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Systematic Literature Review: Application of Augmented Reality to Improve Students' Creative Thinking Skills in Mathematics

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Abstract (English)
The problem in this Literature Review is to improve mathematical creative thinking skills through Augmented Reality. Creativity is a crucial skill to nurture in education, and mathematics plays a significant role in enhancing students' creative thinking abilities. Augmented Reality (AR) serves as a powerful educational tool, enabling educators to deliver information interactively and fostering creativity in students as they solve problems and address real-world scenarios. By utilizing AR as a medium for creative learning, it facilitates collaborative efforts among students and enhances their ability to think creatively. This study employs a Systematic Literature Review (SLR) method, analyzing seven journal articles that explore the use of AR in improving creative thinking skills within the context of mathematics education.

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1. Introduction

In the Industry 4.0 Era, students are required to have high-level thinking intelligence (HOTS). Creativity is one of the essential soft skills required in the Industrial Era 4.0. Critical thinking, another vital skill, is also a cornerstone of 21st-century education (Ghiffar et al., 2018). In this era, individuals are expected to master the 4C skills: Critical Thinking, Creativity, Communication, and Collaboration. Around the globe, creative thinking has become a central focus in the modern educational revolution. It involves generating ideas in unique or unconventional ways. Creative thinking can be identified through four key indicators: fluency, flexibility, originality, and elaboration.

Mathematics is a basic subject that helps students improve logical thinking, learned from childhood until entering university. However, competence in eye mathematics lessons have not yet been achieved. This is due to the lack of integration mathematics learning in everyday life. Therefore it is necessary quality mathematics teaching, appropriate programs and a creative and team of teachers innovative (Rahmawati, Buchori, & Ghoffar, 2022). Teachers need media tools to teaching difficult material for students (Rahmawati, Buchori, & Goffar, 2022). Learning using Augmented Reality media can enhance and foster creativity in students. Munandar (in Fatmawiyati 2018) stated that creativity is a process that is creative or the process of creating something. Based on the explanation above, creativity isthinking

activity to seek and find new ideas or new thoughts by producing new work that is useful for solving problems.

Many studies have been conducted on the application of technology to improve students' understanding of the material. Various technologies are used to increase students' interest in learning, which is expected to affect their learning outcomes. Augmented Reality is one of the emerging technologies designed to enhance learning experiences. It enables users to interact with virtual environments as though they were in the real world, providing a realistic and immersive learning experience. However, further research is needed to explore its potential in developing creative thinking skills, particularly in mathematics education. This study employs the Systematic Literature Review (SLR) method to analyze research on the application of Augmented Reality in mathematics learning.

Based on the problems above, this research was conducted in a systematic manner. A review of research journals, particularly on the topic of applying Augmented Reality to enhance critical and creative thinking skills in mathematics, is the focus of this study. This research aims to provide insights into the use of Augmented Reality in mathematics education.

2. Method

The Systematic Literature Review (SLR) is a research method designed to identify, evaluate, and synthesize all relevant studies on a specific topic. The purpose of SLR is to reconstruct existing information from relevant research and answer research questions using existing empirical data. This method can help researchers avoid bias in article selection and improve the accuracy of research results. Therefore, SLR is widely used in fields such as health, psychology, and information technology.

Triandini et al, 2019 provides comprehensive guidelines regarding SLR journal writing procedures, including:

2.1. Research Questions (Research Questions)

Research questions are formulated based on the specific needs of the chosen topic. These questions serve as a foundation for synthesizing findings, enabling analysis to be organized into relevant categories or themes, ultimately leading to comprehensive conclusions (Petticrew & Roberts, 2006). The research questions for this study are as follows:

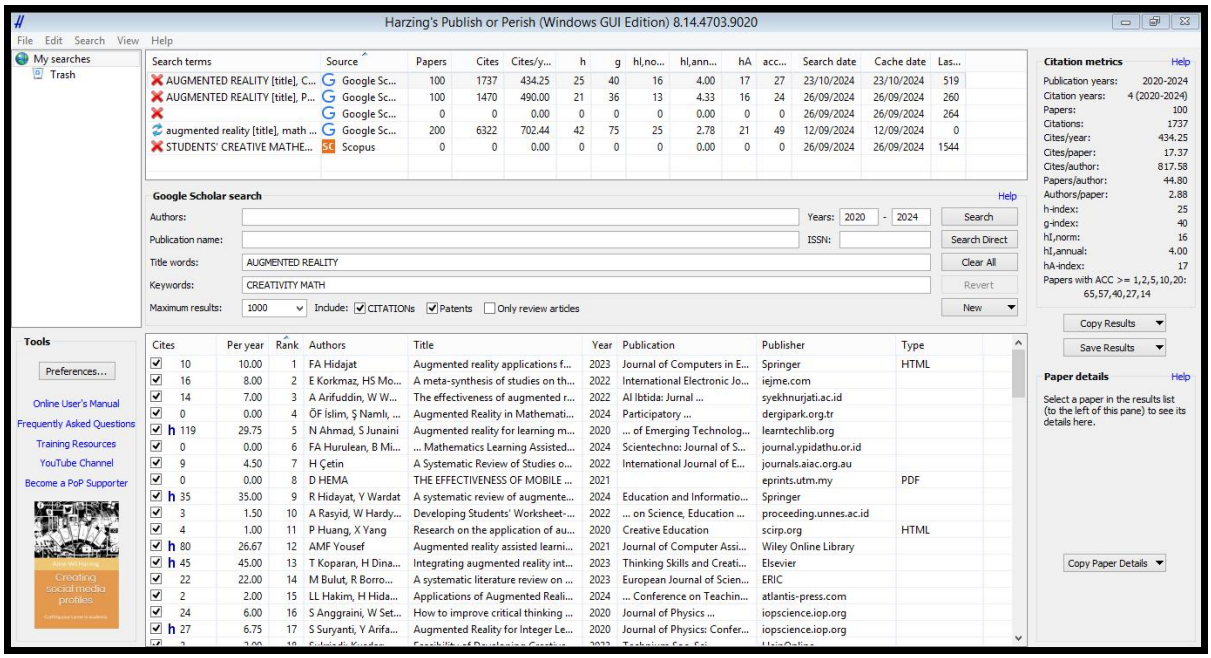
RQ1.What is the impact of using Augmented Reality in mathematics learning on enhancing students' creative thinking skills?

RQ2.To what extent is Augmented Reality effective compared to traditional learning methods in improving students' creative thinking skills in mathematics subjects?

2.2. Search Process (Search Process)

Literature search was conducted with the help of the Publish or Perish 8 application. The searchThe literature resulted in the discovery of 100 literatures from 2020 to 2024. Literature review articles were obtained from Google Scholar. The keywords used in the research literature search were creativity math. The results of the Publish or Perish 8 search are presented in Figure 1 below.

Figure 1 Publish or Perish 8 search results



From various articles, 16 articles were obtained which were then identified, reviewed, evaluated, and interpreted so that 10 articles were selected that met the required article criteria.

2.3. Quality Assessment.

In SLR research, the collected data will be evaluated using the following quality assessment criteria:

QA1. Was the journal article published within the last five years, up to 2024?

QA2. Does this study clearly define the method of applying Augmented Reality in mathematics learning, including the objectives and design of its implementation?

QA3. Does this study measure and report the results of improving students' creative thinking skills specifically, using valid and reliable instruments or indicators?

1. Y (Yes): published in the last 5 years from 2024, defines the method of implementing AR, and reports the results of improving students' creative thinking skills.

2. T (No): if it does not match the question.

3. Results and Discussion

3.1. Inclusion and Exclusion Criteria Selection Results

The results of the search process will be filtered according to the inclusion and exclusion criteria, leaving 10 journals for further analysis. Data scanning will then be conducted. Table 1 presents the quality assessment results based on the provided criteria.

Table. 1 Quality Assessment Results

No.	Writer	Title	Year	QA1	QA2	QA3	Results
1.	Hidajat, F. A.	Augmented reality applications for mathematical creativity: a systematic review. *Journal of Computers in Education*	2023	**Y**	**Y**	**Y**	✓
2.	Hurulean, F. A., & Miliyawati, B.	Constructing Realistic Mathematics Learning Assisted by Augmented Reality Technology to Improve Students' Mathematical Creative Thinking Ability Students' Mathematical Creative Thinking. *Scientechno: Journal of Science and Technology, 3(1)*	2024	**Y**	**Y**	**Y**	✓

3.	Rasyid, A., Hardyanto, W., Ridlo, S., & Parmin, P.	Developing Students' Worksheet-Based Science, Technology, Engineering, and Mathematics Assisted by Augmented Reality to Improve Creative Thinking. In *International Conference on Science, Education, and Technology*	2022	**Y**	**Y**	**Y**	✓
4.	Umam, K., Fatayan, A., Sari, Y. Y., & Awang, I.	Education Management in the Development of Contextual Problems Using Mobile Augmented Reality to Support Mechanical Engineering Students Creativity in Learning Mathematics. *Journal of Higher Education Theory and Practice,*	2024	**Y**	**Y**	**Y**	✓
5.	Angraini, L. M., Alzaber, A., Sari, D. P., Yolanda, F., & Muhammad, I.	Improving Mathematical Critical Thinking Ability Through Augmented Reality-Based Learning. *Aksioma*,	2022	**Y**	**T**	**T**	
6.	Arifuddin, A., Wahyudin, W., Prabawanto, S., Yasin, M., & Elizanti, D.	The effectiveness of augmented reality-assisted scientific approach to improve mathematical creative thinking ability of elementary school students. *Al Ibtida: Jurnal Pendidikan Guru MI*,	2022	**Y**	**Y**	**Y**	✓
7.	Apriani, E.,	The influence of using	2021	**Y**	**Y**	**Y**	✓

	Kuswanto, H., & Nuha, A. A.	physics student worksheets assisted by augmented reality toward students' creative thinking ability. In *6th International Seminar on Science Education*					
8.	Ermawati, D., Riswari, L. A., Wijayanti, E., Prameswari, A., & Lathif, M. I. A.	Pengaruh Media Mabarung Berbasis Augmented Reality Terhadap Kemampuan Bernalar Kritis Matematis Siswa SD. *Scientia*,	2024	**Y**	**T**	**Y**	✓
9.	Estheriani, N. G. N., & Muhid, A.	Pengembangan kreativitas berpikir siswa di era industri 4.0 melalui perangkat pembelajaran dengan media augmented reality. *Insight: jurnal ilmiah psikologi,*	2020	**Y**	**T**	**T**	
10.	Putri, N. W. S.	Systematic Literature Review: Penerapan virtual reality untuk meningkatkan berpikir kritis dan kreatif pada mata pelajaran matematika. *Proceedings Series of Educational Studies*	2023	**Y**	**T**	**T**	

3.2. Discussion of Results.

This section will explain/answer the Research Question (RQ).

RQ1. In what ways does the integration of Augmented Reality in mathematics education contribute to enhancing students' creative thinking abilities?

Through the search process, 13 journals were identified. After applying the inclusion and exclusion criteria using the keyword "creativity math," 10 journal articles were selected for quality assessment. Based on the Quality Assessment (QA) results, 7 relevant journal articles were identified and categorized according to the development platform and approach used to address the research question. These findings provide answers to RQ1 as follows:

The use of Augmented Reality (AR) in mathematics learning has a significant positive effect on students' creative thinking skills. AR enables students to engage with virtual objects within a real-world environment, which enhances their intuition and involvement in grasping complex mathematical concepts. Research shows that AR technology supports students in visualizing abstract concepts, facilitating the manipulation of 3D objects, and providing a more contextual learning experience. This helps students develop creative thinking skills, especially in terms of fluency, flexibility, originality, and elaboration in solving mathematical problems.

RQ2. **To what extent is Augmented Reality effective compared to traditional learning methods in improving students' creative thinking skills in mathematics subjects?**

Each learning method certainly has its own advantages in both traditional and modern methods. However, how effective is the application of modern methods compared to traditional methods in improving students' creative thinking skills in mathematics subjects. Here are the results of answering RQ2:

From the analysis of the effectiveness of Augmented Reality (AR) compared to traditional learning methods in improving students' creative thinking skills in mathematics, it was found that AR is significantly superior. Several studies have shown that students who learn using AR are more actively involved, motivated, and able to understand abstract material through 3D visualization and direct interaction. This allows them to develop original ideas as well as fluent, flexible, and creative thinking skills, which are more difficult to achieve with traditional methods.

In a study comparing AR with traditional methods, the experimental group using AR showed significantly higher creative thinking scores compared to the control group. The average increase in creative thinking aspects such as fluency, flexibility, and originality is evidence that AR supports deeper problem exploration and encourages collaborative discussions among students.

4. Conclusion

The conclusion of the Systematic Literature Review (SLR) to Identify the Application of Augmented Reality to Improve Students' Creative Mathematical Thinking Skills is as follows:

- RQ1: The use of AR in mathematics learning effectively improves students' creative thinking skills. With more concrete visualizations and direct interactions, AR provides an immersive learning experience, broadens students' perspectives, and encourages them to generate innovative solutions to mathematical challenges.
- RQ2: AR-based mathematics learning is proven to be more effective than traditional methods in improving students' creative thinking skills. AR technology provides an immersive interactive experience, allows for better understanding of concepts, and encourages students to think innovatively in solving mathematical problems.

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