Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram
https://e-journal.undikma.ac.id/index.php/prismasains/index
e-mail: prismasains.pkpsm@gmail.com

April 2026. Vol. 14, No. 2
p-ISSN: 2338-4530
e-ISSN: 2540-7899
pp. 705-720

Integration of Augmented Reality (AR) in Learning: An Effort to Promote Elementary Students' Creative Thinking Skills

[1]*Komala, [2]Abdul Rachman Tiro, [3]Retno Wuri Sulistyowati, [4]Lutma Ranta Allolinggi, [5]Ady Akbar

[1]Faculty of Education, Siliwangi Institute of Teacher Training and Education, Cimahi, Indonesia
[2]Faculty of Teacher Training and Education, UNIMUDA Sorong, Sorong, Indonesia
[3]Faculty of Teacher Training and Education, Musamus University, Merauke, Indonesia
[4]Faculty of Teacher Training and Education, Toraja Christian University of Indonesia, Toraja, Indonesia
[5]Faculty of Teacher Training and Education, Sawerigading Makassar University, Makassar, Indonesia

*Corresponding Author e-mail: komalaikipsiliwangi@ikipsiliwangi.ac.id

Received: December 2025; Revised: March 2026; Published: April 2026

Abstract

The use of Augmented Reality (AR) in learning has shown rapid development. This study aims to analyze the effect of AR integration on students' creative thinking abilities in the topic of surface area and volume of cubes and rectangular prisms. We applied a quasi-experimental design by utilizing two existing classes, namely an experimental class consisting of 32 students and a control class consisting of 30 students. We used an essay test instrument measuring creative thinking ability that had undergone expert validation using the Q-Cochran test before being used for data collection. Data analysis was conducted using descriptive statistics and an independent samples t-test. The analysis showed a significant difference between the post-test scores of the two groups, with $t(60) = 2.31$ and $p = 0.012$ (one-tailed). The effect size calculation produced a Cohen's d value of 0.60 (moderate effect). These results indicate that students who participated in AR-assisted mathematics learning obtained higher creative thinking scores than students who participated in learning without AR support. This finding indicates that the implementation of AR is able to provide a meaningful effect as well as a positive contribution to the development of students' creative thinking abilities in solving mathematics problems.

Keywords: Augmented reality; Creative thinking; Elementary school; Quasi-experimental

How to Cite: Komala, K., Tiro, A. R., Sulistyowati, R. W., Allolinggi, L. R., & Akbar, A. (2026). Integration of Augmented Reality (AR) in Learning: An Effort to Promote Elementary Students' Creative Thinking Skills. *Prisma Sains: Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *14*(2), 705–720. https://doi.org/10.33394/j-ps.v14i2.18896

https://doi.org/10.33394/j-ps.v14i2.18896

INTRODUCTION

The Creative Creative thinking skills constitute one of the fundamental competencies that must be developed in 21st-century learning (Akbar et al., 2025; Blegur et al., 2017). Creativity not only serves as the foundation for innovation but also plays a crucial role in enabling students to generate new ideas, adapt to change, and solve complex problems flexibly (Faiziyah et al., 2022). The Organisation for Economic Co-operation and Development or OECD (2017) emphasizes that creativity is among the core competencies that should be cultivated through interdisciplinary learning to prepare students for dynamic global challenges. Theoretically, creative thinking is defined as the ability to generate new, relevant, and meaningful ideas or solutions (Hadar & Tirosh, 2019). Bicer et al. (2024) highlights that creativity involves generating novel approaches to problem solving, while Leikin and Sriraman (2022) view creativity as the capacity to produce original and valuable solutions. The main components of creativity include fluency, flexibility, and originality, along with additional dimensions such as novelty, synthesis, and elaboration (Guilford, 1967; Haylock, 1997).

Despite its importance, numerous studies indicate that elementary school students' creative thinking skills remain at a relatively low level in many countries (Bicer, 2021; Budhiarti et al., 2025). Christopher et al. (2020) reported low levels of mathematical creativity among students in Nigeria. Willemsen et al. (2023) found that teachers in the Netherlands still encounter challenges in implementing instructional practices that foster creativity, despite existing curricular support. Similar conditions have also been observed in Taiwan (Liu et al., 2019; Sadeghi & Hamedi, 2024).

In Indonesia, the limited development of creative thinking skills has also been reported in several studies. Affandy et al. (2024) found that students in Lampung experience difficulties in solving mathematical problems due to limited creative thinking abilities. Findings by Herawati et al. (2023) revealed that third-grade students were unable to solve word problems due to low levels of fluency and elaboration. Siregar (2023) also reported that elementary school students in Pekanbaru demonstrate limited flexibility when solving basic geometry problems. These findings are further supported by international assessments such as Trends in International Mathematics and Science Study Mullis et al. (2016) and the Programme for International Student Assessment (OECD, 2019), which place Indonesian students' mathematics performance at relatively low rankings and highlight weaknesses in higher-order thinking skills, including creativity.

One factor contributing to the low level of creativity is the dominance of traditional teaching methods (Cahyaningsih et al., 2023; Dewanti, 2022). Instruction that primarily centers on the teacher often results in students passively receiving information, thereby limiting opportunities to explore ideas, independently develop concepts, or engage in open-ended analysis—activities that are essential for fostering creativity (Xu et al., 2024). Such limited opportunities for exploration hinder the development of divergent thinking skills required for creative problem solving (Leibovitch et al., 2025).

With the advancement of technology, digital innovations offer new opportunities to enhance the quality of learning, including the development of creative thinking skills (Dewanti & Santoso, 2020; Syarifudin et al., 2021). One technology that has demonstrated considerable potential in education is augmented reality (AR). AR integrates virtual elements with the real environment to create interactive, visual, and contextual learning experiences (Akçayır & Akçayır, 2017). Unlike traditional instructional media, AR enables students to manipulate digital objects, visualize abstract concepts in a more concrete manner, and engage in exploratory learning experiences (Meriyati et al., 2024).

Numerous studies have shown that AR has positive effects on mathematics learning. Cai et al. (2020) reported that the integration of AR improves conceptual understanding, student engagement, and learning outcomes. Koparan et al. (2023) and İslim et al. (2024) found that AR is effective in enhancing students' spatial abilities, which are essential for mathematical problem solving. A study conducted by Demitriadou et al. (2020) in the context of elementary education demonstrated that AR significantly increases students' interest, interactivity, and overall learning experience.

Over the past five years, the use of AR in mathematics education has grown rapidly (Wu et al., 2024). Ivan and Maat (2024), through a systematic review of publications indexed in Scopus and Web of Science, found that research on AR in mathematics education has developed consistently, with Indonesian researchers among the largest contributors. AR has been shown to enhance both cognitive and affective aspects of learning through responsive and immersive learning environments. For instance, an experimental study conducted by Lubis and Idris (2025) demonstrated that the use of AR in mathematics classrooms can improve students' mathematics learning outcomes. Furthermore, research by Pujiastuti and Haryadi (2024) indicated that the use of AR technology in mathematics instruction enhances students' geometric thinking abilities. Meanwhile, findings by Alghamdi and Alshahrani (2025) revealed that the integration of AR in learning increases student motivation and helps reduce learning difficulties.

Although the use of AR in mathematics learning has been widely explored, studies that specifically investigate its impact on the development of creative thinking skills remain relatively limited. Existing research primarily highlights the benefits of AR for general learning outcomes, motivation, or conceptual understanding, but does not sufficiently explain whether AR can facilitate and develop creative thinking as a crucial skill in contemporary education, particularly in elementary mathematics learning. Research that provides a comprehensive analysis of the impact of AR on elementary students' creative thinking abilities, especially in the topics of surface area and volume of cubes and rectangular prisms, still needs to be expanded.

This research gap highlights the need for studies focusing on the impact of augmented reality on elementary school students' creative thinking skills. Therefore, this study aims to analyze the effect of integrating AR technology on students' creative thinking abilities. Specifically, this study examines whether students who participate in AR-assisted mathematics learning demonstrate better creative thinking abilities than those who participate in mathematics learning without AR. Such research is important not only for strengthening the theoretical foundation of creativity in mathematics education but also for providing practical recommendations for teachers in effectively utilizing innovative technologies. Consequently, this study holds both academic and practical relevance in enriching instructional strategies that can enhance creative thinking skills at the elementary education level.

METHOD

Research Design

This study employed a quasi-experimental design due to time constraints that prevented the formation of new classes and to ensure that the learning process continued to run normally. Therefore, the existing class composition was maintained, consisting of one control class (N = 30) and one experimental class (N = 32). Both classes received instruction on the topic of surface area and volume of cubes and rectangular prisms; however, the experimental class used AR technology as a learning aid, whereas the control class did not use AR. The instructional sessions were conducted over five meetings in each class.

During the intervention phase, Augmented Reality (AR) technology was utilized to support students' understanding of three-dimensional geometry concepts. The AR media consisted of interactive three-dimensional objects representing geometric solids, particularly cubes and rectangular prisms. These objects were displayed through a marker-based tracking mechanism, in which the device camera detects markers in the form of printed images provided as part of the learning materials. Once the marker is scanned, the application automatically displays manipulable 3D models, enabling students to visualize abstract mathematical concepts more concretely.

Figure 1. Sample Interface of an AR-Based Geometry App with 3D and Interactive Features

Students interacted with the AR objects through the device's touchscreen, including actions such as rotating, zooming in and out, and moving the objects to observe them from various perspectives. In the learning process, task prompts were also provided to guide students in exploring surface area and volume concepts through direct manipulation of the 3D objects.

For example, students were asked to identify the number of faces, edges, and vertices, as well as to derive and verify formulas based on their observations of the displayed objects.

The AR application used in this study was Augmented Reality Bangun Ruang, which was installed on Android-based smartphones and could be operated offline after initial installation (Arsari, 2022). The application did not require an internet connection during the learning process. Immediate feedback was provided through dynamic visual responses of the 3D objects during user interaction, thereby enhancing student engagement and supporting active and exploratory learning.

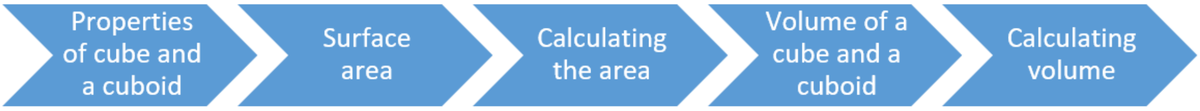

Figure 2. Main Topics For The Five Meetings

In the first meeting, students studied the characteristics of cubes and rectangular prisms by identifying the number of faces, edges, and vertices through observation of three-dimensional models presented using AR. Students explored the objects by rotating them and observing them from various angles to understand the differences and similarities between the two geometric solids. The second meeting focused on discovering the formulas for the surface area of cubes and rectangular prisms through a discovery learning approach. Students observed and unfolded the nets of cubes and rectangular prisms, calculated the area of each face, and then independently formulated the surface area formulas with guidance from the teacher.

In the third meeting, students applied the surface area formulas in various exercises, ranging from routine problems to contextual problems. Group discussions were conducted to encourage fluency and flexibility in problem-solving strategies. The fourth meeting addressed the concept of the volume of cubes and rectangular prisms. Students visualized the process of filling space using small unit cubes (both concretely and through AR media) to discover the relationship between length, width, and height. From this exploration, students concluded the volume formulas and distinguished them from the concept of surface area. In the fifth meeting, students solved problems related to volume calculations, including problem-solving-based tasks.

Participant

The We involved 62 fifth-grade elementary school students in this study. They were on average between eleven and thirteen years old and came from middle socioeconomic backgrounds in Gowa Regency, South Sulawesi Province. Before their participation, we obtained permission from the teachers and sent an email to their parents to inform them about their children's involvement in the study. Student participation in this research was voluntary, and all collected data were kept confidential. Of the 62 students, 30 were in the control class and 32 were in the experimental class. This distribution followed the existing class composition established at their school.

Instrument and Procedure

We used a research instrument in the form of an essay test to measure creative thinking ability. The instrument was first validated by three mathematics education experts to assess its content validity and face validity. At this stage, we employed the Q-Cochran statistical test to examine the consistency of the experts' evaluations. The results of the assessment were then used to revise the test items before conducting a limited trial to obtain external validity and the reliability of the instrument.

Table 1. Results of The Instrument Uniformity Test

Type of validity	Significance	Criterion
Content	0.37	Consistent
Face	0.063	Consistent

The results of the expert validity analysis showed that the significance value of the Q-Cochran test for content validity was 0.37 and for face validity was 0.063. Both values are higher than the significance level of 0.05. These findings indicate that there were no significant differences in the experts' evaluations, suggesting that their assessments regarding the suitability of the content and the appearance of the instrument were consistent. The construction of the mathematical creative thinking test items referred to the four components of creative thinking ability previously developed by Torrance (1966), namely originality, fluency, flexibility, and elaboration. Meanwhile, the reliability of the instrument was analyzed using the Cronbach's alpha formula with the assistance of IBM SPSS software. The reliability coefficient of the test was 0.82, indicating that the test instrument has a very high reliability criterion (Suherman, 2003).

Table 2. Instrument Reliability

Standard Deviation	Reliability Coefficient (r_{xy})	Criteria
5.97	0.82	Highly reliable

Furthermore, the data on creative thinking ability obtained through the pre-test and post-test were analyzed using descriptive and inferential statistical methods. To conduct the inferential test, an independent samples t-test with a significance level of 5% was used to test the research hypothesis. Before the hypothesis testing was conducted, prerequisite tests in the form of normality and homogeneity tests were first applied. The Shapiro–Wilk test was used to examine the assumption of normality in the distribution of mathematical creative thinking ability in both the control and experimental groups. Meanwhile, Levene's test was employed to determine whether the data variances of the two groups were homogeneous.

Table 3. Components of Creative Thinking Skills Measured

Component	Description
Originality	Students are able to generate unusual ideas or solutions and discover new strategies for solving mathematical problems.
Fluency	Students are able to develop a variety of different strategies when solving mathematical problems.
Flexibility	Students are able to provide various solution alternatives using diverse approaches.
Elaboration	Students are able to explain problem-solving steps in a detailed, structured, and logical manner.

Subsequently, hypothesis testing was carried out with the assistance of IBM SPSS Statistics version 25 software. The testing criterion used was that if the p-value was greater than 0.05, it indicated that there was no significant difference between the creative thinking ability of students who participated in AR-assisted learning and those who followed conventional learning. To complement the statistical significance analysis, this study also calculated the effect size using Cohen's d (Hedges, 2025). This analysis aimed to determine the magnitude of the effect of implementing the learning model in the experimental class on students' creative thinking ability. The scoring criteria for the mathematical creative thinking ability test were developed by adapting the rubric for assessing mathematical creative thinking ability developed by Bosch (1997). This rubric has been widely recognized in prior studies, ensuring both the validity and reliability of the assessment process. By adapting Bosch's rubric, the scoring becomes more objective, consistent, and aligned with established theoretical constructs of mathematical creativity, thereby strengthening the overall quality and credibility of the research instrument.

Table 4. Scoring Criteria for Creative Thinking Skills

Indicator	Student Response	Score
Fluency	The student does not provide an answer or does not express any relevant idea.	0

Indicator	Student Response	Score
	The student produces a relevant solution but writes it unclearly.	1
	The student writes a relevant solution clearly and adequately.	2
	The student provides more than one relevant solution, but the explanation is unclear.	3
	The student generates more than one relevant solution and writes them clearly and completely.	4
Flexibility	The student does not produce a solution or provides solutions using one or more methods, but all are incorrect.	0
	The student uses one method but makes calculation errors that lead to an incorrect solution.	1
	The student uses one strategy with accurate calculations and produces a correct solution.	2
	The student uses more than one strategy but still makes errors due to miscalculations.	3
	The student solves the problem using more than one strategy and performs all calculations correctly.	4
Elaboration	The student does not provide a solution or gives an incorrect one.	0
	The student begins to develop a strategy but does so inaccurately and without details.	1
	The student develops a strategy inaccurately and provides insufficient details.	2
	The student develops an accurate strategy and presents the steps coherently but incompletely..	3
	The student develops an accurate, coherent, and complete strategy	4
Originality	Does not provide an answer or provides an incorrect answer.	0
	Writes an answer, but it is difficult or unclear to understand.	1
	Writes an answer; the calculation process is directed but incomplete or inaccurate.	2
	Provides a solution using a particular strategy, but it is inaccurate or contains errors in the calculation process.	3
	The calculation process and the result are correct.	4

The scoring criteria for creative thinking skills cover four indicators which are fluency, flexibility, elaboration, and originality. Fluency reflects the ability of students to generate ideas or solutions, starting from giving no answer up to producing several relevant and clearly written solutions. Flexibility assesses how students use different approaches to solve a problem, and the highest score is given when they successfully apply more than one accurate strategy. Elaboration relates to the completeness and clarity of the steps developed by students, with the best performance shown when they present accurate, coherent, and fully detailed solutions. Originality focuses on the uniqueness and correctness of the students' answers, and the highest score is awarded when they perform the calculations correctly and arrive at the correct solution. Taken together, these criteria provide a comprehensive understanding of the quality of students' creative thinking when working through a problem.

RESULTS AND DISCUSSION

Results

The results of the study indicate differences in the achievement and improvement of creative thinking skills between students in the experimental class, which implemented AR-based learning, and those in the control class, which learned without the use of AR. At the beginning of the learning process, the experimental class obtained an average pretest score of 74.02 with a standard deviation of 7.63, while the control class had an average pretest score of 73.54 with a standard deviation of 8.31. These findings suggest that the initial creative thinking abilities of students in both classes were relatively equivalent before the intervention was carried out. After the learning process took place, the experimental class showed improved performance with an average posttest score of 85.15 and a standard deviation of 8.80. In contrast, the improvement in the control class was relatively lower, with an average posttest score of only 79.59 and a standard deviation of 9.70.

In addition, the N-gain score in the experimental group reached 0.45, which falls into the medium improvement category, whereas the control group obtained an N-gain score of 0.24, classified as low. This difference in N-gain achievement indicates that the implementation of the discovery learning model enriched with AR technology was able to produce a more significant improvement in creative thinking skills compared to discovery learning without AR support. The consistency of learning improvement in the experimental group is also evident from the relatively stable standard deviation, suggesting that the effects of AR-assisted learning were more evenly experienced by students. Conversely, the standard deviation in the control group increased, indicating greater variation in learning outcomes and the possibility of unequal material comprehension without the support of AR. Thus, these findings confirm that integrating AR into learning provides a more effective and stable impact on developing students' creative thinking skills compared to instruction that does not utilize AR.

Table 5. Results of Students' Creative Thinking Skills Test

Group	**Mean**		**Standard Deviation**		**N-gain**
	Pretest	Post-test	Pretest	Post-test	
Experimental	74.02	85.15	7.63	8.80	0.45
Control	73.54	79.59	8.31	9.7	0.24

Based on the distribution of creative thinking skill scores in Table 5, it is evident that the score composition of both groups is relatively comparable across all test items. For Item 1, in the experimental group, 24 out of 32 students (75%) achieved a score of 3, and 6 students (18.75%) obtained a score of 4. Meanwhile, in the control group, 23 out of 30 students (76.67%) scored 3, and 6 students (20%) achieved a score of 4. A similar pattern was also observed for Item 2. In the experimental group, 21 students (65.63%) obtained a score of 3 and 10 students (31.25%) achieved a score of 4. In the control group, 24 students (80.00%) scored 3 and 4 students (13.33%) obtained a score of 4.

Furthermore, for Item 3, the experimental group showed that 28 students (87.50%) scored 3 and 1 student (3.13%) scored 4. In contrast, the control group had 23 students (76.67%) who obtained a score of 3 and 2 students (6.6%) who achieved a score of 4. For Item 4, the experimental group recorded 17 students (53.1%) scoring 3, while the control group showed 19 students (63.3%) at the same score, with no students in either group achieving a score of 4.

Table 6. Students' Creative Thinking Skills Pretest Scores

Item	**Score**									
	0		**1**		**2**		**3**		**4**	
	Exp	**Ctr**	**Exp**	**Ctr**	**Exp**	**Ctr**	**Exp**	**Ctr**	**Exp**	**Ctr**
1	0	0	0	0	2	0	24	23	6	6
	(0)	(0)	(0)	(0)	(6.2)	(0)	(75)	(76.6)	(18.7)	(23.3)
2	0	0	0	0	1	2	21	24	10	4
	(0)	(0)	(0)	(0)	(3.1)	(6.6)	(65.6)	(80)	(31.2)	(13.3)
3	0	1	0	0	3	3	28	23	1	2
	(0)	(3.3)	(0)	(0)	(9.3)	(10)	(87.5)	(76.6)	(3.1)	(10)
4	0	1	1	0	14	10	17	19	0	0
	(0)	(3.3)	(3.1)	(0)	(40.6)	(33.3)	(56.2)	(63.3)	(0)	(0)

Note: The first row shows frequencies; the second row shows percentages (%)

The post-test results show that both groups were able to provide answers relevant to the indicators of creative thinking, as indicated by the absence of students in either the experimental or control group who obtained scores of 0 or 1 on any of the test items. This condition suggests that all students had reached the basic level of creative thinking skills after the learning process was completed. When examining the distribution of higher scores, it becomes evident that the achievements of students in the experimental group are more evenly distributed across scores 3 and 4. For Item 1, for example, 56.25% of students in the experimental group achieved a score of 4 and 43.75% scored 3, while the control group was still dominated by score 3 (56.67%) with only 43.33% scoring 4. A similar pattern appears in Item 2, where the experimental group had an even distribution between scores 3 and 4 (50.00% each), whereas the control group leaned more heavily toward score 3 (70.00%) with only 30.00% achieving score 4.

Table 7. Students' Creative Thinking Skills Post-test Scores

Item	Score									
	0		1		2		3		4	
	Exp	Ctr	Exp	Ctr	Exp	Ctr	Exp	Ctr	Exp	Ctr
1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	14 (43.7)	17 (56.6)	18 (56.2)	13 (43.3)
2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	16 (50)	21 (70)	16 (50)	9 (30)
3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (13.3)	19 (59.3)	17 (56.6)	13 (40.6)	9 (30)
4	0 (0)	0 (0)	0 (0)	0 (0)	3 (9.3)	7 (23.3)	21 (65.6)	19 (63.3)	8 (25)	3 (10)

Note: The first row shows frequencies; the second row shows percentages (%)

For Item 3, 40.62% of experimental group students achieved a score of 4, which is higher than the control group's 30.00%, although the distribution of score 3 in both groups was relatively close (59.38% in the experimental group and 56.67% in the control group). This trend continued in Item 4, where 25.00% of experimental group students obtained a score of 4 and 65.62% scored 3, while the control group showed a lower percentage at score 4 (10.00%) and a higher percentage at score 2 (23.33%), indicating less complete responses compared to the experimental group.

Overall, the percentage distribution indicates that the experimental group consistently had a higher proportion of students achieving the highest score (score 4) on all test items. These findings suggest that the use of the discovery learning model supported by Augmented Reality (AR) was able to encourage students to produce more original, detailed, and flexible mathematical ideas compared to discovery learning without AR. Thus, the implementation of AR in instruction not only enhances understanding but also strengthens the quality of students' mathematical creative thinking skills at the end of the learning process.

Based on the pretest results, the creative thinking skills in the originality dimension (Item 1) between the control and experimental groups were relatively balanced, with average scores of approximately 3.2 and 3.12, respectively. In the fluency dimension (Item 2), both groups also showed nearly identical scores, namely 3.1 and 3.28. Similarly, in the flexibility (Item 3) and elaboration (Item 4) dimensions, the scores of both groups ranged from 2.5 to 3.0, with only minimal differences. This indicates that before the intervention, the participants' creative thinking skills across all dimensions were at comparable levels.

After the intervention, a more significant improvement occurred in the experimental group compared to the control group across all dimensions. In the originality dimension (Item 1), the experimental group's score increased to 3.56, while the control group reached 3.43. In the fluency dimension (Item 2), the experimental group recorded a score of 3.5, higher than the control group's 3.3. For flexibility (Item 3), the experimental group's score rose to 3.4, whereas the control group reached only 3.16. Finally, in the elaboration dimension (Item 4), the experimental group obtained a score of 3.1, while the control group scored 2.83. The consistent improvement across all dimensions of creative thinking demonstrates that the intervention successfully enhanced participants' originality, fluency, flexibility, and elaboration. Therefore, the implemented treatment was effective in improving various aspects of students' creative thinking skills.

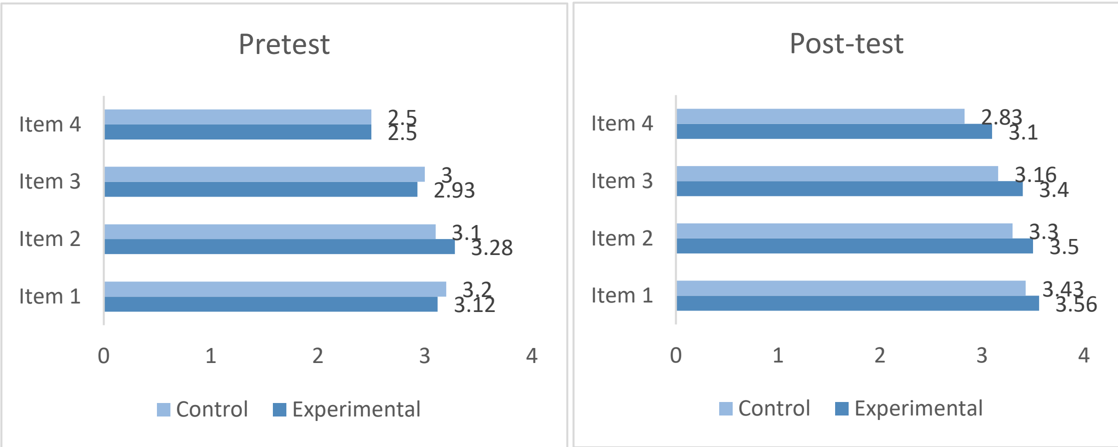

Figure 3. Comparison of Students' Score Achievement by Item

The normality analysis using the Shapiro-wilk test showed that all data in both the experimental group and the control group were normally distributed. In the pretest, the p value for the experimental group was 0.067 and for the control group was 0.091. In the post test, the p values were 0.122 and 0.084, all of which were greater than 0.05. This indicates that the data in all groups and measurement periods followed a normal distribution. In addition, the homogeneity of variance test using Levene's test showed that the variances between groups were uniform. The p value in the pretest was 0.872 and in the post test was 0.093, both greater than 0.05. Thus, the variances of the experimental and control groups can be considered homogeneous. With both assumptions met, namely normality and homogeneity, the data can be analyzed using an independent t test with the assumption of equal variances.

Table 8. Homogeneity and Normality Tests

Group	Pretest		Post-test	
	***p-value* (Levene)**	***p-value* (Shapiro-wilk)**	***p-value* (Levene)**	***p-value* (Shapiro-wilk)**
Experimental		0.067		0.122
Control	0.872	0.091	0.093	0.084

Based on the results of the t test on the pretest data, the obtained t value was 0.53 with 60 degrees of freedom (df) and a significance value (p-value) of 0.597. Since the p value is greater than 0.05, it can be concluded that there was no significant difference between the mean scores of students' initial creative thinking ability in the experiment group and the control group. The mean difference of 1.11 indicates that the gap between the two groups' pretest scores was very small, showing that the students' initial abilities in both groups were at a comparable level before receiving different instructional treatments. Therefore, both groups can be considered to have equivalent starting abilities, making them appropriate for comparison in the subsequent stages of the study.

Table 9. Independent Samples t-test for Pretest Mean Differences

t-test equality of means	**t**	**df**	**p-value**	**Mean differences**
	0.53	60	0.597	1.11

The post-test results show that the value of t = 2.31 with degrees of freedom (df) = 60 and a p-value = 0.012 (one-tailed). Since the p-value is smaller than 0.05, it indicates that there is a significant difference between the creative thinking abilities of students in the experimental class and those in the control class. The mean difference obtained was 5.47, indicating that the average creative thinking ability of students in the experimental class is higher than that of students in the control class. In this study, the experimental class participated in learning assisted by Augmented Reality (AR) technology, while the control class followed learning without using AR technology. These findings indicate that the use of AR technology in the learning process contributes to the improvement of students' creative thinking abilities.

Table 10. Independent Sample t-test and Effect Size of Students' Creative Thinking Ability

t	df	p-value	Mean Diff.	Cohen's d	Interpretation
2.31	60	0.012 *(1-tailed)*	5.47	0.60	Moderate

Furthermore, the effect size analysis using Cohen's d produced a value of 0.60. This value falls into the moderate effect category. Therefore, it can be concluded that the implementation of Augmented Reality-based learning has a meaningful effect on improving the creative thinking abilities of elementary school students compared to learning that does not use AR technology.

Discussion

This study demonstrates that the use of Augmented Reality technology has a strong influence on improving students' mathematical creative thinking abilities. Creative thinking is an important cognitive skill that must be developed in the era of globalization, as stated by (Astuti et al., 2023). In mathematics, this ability is highly relevant because it is related to students' capacity to generate new ideas, think flexibly, and discover original solutions. Guilford (1967) emphasized that creative thinking involves flexibility, fluency, and originality in thinking. Therefore, learning media that facilitate the exploration of concepts in various ways have a strategic role (Sharma et al., 2024).

The findings of this study are consistent with Anwar (2024), who found that Augmented Reality technology can support the development of higher-order thinking skills. This occurs because students can explore geometric objects more deeply and intuitively through the three-dimensional visualization provided by Augmented Reality technology. In addition, the study by Akçayır and Akçayır (2017) shows that Augmented Reality can improve students' spatial abilities. These spatial abilities serve as an important foundation for the development of mathematical creative thinking, especially when students are required to interpret, compare, and modify three-dimensional geometric shapes (Wu et al., 2024).

The spatial skills supported by the use of Augmented Reality technology are also reinforced by the findings of Koparan et al. (2023). They explained that these skills help students interpret and think about objects more deeply, making it easier to solve geometry problems. This study is also consistent with the research of Faradillah and Maulida (2022), which found that the use of Augmented Reality technology encourages students to find multiple ways to solve mathematical problems. The diversity of solution strategies is an important indicator of creative thinking ability (Hadar & Tirosh, 2019; Septiana & Faradillah, 2022).

In addition to improving creativity, the integration of Augmented Reality technology has also been shown to have a positive impact on learning outcomes, as indicated by the research of Koparan et al. (2023). This impact occurs because Augmented Reality technology can present geometric objects in visual forms that are close to real-life conditions, thereby facilitating students' understanding. This finding is supported by Cahyono et al. (2018), who stated that Augmented Reality technology can bridge the gap between mathematical concepts and the real world, thereby improving conceptual understanding and problem-solving abilities.

Although some studies have reported weaknesses of Augmented Reality technology in terms of interactivity, such as those reported by Akkuş and Özhan (2017), this study shows that interactivity can actually increase when instructional design considers didactic aspects such as learning obstacles, learning trajectories, and the TDS framework. The importance of such planning has been discussed in detail by Cahyono et al. (2020), who emphasized that learning experiences using Augmented Reality technology must be carefully designed so that students can construct mathematical knowledge meaningfully. Bereczki and Kárpáti (2021) also explained that the effectiveness of using Augmented Reality technology greatly depends on the pedagogical support provided to teachers and students.

The findings of this study also provide new contributions when compared with the research of Lee and Lee (2008), which implemented Augmented Reality-based games for early childhood students. This study shows that the same technology can also have a positive impact on the mathematical creative thinking abilities of elementary school students. In addition, this study supports the bibliometric findings by İslim et al. (2024), who analyzed six hundred forty-five articles and concluded that the use of Augmented Reality technology has a positive impact on problem-solving abilities that require higher-level strategies.

This study further enriches the understanding of the various benefits of Augmented Reality technology in mathematics learning. Previously, this technology has been found to improve mathematical literacy (Hakim et al., 2024), problem-solving abilities (Cahyono et al., 2018), mathematical computational thinking skills (Angraini et al., 2023), and geometric thinking abilities (Pujiastuti & Haryadi, 2024). The findings of this study expand this scope by demonstrating that Augmented Reality technology is also effective in supporting the development of mathematical creative thinking abilities.

These findings are in line with Alkhabra et al. (2023) and Wang et al. (2024), who stated that Augmented Reality technology can increase students' active engagement, thereby supporting the development of creativity. Dynamic interaction with mathematical objects allows students to explore and understand concepts more deeply. Furthermore, Ivan & Maat (2024) emphasized that Augmented Reality technology can enhance creative thinking abilities through clearer visualization and more meaningful learning experiences. The results of this study are also consistent with the findings of Sanabria and Arámburo-Lizárraga (2017), who stated that Augmented Reality technology is a pedagogical approach capable of promoting creative thinking abilities.

Overall, this study indicates that Augmented Reality technology has significant potential to enhance students' mathematical creative thinking abilities, particularly in the topic of three-dimensional geometry, which requires strong visualization and deep conceptual exploration. This technology provides immersive and interactive learning experiences that facilitate the development of creative thinking in mathematics.

This study has several limitations. First, the study was conducted with a limited number of participants; therefore, the findings cannot yet be generalized widely. Second, the study focused only on three-dimensional geometry topics, so the effectiveness of Augmented Reality technology in other areas of mathematics remains unknown. Third, the short duration of the learning intervention prevented the researchers from assessing the long-term impact of Augmented Reality technology on the development of creative thinking abilities. Fourth, this study did not consider factors such as teacher readiness and the availability of technological infrastructure, which may influence the quality of Augmented Reality implementation.

CONCLUSION

The findings of this study indicate that the integration of Augmented Reality (AR) in mathematics learning contributes positively to the improvement of elementary school students' creative thinking abilities. The use of AR in learning the surface area and volume of cubes and rectangular prisms enables students to interact with three-dimensional object representations more concretely, thereby helping them visualize the structure of geometric solids and explore various problem-solving strategies. This interactive learning environment provides opportunities for students to develop important aspects of creative thinking, such as fluency, flexibility, elaboration, and originality in solving mathematical problems.

Compared with learning without the support of AR technology, students who learned with the assistance of AR demonstrated higher levels of creative thinking ability at the end of the learning process. These findings indicate that the use of AR can enrich mathematics learning experiences by providing clearer visualizations and broader opportunities for students to explore and understand geometric concepts. The magnitude of the effect found in this study suggests that the implementation of AR-based learning has a meaningful impact on improving students' creative thinking abilities, indicating that the use of this technology not only produces statistical differences but also provides a tangible contribution to the learning process.

This study suggests that the integration of AR has the potential to become an effective instructional approach for supporting the development of creative thinking skills in elementary education. Therefore, AR-based technology can be considered an innovative alternative for mathematics instruction that creates more interactive and meaningful learning experiences for students, while also opening opportunities for future research to explore the application of AR in other mathematics topics and cognitive domains.

RECOMMENDATION

Future research is recommended to involve a larger sample size in order to obtain more representative results. Studies across various mathematical topics are also necessary to examine the consistency of the impact of Augmented Reality technology on creative thinking abilities. In addition, longitudinal research is needed to evaluate the sustainability of the effects of this technology. Future studies may also consider other supporting aspects such as student motivation, engagement in learning, and teacher readiness in using Augmented Reality technology. The development of more structured technology-based learning tools is also important to ensure that Augmented Reality technology can be used optimally to enhance students' mathematical creative thinking abilities.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to Maga Institute as a research and educational organization for facilitating the collaboration in this study.

FUNDING INFORMATION

This research received no external funding.

AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Komala	✓	✓		✓	✓	✓		✓	✓	✓			✓	
Abdul Rachman Tiro		✓				✓		✓	✓	✓	✓	✓		
Retno Wuri Sulistyowati	✓		✓				✓	✓			✓		✓	
Lutma Ranta Allolinggi		✓			✓	✓		✓			✓	✓		
Ady Akbar			✓	✓			✓	✓		✓		✓		

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

This study was conducted in accordance with all applicable national regulations and institutional policies. All procedures involving human participants adhered to the ethical principles outlined in the Declaration of Helsinki. The research was conducted with official permission from the Education Office of Gowa Regency. All participants provided informed consent prior to their participation in the study. The confidentiality of participants' data and identities was strictly maintained, and all information obtained was used solely for research purposes.

DATA AVAILABILITY

The data that support the findings of this study can be obtained from the corresponding author upon reasonable request.

REFERENCES

Affandy, H., Sunarno, W., Suryana, R., & Harjana. (2024). Integrating creative pedagogy into problem-based learning: The effects on higher order thinking skills in science education. *Thinking Skills and Creativity*, *53*, 101575. https://doi.org/10.1016/j.tsc.2024.101575

Akbar, A., Herman, T., Suryadi, D., Mursalim, ., Alman, ., Putra, E. D., & Blegur, J. (2025). Integrating Augmented Reality in Mathematics Learning to Improve Critical Thinking Skills of Elementary School Students. *Emerging Science Journal*, *9*(2), 764–779. https://doi.org/10.28991/ESJ-2025-09-02-014

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Akkuş, İ., & Özhan, U. (2017). Matematik ve Geometri Eğitiminde Artırılmış Gerçeklik Uygulamaları. *İnönü Üniversitesi Eğitim Bilimleri Enstitüsü Dergisi*, *4*(8), 19–34. https://doi.org/10.29129/inujgse.358421

Alghamdi, J., & Alshahrani, H. (2025). Exploring the effect of augmented reality in enhancing motivation and mathematics performance for children with learning disabilities. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(12), em2745. https://doi.org/10.29333/ejmste/17489

Alkhabra, Y. A., Ibrahem, U. M., & Alkhabra, S. A. (2023). Augmented reality technology in enhancing learning retention and critical thinking according to STEAM program. *Humanities and Social Sciences Communications*, *10*(1), 174. https://doi.org/10.1057/s41599-023-01650-w

Angraini, L. M., Susilawati, A., Noto, M. S., Wahyuni, R., & Andrian, D. (2023). Augmented Reality for Cultivating Computational Thinking Skills in Mathematics Completed with Literature Review, Bibliometrics, and Experiments for Students. *Indonesian Journal of Science and Technology*, *9*(1), 225–260. https://doi.org/10.17509/ijost.v9i1.67258

Anwar, M. (2024). Leveraging Augmented Reality to Cultivate Higher-Order Thinking Skills and Enhance Students' Academic Performance. *International Journal of Information and Education Technology*, *14*(10), 1405–1413. https://doi.org/10.18178/ijiet.2024.14.10.2171

Arsari, A. (2022). *Augmented Reality Bangun Ruang*. https://drive.google.com/drive/folders/1DWi0UwDP-tOeCdSzJ2fWMSSnmwnm7AtP

Astuti, A., Syahfitriani Br Ginting, Paustina Ngali Mahuze, Serlina Boru Sinaga, Rival Hanip, Najdah Thalib, & Prima Lestari Situmorang. (2023). Kemampuan Berpikir Kreatif Matematika pada Siswa Bergaya Belajar Visual. *Simpati*, *2*(1), 08–15. https://doi.org/10.59024/simpati.v2i1.500

Bereczki, E. O., & Kárpáti, A. (2021). Technology-enhanced creativity: A multiple case study of digital technology-integration expert teachers' beliefs and practices. *Thinking Skills and Creativity*, *39*, 100791. https://doi.org/10.1016/j.tsc.2021.100791

Bicer, A. (2021). Multiple representations and mathematical creativity. *Thinking Skills and Creativity*, *42*, 100960. https://doi.org/10.1016/j.tsc.2021.100960

Bicer, A., Aleksani, H., Butler, C., Jackson, T., Smith, T. D., & Bostick, M. (2024). Mathematical creativity in upper elementary school mathematics curricula. *Thinking Skills and Creativity*, *51*, 101462. https://doi.org/10.1016/j.tsc.2024.101462

Blegur, J., P. Wasak, M. R., & Manu, L. (2017). Penilaian Formatif Peserta Didik Atas Kompetensi Pendidik Dalam Proses Pembelajaran. *Satya Widya*, *33*(2), 117–127. https://doi.org/10.24246/j.sw.2017.v33.i2.p117-127

Bosch, N. (1997). *Rubric for creative thinking skills evaluation*. https://adifferentplace.org/creativethinking.html

Budhiarti, Y., Mytra, P., & Slow, L. (2025). The Role of Deep Learning in Elementary Education : Pedagogical Insights from a Literature Study. *Jurnal Pedagogi Dan Inovasi*

Pendidikaninovasi Pendidikan, *1*(2), 42–51. https://jurnal-pip.com/index.php/jpip/article/view/14%0Ahttps://jurnal-pip.com/index.php/jpip/article/download/14/11

Cahyaningsih, R. D., Purwanto, A., & Khaerudin, K. (2023). Analysis of Students' Creative Thinking in Science Learning. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *11*(3), 719. https://doi.org/10.33394/j-ps.v11i3.7934

Cahyono, A. N., Sukestiyarno, Y., & Asikin, M. (2020). Learning mathematical modelling with augmented reality mobile math trails program: How can it work? *Journal on Mathematics Education*, *11*(2), 181–192. https://doi.org/10.22342/jme.11.2.10729.181-192

Cahyono, B., Firdaus, M. B., Budiman, E., & Wati, M. (2018). Augmented Reality Applied to Geometry Education. *2018 2nd East Indonesia Conference on Computer and Information Technology (EIConCIT)*, 299–303. https://doi.org/10.1109/EIConCIT.2018.8878553

Cai, S., Liu, E., Shen, Y., Liu, C., Li, S., & Shen, Y. (2020). Probability learning in mathematics using augmented reality: impact on student's learning gains and attitudes. *Interactive Learning Environments*, *28*(5), 560–573. https://doi.org/10.1080/10494820.2019.1696839

Christopher, I. O., Julie, O. I., Charity, U. C., & Janehilda, A. O. (2020). Assessment of students' creative thinking ability in mathematical tasks at senior secondary school level. *International Journal of Curriculum and Instruction*, *12*(2), 494–506.

Demitriadou, E., Stavroulia, K.-E., & Lanitis, A. (2020). Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education. *Education and Information Technologies*, *25*(1), 381–401. https://doi.org/10.1007/s10639-019-09973-5

Dewanti, B. A. (2022). Comparing Student Creativity Skills in Experiment-Based and Project-Based Science Learning. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *10*(3), 786. https://doi.org/10.33394/j-ps.v10i3.5348

Dewanti, B. A., & Santoso, A. (2020). Development of 21st Century Learning Skills Assessment Instruments in STEM-Based Science Learning (Science, Technology, Engineering, and Mathematics). *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *8*(2), 99. https://doi.org/10.33394/j-ps.v8i2.3041

Faiziyah, N., Hanan, N. A., Azizah, N. N., Keguruan, F., Pendidikan, I., Muhammadiyah, U., Jalan, S., Yani, A., Pos, T., Pabelan, K., Sukoharjo, J., & Tengah, I. (2022). *Mosharafa: Jurnal Pendidikan Matematika Kemampuan Berpikir Kreatif Siswa dalam Menyelesaikan Soal berbasis Etnomatematika Tipe Multiple Solutions Task*. *11*(3). http://journal.institutpendidikan.ac.id/index.php/mosharafa

Faradillah, A., & Maulida, A. (2022). Students' creative thinking ability assisted augmented reality based on visualizer-verbalizer cognitive style. *Jurnal Elemen*, *8*(2), 659–674. https://doi.org/10.29408/jel.v8i2.5693

Guilford, J. P. (1967). Creativity: Yesterday, Today and Tomorrow. *The Journal of Creative Behavior*, *1*(1), 3–14. https://doi.org/10.1002/j.2162-6057.1967.tb00002.x

Hadar, L. L., & Tirosh, M. (2019). Creative thinking in mathematics curriculum: An analytic framework. *Thinking Skills and Creativity*, *33*, 100585. https://doi.org/10.1016/j.tsc.2019.100585

Hakim, L. L., Hidayat, H., Salmun, A., & Sulastri, Y. L. (2024). *Applications of Augmented Reality in Mathematics Learning: A Bibliometric and Content Analysis* (pp. 250–263). https://doi.org/10.2991/978-2-38476-206-4_29

Haylock, D. (1997). Recognising mathematical creativity in schoolchildren. *Zentralblatt Für*

Didaktik Der Mathematik, *29*(3), 68–74. https://doi.org/10.1007/s11858-997-0002-y
Hedges, L. V. (2025). Interpretation of the Standardized Mean Difference Effect Size When Distributions Are Not Normal or Homoscedastic. *Educational and Psychological Measurement*, *85*(2), 245–257. https://doi.org/10.1177/00131644241278928
Herawati, A., Afiani, K. D. A., & Mirnawati, L. B. (2023). Analisis Kemampuan Berpikir Kreatif Siswa Kelas 3 dalam Menyelesaikan Masalah Soal Cerita pada Pembelajaran Matematika SD. *Al-Madrasah: Jurnal Pendidikan Madrasah Ibtidaiyah*, *7*(3), 1201. https://doi.org/10.35931/am.v7i3.2499
İslim, Ö. F., Namli, Ş., Sevim Çirak, N., Özçakir, B., & Lavicza, Z. (2024). Augmented Reality in Mathematics Education: A Systematic Review. *Participatory Educational Research*, *11*(4), 115–139. https://doi.org/10.17275/per.24.52.11.4
Ivan, V., & Maat, S. M. (2024). The Usage of Augmented Reality Technology in Mathematics Education: A Systematic Literature Review. *International Journal of Academic Research in Progressive Education and Development*, *13*(1). https://doi.org/10.6007/IJARPED/v13-i1/20064
Koparan, T., Dinar, H., Koparan, E. T., & Haldan, Z. S. (2023). Integrating augmented reality into mathematics teaching and learning and examining its effectiveness. *Thinking Skills and Creativity*, *47*, 101245. https://doi.org/10.1016/j.tsc.2023.101245
Lee, H. S., & Lee, J. W. (2008). *Mathematical Education Game Based on Augmented Reality* (pp. 442–450). https://doi.org/10.1007/978-3-540-69736-7_48
Leibovitch, Y. M., Beencke, A., Ellerton, P. J., McBrien, C., Robinson-Taylor, C.-L., & Brown, D. J. (2025). Teachers' (evolving) beliefs about critical thinking education during professional learning: A multi- case study. *Thinking Skills and Creativity*, *56*, 101725. https://doi.org/10.1016/j.tsc.2024.101725
Leikin, R., & Sriraman, B. (2022). Empirical research on creativity in mathematics (education): from the wastelands of psychology to the current state of the art. *ZDM – Mathematics Education*, *54*(1), 1–17. https://doi.org/10.1007/s11858-022-01340-y
Liu, E., Li, Y., Cai, S., & Li, X. (2019). *The Effect of Augmented Reality in Solid Geometry Class on Students' Learning Performance and Attitudes* (pp. 549–558). https://doi.org/10.1007/978-3-319-95678-7_61
Lubis, A. H., & Idris, A. (2025). Realistic Mathematics Education Approach with the Assistance of Augmented Reality Media to Improve Elementary School Students' Mathematics Learning Outcomes. *Jurnal Profesi Guru Indonesia*, *2*(2), 15–21. https://doi.org/10.62945/jpgi.v2i2.746
Meriyati, M., Nitin, M., Bradford, S., & Wiliyanti, V. (2024). The Impact of Applying Augmented Reality Technology in Learning on Student Learning Experiences. *Journal Emerging Technologies in Education*, *2*(2), 215–228. https://doi.org/10.70177/jete.v2i2.1067
Mullis, I. V. ., Martin, M. O., Foy, P., & Hopper, M. (2016). Timss 2015 International Results in Mathematics. In *TIMSS & PIRLS International Study Center*. http://timss2015.org/timss-2015/science/student-achievement/distribution-of-science-achievement/
OECD. (2017). *PISA 2021 Mathematics: A Broadened Perspective*. OECD.
PISA 2018 Assessment and Analytical Framework. (2019). OECD Publishing. https://doi.org/10.1787/b25efab8-en
Pujiastuti, H., & Haryadi, R. (2024). The Effectiveness of Using Augmented Reality on the Geometry Thinking Ability of Junior High School Students. *Procedia Computer Science*, *234*, 1738–1745. https://doi.org/10.1016/j.procs.2024.03.180
Sadeghi, Z., & Hamedi, A. (2024). The Impact of Philosophizing Training on Students' Inquisitiveness and Creative Thinking. *Iranian Journal of Educational Sociology*, *7*(2), 150–157. https://doi.org/10.61838/kman.ijes.7.2.18

Sanabria, J. C., & Arámburo-Lizárraga, J. (2017). Enhancing 21st Century Skills with AR: Using the Gradual Immersion Method to develop Collaborative Creativity. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(2). https://doi.org/10.12973/eurasia.2017.00627a

Septiana, C., & Faradillah, A. (2022). Flipped Classroom Learning: Mathematical Creative Thinking Skills Based on Mathematical Resilience using Augmented Reality. *Jurnal Pendidikan Progresif*, *12*(3), 1218–1231. https://doi.org/10.23960/jpp.v12.i3.202217

Sharma, A. K., Goyal, A., & Sharma, A. (2024). Relevance of classical management concepts in the contemporary era – a case study of Fayol's principles. *IIMT Journal of Management*, *1*(1), 112–120. https://doi.org/10.1108/IIMTJM-10-2023-0026

Siregar, S. (2023). Analisis Keterampilan Berpikir Kreatif dalam Pengerjaan Soal Matematika Siswa Kelas IV. *Jurnal Arjuna : Publikasi Ilmu Pendidikan, Bahasa Dan Matematika*, *1*(5), 222–229. https://doi.org/10.61132/arjuna.v1i5.280

Suherman, E. (2003). *Evaluasi Pembelajaran Matematika*. JICA Universitas Pendidikan Indonesia.

Syarifudin, A., Nurdin, N., Sururi, S., & Akbar, A. (2021). Integrasi Teknologi dalam Pemblajaran: Kajian Pedagogi untuk Mengembangkan Kemampuan Berpikir Kritis. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, *32*(3), 167–186.

Torrance, E. P. (1966). *Torrance tests of creative thinking: Norms technical manual (Research Edition)*. Personnel Press.

Wang, X.-M., Huang, X.-T., Han, Y.-H., & Hu, Q.-N. (2024). Promoting students' creative self-efficacy, critical thinking and learning performance: An online interactive peer assessment approach guided by constructivist theory in maker activities. *Thinking Skills and Creativity*, *52*, 101548. https://doi.org/10.1016/j.tsc.2024.101548

Willemsen, R. H., de Vink, I. C., Kroesbergen, E. H., & Lazonder, A. W. (2023). The role of creative thinking in children's scientific reasoning. *Thinking Skills and Creativity*, *49*, 101375. https://doi.org/10.1016/j.tsc.2023.101375

Wu, J., Jiang, H., Long, L., & Zhang, X. (2024). Effects of AR mathematical picture books on primary school students' geometric thinking, cognitive load and flow experience. *Education and Information Technologies*, *29*(18), 24627–24652. https://doi.org/10.1007/s10639-024-12768-y

Xu, H., Deng, T., Xu, X., & Gu, X. (2024). The effectiveness of educational interventions on thinking and operational skills in complex learning—A meta-analysis. *Thinking Skills and Creativity*, *53*, 101574. https://doi.org/10.1016/j.tsc.2024.101574