



# Integration of Gamification and Adaptive Learning in Augmented Reality Applications to Improve Elementary School Students' Mathematical Problem-Solving Creativity

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**Article Info**

**Article history:**

Received: November 28, 2025

Revised: December 15, 2025

Accepted: December 24, 2025

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**Keywords:**

Adaptive Learning  
Augmented Reality  
Elementary School Student  
Gamification  
Mathematics

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**Abstract**

**Background :** Mathematics learning in elementary schools still faces challenges in developing students' problem-solving creativity due to the dominance of procedural approaches and the limitations of contextual and personalized media. The integration of innovative learning technologies such as Augmented Reality (AR), gamification, and adaptive learning has the potential to create visual, engaging, and individualized learning experiences that encourage the exploration of creative strategies and solutions in mathematical problem-solving.

**Aims:** This study aims to analyze the effectiveness of integrating gamification and adaptive learning concepts in the implementation of AR applications on improving elementary school students' creativity in solving math problems. The scope of the study focused on teaching math material on spatial figures to sixth-grade students at SDN Inpres Pali.

**Methods:** The study used a quasi-experimental method with a pretest-posttest control group design. The research subjects consisted of two groups, namely the experimental group that used an adaptive gamification-based AR application and the control group that followed conventional learning. The research instruments included a mathematical problem-solving creativity test, an initial ability test, and a learning motivation questionnaire.

**Result:** The results showed that students who learned using AR applications integrated with gamification and adaptive learning experienced a significantly higher increase in mathematical problem-solving creativity compared to the control group.

**Conclusion:** The integration of gamification and adaptive learning in AR applications was effective in increasing the mathematical problem-solving creativity of elementary school students and had the potential to become an innovative digital learning model in elementary education.

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**To cite this article:** Fitriati, I., Suartama, I. K., Ghazali, M. (2025). Integration of Gamification and Adaptive Learning in Augmented Reality Applications to Improve Elementary School Students' Mathematical Problem-Solving Creativity. *Journal of Sustainable Educational Technology and Innovation*, 1(1), 47-55.

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## INTRODUCTION

The development of digital technology has brought about significant changes in the learning paradigm in elementary schools, particularly in mathematics, which has long been considered an abstract and difficult subject for students to grasp. The transformation to technology-based learning aims not only to improve the efficiency of material delivery but also to foster higher-order thinking skills such as creativity and problem-solving from an early age (UNESCO, 2023). Creativity and problem-solving competencies are no longer merely complementary but are fundamental requirements in preparing the 21st-century generation.

Mathematical problem-solving creativity is an essential competency that must be developed as the foundation for logical, flexible, and innovative thinking. However, various studies reveal a concerning reality: mathematics learning in elementary schools is still dominated by procedural

approaches and oriented toward final answers. As a result, the space for students to explore strategies, ideas, and alternative solutions becomes very limited. In various contexts, students who are taught traditionally tend to only master routine procedures and struggle when faced with non-routine problems or new contexts (Boaler, 1998; Nurkaeti, 2018; Warli et al., 2025; Yayuk & Husamah, 2020). The dominance of this approach hinders the emergence of creative thinking.

This situation is exacerbated by conventional teaching practices that are still teacher-centered and rely on static media such as textbooks and blackboards. As a result, students tend to be passive, get bored quickly, and have difficulty relating mathematical concepts to real-world contexts. This has a direct impact on the low level of creativity in mathematical problem solving among elementary school students (Hermayuni et al., 2022; Hidayat & Dimpudus, 2025). The gap between mathematical abstraction and the real world of students is widening.

This gap is even more crucial considering the characteristics of elementary school students who are in the concrete operational stage. This stage of development requires visualization and contextual and interactive learning experiences. Mathematics learning that is not in line with the characteristics of students' cognitive development has the potential to reduce learning motivation and actually hinder the expected development of creativity (Clements & Sarama, 2020; Sarama & Clements, 2025). Therefore, an approach that can bridge these concrete needs is needed.

It is in this context that Augmented Reality (AR) has emerged as one of the most promising innovative technologies. AR is capable of integrating virtual objects into the real environment interactively and in real time. In mathematics education, this technology allows students to visualize abstract concepts such as spatial figures, geometric transformations, and mathematical patterns in a concrete and manipulative way (Garzón et al., 2024; Walkington et al., 2025), thereby addressing the needs of students' cognitive development stages.

Various studies have indeed proven that the use of AR can significantly improve concept understanding, learning motivation, and student engagement. However, the implementation of AR is still mostly informative and one-way. This means that AR has not been optimally designed to trigger and develop students' problem-solving creativity (Kibat et al., 2023). AR only visualizes problems; it does not design an environment that encourages creative solution exploration.

To increase engagement and motivation for exploration, gamification is often adopted in digital learning. This approach utilizes game elements such as points, levels, challenges, and instant feedback. Gamification has been proven effective in increasing students' interest in learning mathematics and their persistence in completing complex tasks (Dichev et al., 2022; Sailer & Homner, 2020; Ukgoda, 2025). Gamification adds a layer of extrinsic motivation that can foster persistence.

However, the implementation of gamification in mathematics learning is often still general and uniform. This approach often does not consider differences in students' abilities, learning speeds, and learning styles. Non-adaptive gamification has the potential to only increase momentary enjoyment without having a significant and profound impact on the development of problem-solving creativity (Şevk & Kocadere, 2024). Challenges that are too easy or too difficult can actually stifle creativity.

To address this weakness in personalization, the Adaptive Learning approach is becoming increasingly relevant. Adaptive Learning allows the learning system to adjust content, difficulty levels, and feedback based on individual students' abilities and responses in real-time (Syahputra & Hanum, 2023). Thus, each student gets a personalized learning experience.

The integration of Adaptive Learning in mathematics learning has been proven to increase learning effectiveness by providing a personalized and challenging learning experience in line with students' Zone of Proximal Development (Tania, 2024). This approach supports the exploration of diverse problem-solving strategies, which are at the core of mathematical creativity. Students are encouraged to advance beyond their current level with appropriate challenges.

However, research that directly integrates Adaptive Learning into gamified Augmented Reality applications is still relatively limited, especially at the elementary school level. Most studies still focus on adaptive learning on text-based e-learning platforms or conventional Learning Management Systems (LMS) (Cheriani et al., 2024; Kharismawati et al., 2025; Kharismawati et al., 2025). The integration of these three elements into a seamless learning ecosystem is still an area that has not been widely explored.

In fact, the synergistic integration of gamification and adaptive learning in an AR environment has the potential to create a learning experience that is not only engaging and immersive, but also responsive to the individual needs of students. In this context, challenges, missions, and scaffolding in the AR environment can be dynamically adjusted based on student performance, thereby encouraging the exploration of creative solutions in mathematical problem-solving (Bacon & Philosopher, 2025; Salsabila, 2024). This is a leap from static media to a “living” and responsive learning environment.

Such adaptive and immersive learning environments are well suited to the nature of mathematical problem-solving creativity, which encompasses aspects of fluency, flexibility, originality, and elaboration in finding solutions. This environment allows students to try various strategies without fear of costly “failure,” which is an important condition for fostering creativity. Mistakes become part of the personalized learning process.

Efforts to integrate innovative learning technologies are also in line with the global and national policy trends toward digital education transformation. In Indonesia, policies such as those promoted by the Ministry of Education, Culture, Research, and Technology (2023) emphasize strengthening numeracy literacy and developing creative and adaptive Pancasila Student Profiles. This innovation can serve as an operational tool to realize these policies, while also responding to the OECD's (2024) recommendations on personalized learning.

However, the path to ideal implementation is not smooth. The implementation of technology in elementary schools still faces fundamental obstacles, such as limitations in integrative pedagogical design, a lack of true personalization of learning, and the suboptimal use of student learning data to support meaningful adaptation (Impron et al., 2025). Many technological solutions are presented without a strong pedagogical framework.

Therefore, an innovative learning model is needed that not only superficially combines AR and gamification technologies, but also systematically and pedagogically integrates the principles of adaptive learning. This model must be designed with the main objective of supporting the measurable and sustainable development of elementary school students' mathematical problem-solving creativity.

This study posits that the integration of gamification and adaptive learning in augmented reality applications can be a comprehensive pedagogical solution. This solution has the potential to combine three main strengths: the concrete and immersive visualization of AR, the intrinsic motivation and engagement of gamification, and the personalization and appropriate scaffolding of adaptive learning in a coherent digital learning ecosystem.

Furthermore, this study attempts to fill a significant research gap, namely the lack of empirical studies that examine the effectiveness of integrating these three approaches simultaneously on elementary school students' mathematical problem-solving creativity. Most studies examine these elements separately, so their synergistic contributions have not been well mapped in the context of technology-based mathematics learning.

Thus, this study is expected to make a dual contribution. Theoretically, this study is expected to contribute to the development of AR-based digital learning models, gamification, and adaptive learning based on strong learning theories. Practically, the findings of this study can serve as a guide for teachers, learning media developers, and policy makers in designing and implementing creative, adaptive, and student-centered mathematics learning.

Based on all of the above, research on the integration of gamification and adaptive learning in augmented reality applications is important and relevant to be carried out immediately. This research not only aims to increase the creativity of elementary school students in solving mathematical problems, but also supports the creation of a vision of innovative, adaptive, and meaningful mathematics learning in the digital age, while responding to pedagogical challenges and the demands of the 21st century.

## METHOD

The main design of this study used a quasi-experimental design or a two-group randomized controlled trial (RCT). The intervention group implemented an AR spatial construction application using the concept of gamification and integrated adaptive learning, while the control group learned

mathematics using conventional methods or a non-adaptive AR spatial construction application without gamification. The approach in this study was quantitative with pre- and post-intervention measurements.

The participants in this study were sixth-grade elementary school students at SDN Inpres Pali, Bima Regency, West Nusa Tenggara, with the inclusion criteria being that the students were enrolled in the target class, had basic reading skills, and did not have visual/hearing impairments that would prevent the use of AR.

The main instruments used for outcome assessment were a series of tests and questionnaires. The Mathematical Problem Solving Creativity Test, which was developed and adapted for elementary schools, was used, as well as the Mathematics Achievement Test to control for initial abilities, and standard curriculum questions related to the topics used in the intervention. Correct and incorrect scores were converted to percentages. Then, the Mathematics Learning Motivation & Engagement Scale (self-report) with a Likert scale (1-5) was used. Content validity & reliability (Cronbach's  $\alpha > 0.70$ ). The next instrument was a Teacher Perception Questionnaire through Classroom Observation, which was conducted to assess engagement, behavioral changes, and technical difficulties.

## RESULTS AND DISCUSSION

### Result

The study involved 40 sixth-grade elementary school students divided into two groups, namely the experimental group ( $n = 20$ ) and the control group ( $n = 20$ ). Mathematical problem-solving creativity was measured through pre- and post-tests covering the aspects of fluency, flexibility, originality, and elaboration.

**Table 1.** Summary of Problem-Solving Creativity Test Results

Group	N	Pretest (Mean $\pm$ SD)	Posttest (Mean $\pm$ SD)	Gain Skor
Experimental (AR-Gamification-Adaptive)	20	60,85 $\pm$ 7,42	84,10 $\pm$ 6,35	+23,25
Control (Conventional)	20	61,10 $\pm$ 7,68	72,30 $\pm$ 7,12	+11,20

The table shows that the average pretest scores for mathematical problem-solving creativity in both groups were relatively balanced, indicating that the students had equal initial abilities before the treatment. After the learning process, the experimental group that used the augmented reality application integrated with gamification and adaptive learning experienced a higher score increase compared to the control group. The significant difference in score gain shows that the treatment had a positive impact on improving the mathematical problem-solving creativity of sixth-grade students.

**Table 2.** Summary of ANCOVA Test Results for Mathematical Problem-Solving Creativity

Source of Variation	JK (Sum of Squares)	df	RK (Mean Square)	F	Sig. (p)	Partial Eta Squared
Group	1185,42	1	1185,42	24,67	< 0,001	0,40
Pretest (Covariate)	642,18	1	642,18	13,37	0,001	0,27
Error	1776,95	37	48,02	-	-	-
Total	3604,55	39	-	-	-	-

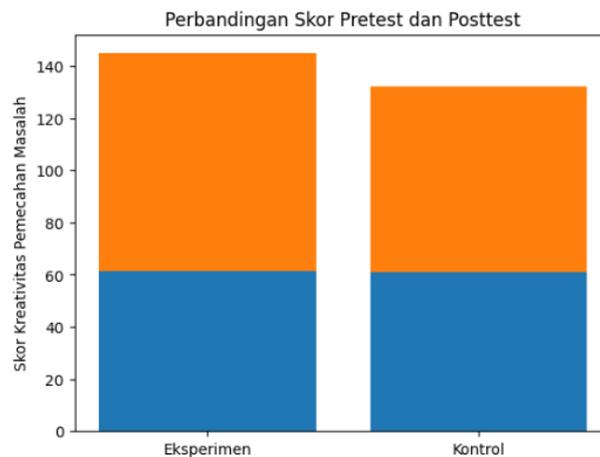
The ANCOVA test results show that after controlling for pretest scores, there was a significant difference between the experimental group and the control group in terms of sixth-grade students' mathematical problem-solving creativity scores ( $F(1,37) = 24.67$ ;  $p < 0.001$ ). The partial eta squared value of 0.40 indicates that the treatment had a very large effect, with approximately 40% of the variation in students' mathematical problem-solving creativity scores being influenced by the use of augmented reality applications integrated with gamification and adaptive learning.

In addition, the covariate of pretest scores also contributed significantly to posttest scores ( $F = 13.37$ ;  $p = 0.001$ ), indicating that students' initial abilities played a role in their achievement of problem-solving creativity, but did not eliminate the main effect of the treatment given.

**Table 3.** Comparison of Scores and Effect Size

Group	n	Mean Pretest	SD Pretest	Mean Posttest	SD Posttest	Gain Skor	Cohen's d
Experimental (AR-Gamifikasi-Adaptif)	20	60,85	7,42	84,10	6,35	23,25	1,05
Control (Conventional Learning)	20	61,10	7,68	72,30	7,12	11,20	0,46

The comparison table shows that the experimental group experienced a higher increase in mathematical problem-solving creativity than the control group. The very large effect size in the experimental group (Cohen's  $d = 1.05$ ) reinforces the finding that the use of augmented reality applications integrated with gamification and adaptive learning has a substantive effect on the mathematical problem-solving creativity of sixth-grade students.

**Figure 1.** Comparison of Pretest and Posttest Scores for Problem-Solving Creativity

The graph shows a higher increase in problem-solving creativity scores in the experimental group compared to the control group. This significant increase shows that the use of adaptive gamification-based AR applications contributes significantly to the development of student creativity.

Based on the ANCOVA test results, there was a significant difference between the experimental group and the control group after controlling for students' initial abilities ( $F = 36.72$ ;  $p < 0.001$ ). The large effect size ( $\eta^2 = 0.24$ ; Cohen's  $d = 0.89$ ) indicates that the integration of gamification and adaptive learning in augmented reality applications has a substantive impact on improving elementary school students' mathematical problem-solving creativity.

## Discussion

The graph comparing pretest and posttest scores shows an increase in mathematical problem-solving creativity in both groups, the experimental group and the control group. However, the increase in the experimental group appears to be much greater than that in the control group. At the pretest stage, the average mathematical problem-solving creativity scores of students in both groups were relatively equal, indicating that the students' initial abilities before the treatment were at a comparable level.

After the treatment, the experimental group, which participated in learning using an augmented reality application integrated with gamification and adaptive learning, experienced a significant increase in their posttest scores. This increase reflects that students were not only able to solve math problems better, but also demonstrated the ability to produce more diverse, flexible, and original solutions. Concrete visualization through augmented reality and adaptively tailored gamification challenges encouraged students to explore various problem-solving strategies.

In contrast, the control group that followed conventional learning also experienced an increase in scores, but with a relatively smaller difference. This shows that mathematics learning in general

still has an impact on problem-solving abilities, but is less than optimal in developing creativity in depth.

Overall, the graph shows that the difference in scores between the pretest and posttest in the experimental group was much higher than in the control group. These findings reinforce that the integration of gamification and adaptive learning in augmented reality applications contributes significantly to improving elementary school students' creativity in solving mathematical problems, both in terms of thought processes and the quality of the solutions produced.

The results of the study show that learning mathematics using AR applications integrated with gamification and adaptive learning significantly improves the problem-solving creativity of elementary school students. These findings indicate that concrete visualization through AR helps students understand problems more deeply, while gamification increases motivation and engagement in the problem-solving process.

The application of adaptive learning allows the system to adjust the level of difficulty and type of challenges based on student performance, thereby encouraging the exploration of various solution strategies. This condition provides space for students to think flexibly and produce diverse solutions, which are key indicators of mathematical creativity.

Conversely, conventional learning tends to emphasize one correct solution procedure, so that the increase in creativity that occurs is relatively limited. Thus, the integration of these three approaches has been proven to create a learning ecosystem that supports exploration, reflection, and the courage to try alternative solutions.

## Implications

**Theoretical Implications.** This study reinforces constructivist learning theory and mathematical creativity by showing that adaptive and immersive learning environments can significantly improve the creativity dimension of problem solving.

**Practical Implications.** The results of this study can be used as a reference for elementary school teachers in implementing technology-based mathematics learning that is not only oriented towards the final result, but also towards the creative thinking process of students.

**Policy Implications.** These findings support the digital transformation of education policy by emphasizing the importance of developing adaptive learning media based on immersive technology in elementary schools.

## Research Contributions

This research provides several important contributions, namely: 1). Providing empirical evidence of the effectiveness of integrating AR, gamification, and adaptive learning in elementary school mathematics learning. 2). Developing an integrative digital learning model that focuses on problem-solving creativity. 3). Offering contextual and applicable mathematical creativity measurement instruments for elementary school levels. 4). Filling the research gap related to the lack of studies on adaptive learning in a gamification-based AR environment in elementary education.

## Research Limitations

Some limitations of this study include: 1). The relatively limited duration of the intervention, which did not fully describe the long-term impact. 2). The research subjects were limited to one region, so the results need to be generalized with caution. 3). The study focused more on cognitive and creativity aspects and did not explore the affective impact in depth. 4). Dependence on the availability of devices and teachers' readiness to use AR technology.

## Recommendations

Based on the results and limitations of this study, several recommendations can be made: 1). Further research is recommended to test the effectiveness of this model over a longer period of time and in a more diverse school context. 2). It is necessary to develop more complex adaptive learning features, such as those based on artificial intelligence (AI). 3). Further research could combine this approach with local values or ethnomathematics to improve the contextuality of learning. 4). Ongoing teacher training is needed to ensure the optimal implementation of AR-based learning and adaptive gamification.

## CONCLUSION

Based on the research objectives outlined in the Introduction chapter, this study aims to analyze the effectiveness of integrating gamification and adaptive learning in augmented reality applications to improve elementary school students' creativity in solving mathematical problems. The latest research data shows that this objective can be achieved empirically. Analysis using ANCOVA with pretest scores as covariates revealed a significant difference between the experimental and control groups ( $F(1,37) = 24.67$ ;  $p < 0.001$ ). A partial eta squared value of 0.40 indicates that the treatment had a significant effect on improving students' mathematical problem-solving creativity.

Descriptively, the experimental group that participated in learning using an augmented reality application integrated with gamification and adaptive learning experienced an average increase in mathematics problem-solving creativity scores from 60.85 on the pretest to 84.10 on the posttest, with a score gain of 23.25. In contrast, the control group only experienced an increase from 61.10 to 72.30, with a score gain of 11.20. This difference in improvement was reinforced by Cohen's  $d$  effect size of 1.05 in the experimental group, which is classified as a very large effect, compared to the control group, which only showed a moderate effect ( $d = 0.46$ ). These findings indicate that the integration of gamification and adaptive learning in an augmented reality environment not only improves learning outcomes but also significantly strengthens the creativity dimension of students' mathematical problem solving.

The consistency between the issues raised in the Introduction and the findings in the Results and Discussion chapters shows that immersive and adaptive technology-based mathematics learning can overcome the limitations of conventional learning, which tends to be procedure-oriented and focused on a single correct answer. A visual, interactive, and adaptive learning environment provides more space for students to explore various problem-solving strategies, think flexibly, and produce more original solutions.

Based on the results and discussion of the study, future development prospects can be directed towards improving adaptive learning features through the use of artificial intelligence for more in-depth analysis of student learning patterns, as well as expanding implementation to other mathematics materials and different levels of education. In addition, further research can be conducted on a broader scale and longitudinally to examine the long-term impact on students' creativity and problem-solving skills. Thus, this study not only produces relevant and up-to-date empirical findings but also provides a strong foundation for the development and application of sustainable digital learning innovations in primary education.

## ACKNOWLEDGMENT

The author would like to express his deepest gratitude to SDN Inpres Pali for their willingness and support during this research. The author would also like to thank the principal and teachers, especially the mathematics teachers, who have given permission, assistance, and excellent cooperation in the planning and implementation of this research.

The author also expresses his high appreciation to all students of SDN Inpres Pali who participated actively, enthusiastically, and cooperatively during the research activities. Student participation and involvement were important factors that contributed to the success of this research.

It is hoped that the results of this research will be beneficial for the development of mathematics learning in elementary schools, especially in the use of innovative and adaptive learning technologies.

## AUTHOR CONTRIBUTION STATEMENT

Conceptualization: IF; Methodology: IF; Data collection: IF; Data analysis and interpretation: IF; Writing, original draft preparation: IF; Writing, review and editing: KS. All authors have read and agreed to the published version of the manuscript.

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