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The Effect of Augmented Reality (AR)-Assisted Problem-Based Learning (PBL) on Students' Mathematical Creative Thinking Skills

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ABSTRACT

Procedural mathematics learning limits students' mathematical creative thinking skills, causing the development of these skills to receive suboptimal attention. This study examines how integrating the Augmented Reality (AR)-enhanced Problem-Based Learning (PBL) through Assemblr Edu has an impact on the mathematical creative thinking skills of tenth-grade high school students in trigonometry ratios. A quasi-experimental approach featuring a nonequivalent control group design was executed, involving an experimental class ($n = 30$) that underwent AR-assisted PBL and a control class ($n = 30$) undergoing conventional instruction. Participants were chosen via purposive sampling, and data were collected through valid contextual open-ended essay tests at SMAN 13 Depok. The Mann-Whitney test revealed a significant difference in creative thinking skills between the groups ($p < 0.05$) with a large effect size of 0.673. The experimental class achieved higher score gains than the control class in fluency (47.08 vs. 38.75), originality (40.83 vs. 22.45), and elaboration (51.67 vs. 31.66), due to spatial visual exploration. Conversely, the control class recorded a slightly higher gain in flexibility (39.16 vs. 36.24), due to habituation to a single procedural method rather than genuine conceptual flexibility. Overall, AR-assisted PBL positively influences creative thinking by fostering 3D visual exploration and open-mindedness.

1. Introduction

Mathematics learning serves a fundamental function in helping students develop creative thinking patterns for solving problems and making decisions in everyday life. Mathematical creative thinking skills are considered higher-order thinking skills (HOTS) that are essential for students in generating diverse ideas to solve problems. These skills require students to identify problems, generate ideas, and effectively communicate solutions (Sintawati & Mardati, 2023). Fundamentally,

mathematical creative thinking refers to an individual's ability to produce novel, diverse, and adaptive solutions (Acesta, 2020; Darwanto, 2019). Therefore, mathematical creative thinking emphasizes the ability to view problems from multiple perspectives in order to create innovative solutions. Operationally, mathematical creative thinking skills are measured through four interrelated indicators: fluency, flexibility, originality, and elaboration. Mastery of these indicators is crucial for enabling students to solve mathematical problems systematically, deeply, and logically (Lubis, 2023).

However, the reality in the field reveals a significant gap. Data from PISA 2022 indicates that Indonesian students perform well below 20% in achieving top-performer status in creative thinking and mathematics, compared to the OECD average of 20% (OECD, 2024). Mathematical creative thinking skills in schools have not yet been optimally developed (Siregar et al., 2026). Based on classroom observations, the low level of these skills is particularly evident in trigonometric ratio topics. Students tend to demonstrate low curiosity, limited depth of thinking, and a tendency to provide simple and instant answers (Atiyah & Nuraeni, 2022). Consequently, when presented with contextual problems involving slight modifications in their presentation, students experience considerable difficulties. These findings are consistent with the study conducted by Astria and Kusuma (2023), which reported that students frequently make errors due to their inability to identify concepts in problems requiring higher-order analysis.

The inability to solve analytical problems ultimately affects students' affective aspects, as such difficulties may foster negative perceptions of mathematics as a tedious subject (R. F. Sari & Afriansyah, 2022). This condition is further exacerbated by teacher-centered and less interactive classroom instruction. Such learning processes are often caused by the lack of variation in learning models or the selection of instructional approaches that are incompatible with the characteristics of the subject matter and classroom conditions. The use of inappropriate learning models may hinder students from thinking creatively when solving mathematical problems (Noverianto & Munahefi, 2023; Siregar et al., 2026). Teachers' limitations in adapting learning models to students' needs can become a major obstacle in mathematics instruction (Oktavia & Qudsiyah, 2023). This issue is reinforced by observation results indicating that learning activities predominantly focus on practicing routine exercises through teacher-led discussions. Such instructional patterns may directly reduce students' motivation and opportunities for participation (Siagian et al., 2019). As a result, students have limited opportunities to actively engage in learning and explore their abilities, leading to difficulties when faced with open-ended problems or tasks requiring alternative solution perspectives.

As an alternative solution to these challenges, adopting the Problem-Based Learning (PBL) model is highly pertinent as it introduces contextual problems that prompt students to refine their thinking skills (Nurmala et al., 2021). The effectiveness of PBL has been demonstrated in significantly improving students' abilities compared with conventional approaches (Siregar et al., 2026). Through its systematic learning syntax, PBL facilitates meaningful student-centered

learning that supports the internalization of cognitive concepts (Rukhmana, 2022). Students are provided with opportunities to express ideas and develop creative problem-solving strategies (Fitriani & Jusra, 2024). This is because the characteristics of PBL support active learning by stimulating curiosity and enhancing students' collaboration and communication skills (Hakim, 2022). Therefore, the implementation of PBL in mathematics education is expected to improve students' mathematical creativity through active participation.

To support the implementation of PBL in abstract mathematics learning, Augmented Reality (AR) technology serves as a medium capable of interactively projecting digital objects into physical reality (Bulut & Ferri, 2023). The visualization of digital objects through AR has been proven effective in facilitating the transition from rigid and abstract spatial reasoning to more concrete understanding (Ahmad & Junaini, 2020). One AR-based platform that is accessible, user-friendly, and relevant for school environments is Assemblr Edu (Faradillah & Maulida, 2022). The use of this platform has successfully encouraged two-way creativity and stimulated high levels of learning interest (Masri et al., 2023). Furthermore, Assemblr Edu has been shown to transform abstract mathematical concepts into more meaningful visual representations (Meilindawati et al., 2023). Through the AR features available in the Assemblr Edu, students can construct their mathematical understanding through dynamic object visualization, such as viewing, rotating, zooming in, and exploring object dimensions from multiple perspectives using digital devices. In the context of trigonometric ratio topics, these digital visualizations significantly assist students in representing abstract conceptual problems, such as trigonometric relationships, object heights, and angles of elevation, into right-triangle representations that are easier to analyze. This process can stimulate indicators of creative mathematical thinking, particularly flexibility and originality.

Prior studies have extensively examined the application of PBL and AR as distinct instructional interventions. Ahmad & Junaini (2020), Aliyah & Nurafni (2026), as well as Oktama et al. (2026), for instance, have largely focused on using AR to enhance conceptual understanding, spatial reasoning, and visual spatial literacy. Conversely, studies by Nurmala et al. (2021) and Fitriani & Jusra (2024) primarily emphasized the impact of PBL syntax on general problem-solving skills and learning motivation. Although Al-Zahra & Handayani (2025) recently investigated AR-assisted PBL to foster student creativity within primary education science topics, the specific integration of 3D AR visualizations directly into the syntax of PBL to cultivate mathematical creative thinking skills across distinct indicators in senior high school trigonometry remains largely unexplored. The novelty of this study lies in embedding Assemblr Edu based 3D AR visualizations directly into the investigation and presentation stage of the PBL syntax. Rather than employing AR merely as a supplementary visual aid, this integration provides an interactive bridge between abstract trigonometric ratios and concrete spatial models, deliberately supporting the indicators of mathematical creative thinking, namely fluency, flexibility, originality, and elaboration. Therefore, this study aims to examine the effect of Problem-Based Learning (PBL) assisted by Augmented Reality (AR) via Assemblr Edu on tenth-

grade students' mathematical creative thinking skills in trigonometric ratio learning.

2. Methodology

This study applied a quantitative approach utilizing a quasi-experimental method with a nonequivalent control group design. The research sample was chosen with purposive sampling, considering the characteristics and objectives of the study (Rasyid, 2022). The participants comprised two groups of tenth-grade students from SMAN 13 Depok. These participants were divided into an experimental class ($n = 30$), which experienced Problem-Based Learning (PBL) assisted by Augmented Reality (AR), and a control class ($n = 30$), which followed conventional instruction.

Instrument

The research data were collected using an open-ended essay test consisting of two questions on the topic of trigonometric ratios. The test was designed to measure four indicators of mathematical creative thinking: fluency, flexibility, originality, and elaboration. Prior to its implementation, the instrument was validated through expert judgment and empirical testing using the Product Moment correlation and Cronbach's Alpha coefficient. After meeting the validity and reliability requirements, the instrument was administered as both a pretest and a posttest to evaluate students' mathematical creative thinking skills following the intervention.

Data Collection

Data collection was conducted through three sequential stages. First, a pretest was delivered to evaluate students' preliminary mathematical creative thinking skills prior to the intervention. Second, the instructional treatment was conducted across four learning sessions, where the experimental class was taught using PBL assisted by Assemblr Edu AR media, whereas the control class received conventional instruction. Third, a posttest was administered at the end of the intervention to measure the students' final mathematical creative thinking skills.

Data Analysis

Statistical processing of the quantitative pretest and posttest outcomes was executed with SPSS version 26. Descriptive statistics were computed to present the mean scores and variances. Prerequisite tests were conducted by applying Shapiro-Wilk normality tests and Levene's variance homogeneity tests. Due to non-normal and non-homogeneous data distributions, hypothesis testing was conducted using the non-parametric Mann-Whitney U test. Finally, Cohen's effect size coefficient (r) was calculated to measure the overall strength of the treatment effect.

3. Results and Discussion

Implementation Process of AR-Assisted PBL

The implementation of PBL assisted by AR in the experimental class was systematically structured across the PBL syntax stages. This instructional design aimed to bridge abstract trigonometric concepts with concrete spatial visualizations through the Assemblr Edu. Learning activities began with the orientation of students to real-world trigonometric problems, such as calculating kite heights and determining horizontal distances between objects under varying angles of elevation. These contextual scenarios challenged students to look beyond standard procedural formulas and explore diverse analytical perspectives. During the subsequent phase of organizing students for learning, students formed small collaborative groups and received worksheets containing structured problem-solving tasks. In the guiding group investigations stage, students actively utilized personal mobile devices to explore 3D AR geometric models via Assemblr Edu. As depicted in Figure 1, students interactively manipulated digital objects by viewing, rotating, and inspecting right-triangle overlays from different angles to construct concrete spatial representations, while collaboratively testing alternative solution strategies such as utilizing reciprocal functions or decomposing complex structures into separate right triangles.



Figure 1. Students Engaging in Collaborative Group Investigation and 3D Object Manipulation via Assemblr Edu

In the developing and presenting phase, each group synthesized their findings into a creative report detailing their mathematical reasoning, step-by-step calculations, and unique solutions pathways. Representative groups presented their original solving methods to the class, while other teams actively engaged in discussions and provided feedback on the alternative analytical perspectives identified. Finally, during the analyzing and evaluating the problem-solving process stage, the teacher and students collectively reflected on the diverse strategies generated during the investigation. This reflective session reinforced that complex trigonometric problems can be solved through various valid visual and analytical approaches when executed with precision. By integrating 3D spatial object manipulation directly into these group investigation and presentation stages, the

AR-assisted PBL created an interactive learning environment specifically structured to foster students' mathematical creative thinking skills.

Descriptive Statistics Summary

To provide an initial overview of students' mathematical creative thinking skills prior to and following the intervention, descriptive statistics were calculated for both the pretest and posttest scores of both groups are presented in Table 1.

Table 1. Descriptive Statistics of Pretest and Posttest Data

	Group	N	Mean	Variance
Pretest	Experimental	30	38.65	295.32
	Control	30	30.31	304.52
Posttest	Experimental	30	82.60	196.45
	Control	30	63.33	26.90

Based on the data in Table 1, the pretest results indicate that both groups started with relatively low initial skills prior to the intervention, though the experimental class recorded a slightly higher mean score of 38.65 compared to the control class with 30.31. Following the learning treatment, both groups demonstrated progress, but with distinct posttest outcomes and data distributions. The experimental class achieved a posttest mean score of 82.60 with a variance of 196.45. Meanwhile, the control class reached a posttest mean score of 63.33 with a significantly lower variance of 26.90.

Prerequisite Tests for Analysis

This analysis stage is then continued with prerequisite testing in the form of normality and homogeneity testing before conducting hypothesis testing to evaluate whether significant variations exist between the two groups. Table 2 presented the results of the normality test.

Table 2. Shapiro-Wilk Normality Test

	Class	Statistics	df	Sig.
Pretest	Experimental	.886	30	.004
	Control	.823	30	.000
Posttest	Experimental	.909	30	.014
	Control	.705	30	.000

Referring to Table 2, the significance value (Sig.) of Shapiro-Wilk normality test result revealed that test results for both groups were below 0.05. This means that the mathematical creative thinking skills scores of students in both groups were not normally distributed. The next analysis step was to test for homogeneity using Levene's Test as presented in Table 3.

Table 3. Homogeneity of Variance Test

		Levene Statistic	df1	df2	Sig.
Pretest	Based on Median	.121	1	58	.729
Posttest	Based on Median	38.855	1	53.474	.000

As detailed in Table 3, the pretest data yielded a significance value of 0.729. In contrast, the posttest data yielded a significance value of 0.000, confirming that variance homogeneity between the experimental and control groups was not met. The failure of the posttest data to satisfy the prerequisite assumptions of normality and homogeneity fully justified the use of a non-parametric statistical approach through the Mann-Whitney test (U-test).

Hypothesis Testing and Effect Size Analysis

A non-parametric Mann-Whitney U test was performed to examine whether students in experimental and control class showed a statistically significant difference in mathematical creative thinking skills. The outcomes of the hypothesis testing are summarized in Table 4.

Table 4. Mann-Whitney Test

	Posttest
Mann-Whitney U	103.000
Wilcoxon W	568.000
Z	-5.212
Asymp. Sig. (2-tailed)	.000

According to the statistical output in Table 4, the Asymp. Sig (2-tailed) value obtained was 0.000, which is strictly less than the alpha threshold ($p < 0.05$). Consequently, the null hypothesis (H_0) was rejected, proving a statistically significant difference in mathematical creative thinking skills between students taught via AR-assisted PBL and those taught through conventional instruction. Following the confirmation of statistically significant difference, an effect size calculation was conducted to measure the level of the treatment's impact. Using Cohen's criteria, the calculated effect size coefficient (r) was 0.673. This value falls into the large effect classification, which means that learning treatment exerts a substantial positive influence on enhancing students' mathematical creative thinking skills.

Theoretically, the difference in outcomes between the two groups can be traced to the syntactic characteristics of PBL, which familiarize students with facing and solving contextual problems in real life (Y. Sari et al., 2022). Students in the experimental class were given repeated opportunities to actively participate and express their ideas systematically through Assemblr Edu, and the resulting activities were noticeably more engaging and better received by students (Masri et al., 2023). A similar pattern was reported by Ardiana et al. (2025), whose study on PBL combined with interactive digital media likewise found that a student-centered, technology-supported environment tends to improve learning outcomes, echoing what was observed in the present classroom.

The use of AR-based media contributes positively to improving mathematical creative thinking skills through the visualization of abstract mathematical objects (Arifuddin et al., 2022). This new experience triggers students' high curiosity. Something similar occurred in this study; students using Assemblr Edu appeared genuinely engaged, consistent with Anjali et al. (2024), who observed that the platform tends to make learning more interactive and enjoyable. Because students could manipulate 3D spatial models directly rather than merely viewing static illustrations, their abstract thinking was scaffolded in a way that encouraged them to explore problems and generate new ideas of their own, a pattern that lines up with Rozi & Pujiriyanti (2026) and with Novella et al. (2024), who found direct student involvement in technology-assisted PBL to be a key driver of creative thinking gains. Interestingly, this also extends the picture drawn by Khairunnisa & Faradillah (2023), who found AR-assisted PBL to strengthen mathematical reasoning in general; the present findings suggest that the same integration can just as effectively cultivate creative thinking specifically, not only reasoning ability.

Looking more closely at how each stage of the PBL syntax shaped the four mathematical creative thinking indicators, the pattern that emerges is fairly consistent with what has been reported elsewhere. During the orientation stage, teachers present non-routine contextual problems designed to spark students' curiosity and prompt an initial flow of ideas; interactive visual representations at this stage have similarly been shown to encourage students to explore alternative solution pathways rather than settling on the first idea that comes to mind (Nurfadhila et al., 2026). The AR component itself came into play more directly during the investigation stage, where small groups used Assemblr Edu to scan markers and manipulate 3D geometric models. Exploring these overlays from multiple angles seemed to help students move past rigid procedural habits, building the kind of flexibility needed to try more than one trigonometric approach to the same problem.

This is broadly in line with Eddelweis & Yulianawati (2026) and their observation that embedding Assemblr Edu into exploration-based learning tends to boost both activeness and flexible thinking. Compared to Fitriani & Jusra (2024), whose use of static 2D audio-visual media in PBL offered a more fixed viewing experience, the real-time spatial manipulation available here appeared to engage students' spatial reasoning more deeply. It is also worth noting that while Noverianto & Munahefi (2023) achieved comparable gains using a Javanese ethnomathematics-based PBL among middle school students, the present study shows that AR-based visualization alone, without leaning on cultural context as the primary instructional device, can produce a similar effect among senior high school students.

Once students moved into developing and presenting their work, combining PBL with AR-based exploration gave them room to construct fairly unique, non-routine solution strategies, and having to lay out detailed arguments and sketches for their peers seemed to sharpen both originality and elaboration. Al-Zahra & Handayani (2025) reported much the same thing: PBL supported by Assemblr

Edu tends to give students the autonomous space they need to elaborate on authentic mathematical solutions, and the large effect size in the present study points to a similar dynamic. One difference worth flagging is that Faradillah & Maulida (2022) took a qualitative approach, grouping students by cognitive style (visualizer vs. verbalizer), whereas this study evaluated creative thinking gains quantitatively across the whole experimental class, offering a somewhat more generalizable picture of how effective AR-assisted PBL can be. To provide a detailed breakdown of performance across specific cognitive domains, the mean score gains for each creative thinking indicator are shown in Figure 2.

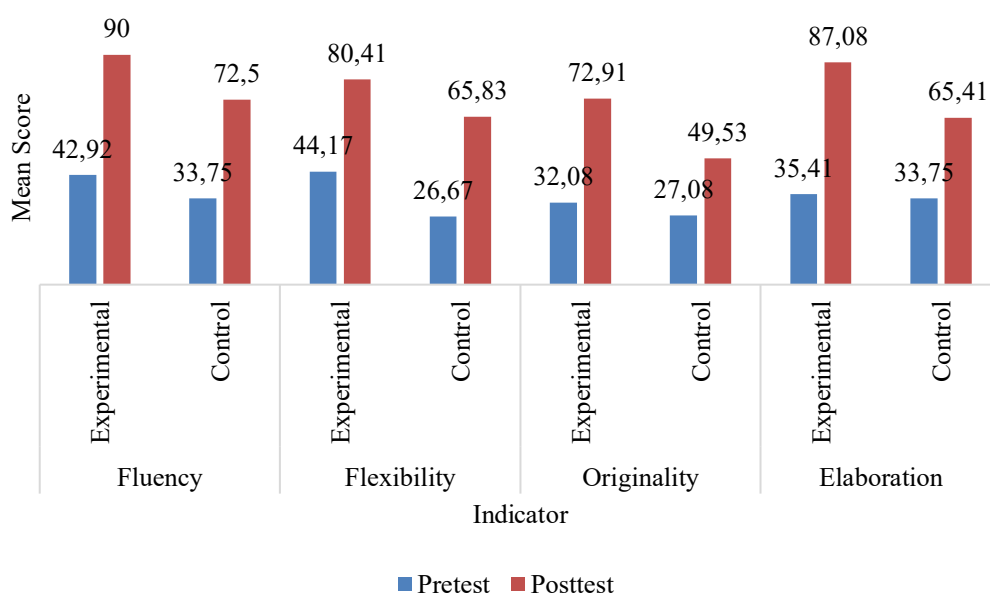


Figure 2. Average Indicator of Mathematical Creative Thinking Skills

As illustrated in Figure 2, the experimental class demonstrated superior score gains across three out of four indicators. In the fluency indicator, the experimental class achieved the highest increase of 47.08 points, outperforming the control class which only increased by 38.75. This trend of experimental class dominance continued in originality with an increase of 40.83 compared to 22.45, and elaboration with a gain of 51.67 compared to 31.66. Conversely, in the flexibility indicator, the control class experienced a slightly higher increase of 39.16 compared to 36.24 in the experimental class, although the experimental class maintained a higher final posttest average.

The high average posttest achievement in flexibility indicator and distinct variance between the experimental class which was 196.45 and the control class which was only 26.90 are closely related to the contrasting problem-solving habits of the two groups. The abilities of students in the control class were very uniform because they were accustomed to conventional learning methods such as drilling routine practice questions procedurally. Because students in the control class were already habituated and fluent in executing standard procedural steps, they could quickly complete procedural solutions during the test. However, excessive focus on procedural aspects can risk inhibiting students from constructing their original

thoughts (Siregar et al., 2026). As a result, when faced with an open-ended essay test requiring two different solution methods, students in the control class misinterpreted the instructions and focused on completing one procedural method they had mastered completely. This habit of thinking led students in the control class toward fixation (Putri & Alberida, 2022), not unlike what Indayanti & Sagala (2023) described as a broader tendency in traditional instruction to overemphasize final procedural answers at the expense of deeper conceptual processing. Novella et al. (2024) make a related point: when a teacher-centered paradigm treats procedural accuracy as equivalent to genuine mastery, it tends to close off students' opportunities to develop their own creative thinking.

Conversely, the experimental class broke the traditional procedural constraints through the intervention of PBL assisted by AR Assemblr Edu. The spatial visualization of elevation and depression angles successfully triggered a significant increase in fluency, originality, and elaboration within the experimental class, proving that visualization of three-dimensional objects can stimulate students to produce authentic and non-routine mathematical solutions. Meanwhile, the higher posttest variance in the experimental class indicates a dynamic adaptation of students' mathematical creative thinking skills as they transitioned to new problem-solving habits. This is due to learning habits that influence and limit students' skills in solving new, non-routine problems (Rukhmana, 2022). While experimental students spent significant cognitive effort attempting to construct and elaborate two different authentic methods, time constraints during testing prevented some from completing both methods thoroughly, explaining the variance while confirming a genuine shift toward creative reasoning.

The concrete representation of 3D objects helps bridge abstract trigonometric concepts into measurable visual models, as illustrated in Figure 3. Through this visualization, students no longer have to guess the altitude and projection of a right triangle in a contextual problem, but can instead observe the three-dimensional spatial arrangement of the model through their devices. The diversity of thought processes and the courage to generate new ideas are part of mathematical creative thinking skills (Darwanto, 2019). In this context, the ability to view problems from different perspectives, possessed by the experimental class, is a key asset in developing higher-order thinking skills (Ndiung et al., 2024). The ability to solve problems using innovative solutions with the help of interactive visualizations from various perspectives essentially represents the main characteristics of all indicators of mathematical creative thinking skills.

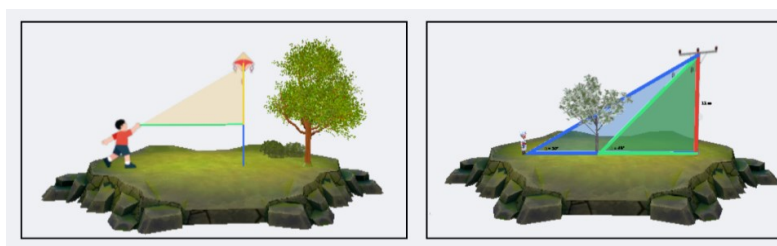


Figure 3. AR Visualization on Assemblr Edu

The novelty of this research lies in the integrated synthesis between PBL syntax and 3D AR spatial manipulation specifically engineered to stimulate distinct indicators of mathematical creative thinking skills in trigonometry. Theoretically, this study contributes to technology-enhanced constructivist learning by demonstrating how interactive AR serves as visual scaffolding for higher order thinking skills. Practically, it provides an actionable instructional framework that mathematics teacher can directly adopt to alleviate low mathematical creativity in secondary classrooms. Overall, the implementation of AR-assisted PBL proves that mathematical creative thinking skills are not merely oriented towards uniform procedural results, but rather on the richness of thought processes, cognitive flexibility, and student independence in solving non-routine problems. The success of the experimental class in dominating score gains across fluency, originality, and elaboration demonstrates that the PBL model supported by AR Assemblr Edu effectively stimulates students' cognitive structures. By transforming abstract 3D concepts into interactive spatial visualizations, this approach fosters independent concept discovery, refines mathematical reasoning, and comprehensively enhances students' creative thinking skills.

4. Conclusion

The implementation of AR-assisted PBL through Assemblr Edu has a statistically significant influence on students' mathematical creative thinking skills, with a large effect size. Descriptively, the experimental class demonstrated higher average achievements in three indicators; fluency, originality, and elaboration. Conversely, the control class experienced a slightly higher score gain only in the flexibility indicator, which was heavily driven by their habituation toward routine and procedural problem-solving using a single memorized method.

Crucially, these findings demonstrate that evaluating students' mathematical creative thinking skills cannot be judged solely by their final scores, but must account for the underlying cognitive process and the diversity of thinking paths demonstrated during problem-solving. While high scores in procedural tasks reflect speed and routine mastery, true mathematical creativity encompasses the willingness to construct novel, deeply reasoned, and diverse solutions. The integration of 3D visual objects in AR technology effectively stimulates students' open-mindedness to explore trigonometric ratio problems from various non-routine perspectives and generate unique solutions, rather than simply memorizing formulas.

Based on these findings, further research should focus on managing learning time allocation more flexibly and proportionally. This adjustment is essential to allow students sufficient time to adapt to digital technology exploration without compromising the speed needed to perform thorough, coherent, and systematic mathematical calculations across all creativity indicators.

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