrative to spark the emergence of a problem. Additionally, the teacher encourages students to actively participate in addressing the chosen issue.

Stage / Phase	Teacher Behavior
Stage-2 Organizing students to study	The teacher guides students in identifying and structuring the learning activities that are connected to the problem at hand.
Stage-3 Guiding individual and group investigations	The teacher motivates students to gather relevant information and conduct experiments in order to obtain explanations and develop solutions to the problem.
Stage-4 Develop and present the work	The teacher supports students in organizing and creating suitable outputs such as reports, videos, or models, and also helps them collaborate and distribute tasks among their peers.
Stage-5 Analyze and evaluate the problem solving process	The teacher assists students in reflecting on and assessing their investigations, as well as the methods they applied during the process.

Following the stages outlined in Table 1, the implementation of STEAM-integrated Problem-Based Learning (PBL) in the mathematics classroom at SMP Negeri 26 Makassar was carried out through a Participatory Action Research (PAR) approach involving collaborative planning, action, observation, and reflection. In this study, the action phase was conducted based on a jointly developed lesson plan prepared by the research team, pre-service teachers, and the classroom teacher.

During the implementation, the research team and pre-service teachers facilitated the opening activities by organizing the classroom, taking attendance, and introducing the learning objectives. The objectives were explicitly communicated to emphasize the integration of STEAM elements within the PBL framework.

As part of the learning action, facilitators explained the assessment criteria, specifying that students would be evaluated based on their participation in group discussions, problem-solving processes, and presentations. To initiate student engagement, the facilitators posed guiding questions related to arithmetic sequences, such as students' prior experiences with number patterns and examples from everyday contexts. These actions were intended to activate students' prior knowledge and support their readiness for subsequent collaborative problem-solving tasks.

Classroom observations during this stage showed that students responded to the guiding questions by sharing initial ideas and examples, indicating early engagement in the learning process. An overview of this initial implementation stage is presented in Figure 2.

Figure 2. Initial classroom activity during STEAM-based PBL implementation

Following the introductory activities, students were organized into small collaborative groups to support interaction and collective inquiry, which are central elements of both the STEAM approach and Participatory Action Research (PAR). To create an engaging and participatory learning environment, a random grouping strategy was used. The facilitators prepared slips of paper labeled with animal names: cow, chicken, goat, and snake, which students selected randomly. Students who drew the same animal formed a group and briefly mimicked the corresponding animal sound. This playful activity fostered a positive classroom atmosphere, increased students' engagement, and facilitated the formation of collaborative learning groups. Figure 3 illustrates the activity of forming collaborative learning groups through a random selection strategy.

Figure 3. Group formation activity through random selection

In the first phase of the problem-solving activity, the facilitators presented a contextual problem involving the design of a staircase with a constant increase of 20 cm per step to introduce the concept of arithmetic sequences in a real-world context. Students then worked collaboratively in groups to analyze the problem and identify numerical patterns.

Within the STEAM-integrated PBL activity, each element was operationalized through specific student actions. In the Science component, students observed and discussed repetitive patterns in the staircase structure and related them to patterns found in everyday contexts. In the Technology component, students used calculators and, where available, digital tools to verify numerical patterns and perform calculations. For the Engineering component, students determined the height and number of steps required, considering measurement accuracy and the practicality of the staircase design. In the Arts component, students sketched visual representations of the staircase pattern to illustrate the sequence progression. In the Mathematics component, students formulated arithmetic sequences, identified common differences, and interpreted the relationship between step number and height.

These observed activities indicate that students engaged in analyzing the contextual problem through multiple STEAM dimensions while constructing their understanding of arithmetic sequences. Students' activities in this phase are illustrated in Figure 4.

Figure 4. Students analyzing a real-world staircase problem

Students subsequently collaborated within their groups to formulate initial hypotheses regarding the characteristics of arithmetic sequences based on their observations of the contextual problem. Throughout this process, the facilitators, consisting of the research team, pre-service teachers, and the classroom teacher, provided guided questioning and scaffolding to stimulate deeper reasoning and to support students in linking their emerging ideas to the interdisciplinary perspectives emphasized in the STEAM framework.

During the investigation phase, students analyzed the numerical patterns they had identified using digital tools, including mathematical applications and calculators, to verify the structure of the arithmetic sequence. In addition, students explored relevant online resources to broaden their understanding of the concept and its practical applications. This activity encouraged students to engage in critical inquiry while integrating technological resources, reflecting the collaborative and inquiry-oriented principles of the PAR approach. The use of digital tools during the investigation phase is illustrated in Figure 5.

Figure 5. Digital tool utilization during STEAM-based mathematics investigation

In the evaluation and communication stage, students collaboratively developed digital presentations using platforms such as PowerPoint and Canva to communicate their findings. These presentations highlighted the relationship between the mathematical concept of arithmetic sequences and its real-world applications, illustrating the interdisciplinary integration characteristic of the STEAM approach. Working within their groups, students incorporated elements of Science, Technology, Engineering, Arts, and Mathematics into their visual and conceptual representations to demonstrate a comprehensive understanding of the investigated problem. Students' collaborative development of digital presentations is illustrated in Figure 6.

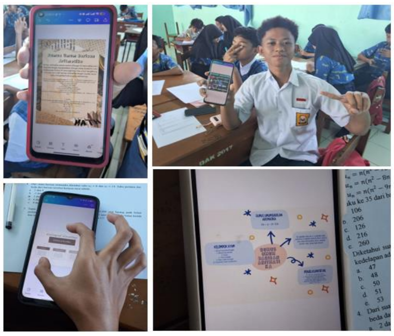

Figure 6. Students collaboratively creating digital presentations

In the subsequent phase, each student group presented their findings to the class using the digital presentations they had developed through PowerPoint and Canva. These presentations provided an opportunity for students to demonstrate their understanding of arithmetic sequences and illustrate how the different components of STEAM were integrated within their problem-solving process. The facilitators, comprising the research team, pre-service teachers, and the classroom teacher, provided constructive feedback on the clarity of explanations, conceptual accuracy, and the integration of STEAM elements. At the same time, students from other groups were encouraged to offer peer feedback, fostering collaborative learning and reflective dialogue among participants. Students' group presentations of their findings are illustrated in Figure 7.

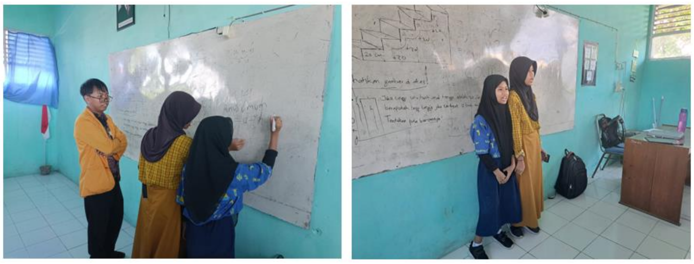

Figure 7. Student group presentations

Consistent with the reflective nature of Participatory Action Research, each group engaged in a brief reflection and revision process after receiving feedback. Students refined their explanations and presentation materials before submitting their final work. Following the presentation session, the facilitators reinforced the key concept by explaining the general formula for the n-th term of an arithmetic sequence, explicitly linking the mathematical formulation to the patterns identified in students' investigations. Students were then given opportunities to solve related problems individually or collaboratively to further consolidate their conceptual understanding.

Finally, students completed a formative assessment consisting of five questions related to arithmetic sequences to evaluate their understanding of the topic. The evaluation followed the assessment rubric specified in the lesson plan, which assessed both group performance during the presentations and individual problem-solving abilities. The descriptive statistics of students' formative test scores are presented in Table 2.

Table 2. Descriptive Statistics of Students' Formative Test Scores

Statistik	Nilai Test
Ukuran Sampel	26
Mean	92.5
Median	90
Modus	90
Standar Deviasi	7.11
Range	20
Nilai Minimum	80
Nilai Maksimum	100

Descriptive analysis of the students' formative test scores shows that the sample size consisted of 26 students. The results indicate that the mean score was 92.5, suggesting that overall student performance on the formative test was very good. The median score was 90, meaning that half of the students obtained scores equal to or below 90 while the other half scored 90 or above. The mode was 90, indicating that it was the most frequently occurring score. In terms of data dispersion, the standard deviation was 7.11, showing relatively low variability, with most scores clustered around the mean. The minimum score was 80 and the maximum score was 100, resulting in a range of 20, which indicates that the difference between the highest and lowest scores was not large. Overall, these results suggest that students demonstrated strong performance with relatively consistent achievement across the class.

Following the learning activities, a collaborative reflection session was conducted involving the classroom teacher, pre-service teachers, and the university research team, consistent with the reflective cycle emphasized in Participatory Action Research (Kemmis & Wilkinson). During this session, the participants discussed the effectiveness of the PBL–STEAM implementation, students' engagement during group investigations, and the extent to which the activities supported the development of creative thinking and problem-solving skills. Observational notes and students' learning artifacts were collectively reviewed to identify strengths and areas for improvement. The discussion also generated recommendations for refining the instructional design, including adjustments to the scaffolding strategies and the integration of digital tools to better support students' collaborative inquiry in future learning cycles.

2. Discussion

The implementation of the STEAM-based Problem-Based Learning (PBL) approach in mathematics learning at SMP Negeri 26 Makassar demonstrated positive impacts on student engagement, creativity, and problem-solving abilities. Integrating the STEAM framework created an interdisciplinary learning environment that encouraged students to explore mathematical concepts through contextual problem-solving and collaborative inquiry. Previous studies have indicated that STEAM-oriented learning environments can promote deeper conceptual understanding and stimulate students' creative thinking by connecting scientific and mathematical ideas with real-world applications (Quigley & Herro, 2016; Yakman & Lee, 2012). In this study, collaborative group activities enabled students to exchange ideas, negotiate strategies, and apply mathematical reasoning collectively, which supported a deeper understanding of the concept of arithmetic sequences.

The integration of digital tools, including mathematical applications and presentation platforms, further enhanced students' learning experiences. Technology-supported learning environments enable students to visualize abstract mathematical patterns and support exploratory learning processes that foster conceptual understanding (Papanastasiou, 2019). Furthermore, the use of digital presentation tools facilitated students' ability to articulate their mathematical reasoning more clearly, while simultaneously fostering digital literacy and communication skills as key competencies required in 21st-century education (Zakir et al., 2025).

Formative assessment conducted through observations, collaborative discussions, and student presentations revealed an average achievement score of 92.5, based on the rubric specified in the lesson plan. This finding indicates that students were able to apply the concept of arithmetic sequences successfully while demonstrating improvement in their analytical and problem-solving abilities. Reflection and feedback activities embedded in the learning process also played an important role in reinforcing conceptual understanding. Reflective learning practices have been widely recognized as effective strategies for encouraging students to evaluate their thinking processes and learn from peer interactions (Boud, Keogh, & Walker, 2013).

Despite these positive outcomes, several challenges emerged during the implementation. Some students initially showed limited participation during group discussions and required additional scaffolding from the teacher to engage more actively in collaborative problem-solving activities. Similar challenges have been reported in inquiry-based learning environments, where students may need time to adapt to student-centered learning approaches that require greater autonomy and participation (Belland, Kim, & Hannafin, 2013). However, with continuous guidance and structured group interactions, most students gradually became more actively involved in the learning process.

Recognition of group performance also contributed to sustaining student motivation. The identification of the best-performing group, based on the established assessment rubric, encouraged healthy competition and reinforced collaborative engagement among students. Providing small rewards served as a motivational strategy that helped maintain students' enthusiasm during the learning activities.

Overall, the findings suggest that the STEAM-based PBL approach is an effective strategy for promoting creativity, critical thinking, and collaborative problem-solving skills in mathematics learning. The interdisciplinary nature of the STEAM framework provides meaningful contexts that support students in connecting mathematical concepts with real-life situations. These results highlight the potential of integrating STEAM and problem-based learning as innovative instructional approaches that can enhance student engagement and learning outcomes in mathematics classrooms. Furthermore, the findings may serve as a valuable reference for educators and schools in Indonesia seeking to implement interdisciplinary and technology-supported learning strategies in mathematics education.

CONCLUSION

The implementation of the STEAM-based Problem-Based Learning (PBL) approach in mathematics learning at SMP Negeri 26 Makassar demonstrated positive outcomes in terms of student engagement, collaborative learning, and conceptual understanding. Through contextual problem-solving activities related to arithmetic sequences, students were able to actively explore mathematical concepts while integrating perspectives from Science, Technology, Engineering, Arts, and Mathematics. The collaborative investigation process, supported by digital tools and guided facilitation, encouraged students to develop analytical reasoning, creative thinking, and effective communication skills.

The results of the formative assessment indicated a high level of student achievement, with an average score of 92.5 and relatively low score variability among students. These findings suggest that the STEAM-based PBL approach can effectively support students' understanding of mathematical concepts while fostering problem-solving abilities and interdisciplinary thinking. Although some students initially required additional guidance to participate actively in group discussions, structured scaffolding and collaborative learning strategies helped improve their involvement throughout the learning process.

Overall, this study highlights the potential of integrating STEAM and Problem-Based Learning as an innovative instructional approach for mathematics education. The approach not only enhances students' academic performance but also promotes essential 21st-century skills such as critical thinking, collaboration, and digital literacy. Future studies may further explore the long-term impact of STEAM-based PBL and its application to other mathematical topics and educational contexts.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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