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Integration of Artificial Intelligence in Mathematics Learning : Systematic Literature Review

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ABSTRACT

Integrasi kecerdasan buatan (AI) dalam pembelajaran matematika memperkenalkan paradigma baru dalam pendidikan matematika dengan memanfaatkan teknologi untuk memperluas dan memperkaya pengalaman belajar siswa. Penelitian ini adalah tinjauan literatur sistematis. Tujuan dari penelitian ini adalah untuk memberikan wawasan mendalam tentang integrasi kecerdasan buatan dalam pendidikan matematika dan membangun fondasi untuk penelitian dan pengembangan lebih lanjut di bidang ini. Berdasarkan analisis status publikasi, kami menemukan lima artikel penelitian yang mengkaji penggunaan kecerdasan buatan (AI) dalam pendidikan matematika di berbagai tingkat pendidikan, yang diterbitkan dalam 11 jurnal internasional yang diindeks oleh Scopus. Salah satu pendekatan yang umum digunakan adalah pembelajaran berbasis permainan yang didukung oleh AI, selain berbagai teknologi AI lainnya. Dalam konteks tingkat pendidikan, sekolah menengah pertama menjadi fokus utama untuk penerapan teknologi AI. Oleh karena itu, Tinjauan Literatur Sistematis (SLR) ini memberikan wawasan berharga untuk pengembangan lebih lanjut dalam integrasi AI dalam pendidikan matematika.

ABSTRAK

The integration of artificial intelligence (AI) in mathematics learning introduces a new paradigm in mathematics education by utilizing technology to broaden and enrich students learning experience. This study is a systematic literature review. The objective of this study is to provide in-depth insights into the integration of artificial intelligence in mathematics education and to establish a foundation for further research and development in this field. Based on the analysis of publication status, we found five research articles that examine the use of artificial intelligence (AI) in mathematics education across various educational levels, published in 11 international journals indexed by Scopus. One of the commonly used approaches is AI-driven game-based learning, alongside various other AI technologies. In the context of educational levels, unior high school stands out as the primary focus for the implementation of AI technology. Therefore, this Systematic Literature Review (SLR) provides valuable insights for further development in the integration of AI in mathematics education.

INTRODUCTION

Artificial Intelligence (AI) has been one of the most dynamic and influential fields of technology since the concept was first introduced in the mid-20th century. Initially, the main focus of AI was on developing systems that could mimic human intelligence through logic programming and algorithms (Bellas, Sara, Martin, & Richard J, 2023). Although the technology was limited back then, the foundation for further advancements in AI was laid, paving the way for further exploration and innovation in the field. With the advancement of computing technology and the accumulation of more data, AI began to evolve from rule-based approaches to more adaptive and self-learning methods. The innovation of AI not only expands the capabilities of AI, but also enables the application of this technology in various sectors, including the education sector.

In education, Artificial Intelligence or AI has a huge role. Artificial Intelligence (AI) is a field of computer science that focuses on developing computer systems that can perform tasks that require human intelligence. AI aims to create machines that can think, learn, and make decisions like humans albeit within certain limitations and contexts. The use of AI has accelerated the development of systems that facilitate formal and informal learning that can be accessed anytime and anywhere by everyone through open online learning resources and mass online courses (Verma, 2018). In other words, AI holds immense potential to revolutionize the way we teach and learn. The integration of AI in education enables personalized learning, enhances the efficiency of educational processes, and equips students for a rapidly digital and interconnected world. Overall, the integration of AI in education has opened up new opportunities for transformation and innovation in the learning process..

In mathematics learning, AI has a very important role in enriching students' learning experience with interactive learning and supporting educators in improving teaching effectiveness (Bhutoria, 2022). AI enables the development of adaptive learning solutions, which can customize learning materials and approaches according to students' individual needs and abilities. It can improve the interaction between teachers and students and provide more opportunities for students to explore their interests outside of math learning (Mohamed , Hidayat, Suhaizi, Sabri, Mahmud, & Baharuddin, 2022). AI enables the development of adaptive learning solutions, which can customize learning materials and approaches according to students' individual needs and abilities. With the tools and resources provided by AI, students can deepen their knowledge in areas of interest and develop new skills in a more independent and personal interest-oriented way. This not only enriches students' learning experience but also encourages intrinsic motivation and active engagement in the learning process.

AI's ability to adaptively present learning materials according to the individual needs of students results in a more focused and personalized learning experience. AI can identify students' specific weaknesses and needs (Majid & Lakshmi, 2022), leads to timely presentation of material and appropriate level of difficulty (Muengsan & Chatwattana, 2024). Providing directed practice and instant feedback, AI helps students to overcome difficulties and strengthen their understanding of math concepts. Moreover, through careful data analysis, AI allows teachers to monitor individual student progress and identify areas that require further attention. Thus, AI's effectiveness in improving mathematical understanding lies in its ability to provide customized learning, timely feedback (Abdulqayyum & Potter, 2024), engaging interactive experiences, and in-depth data analysis, all of which contribute to students achieving better math learning goals.

In today's digital era, the integration of AI in math learning has become one of the most important evolutions in education. Various AI applications have been specifically designed to support the learning process of mathematics, creating a more interactive and personalized learning experience. Through these apps, students can access adaptive exercises tailored to their abilities, enabling more effective and efficient learning. In addition, some apps use visualization and simulation technology to help students understand complex mathematical concepts more easily and enjoyably (Stanislav & Tadeas, 2019). This AI application provides new opportunities for educators and students to improve the quality and effectiveness of math education, preparing future generations with strong and comprehensive math skills.

Visualization technologies leveraged by AI, such as augmented reality (AR) and virtual reality (VR) have changed the way students understand complex mathematical concepts (Papanastasiou, Drigas, & Papanastasiou, 2019). Dynamic and interactive visualization, students can visualize mathematical concepts in a more concrete and understandable form. This not only makes the learning process more engaging, but also makes it easier for students to internalize difficult mathematical concepts. From early computer programs to complex online learning platforms, AI continues to be a valuable tool in helping students better understand and master mathematical concepts.

Implementing Game-Based Learning in mathematics learning brings a variety of potential benefits, but also faces certain challenges that need to be overcome. One of the main challenges is the need for adequate technological infrastructure and sufficient accessibility to AI technologies in educational settings. The implementation of AI requires investment in hardware, software, but equally important, is the investment in training for educators. This training is essential to prepare educators with the necessary knowledge and skills to integrate and utilize AI in the curriculum and daily learning. With the right investment commitment in hardware, software, and educator training, AI implementation in education can be a significant source of innovation and improvement in the quality of learning.

In addition, the integration of AI in mathematics learning requires adaptation of the existing curriculum and teaching methods. (Pedro, Subosa, Rivas, & Valverde, 2019) stated that traditional learning approaches may not always fit the needs of AI, so it is necessary to adjust and develop learning materials that support AI technology. The difficulty in measuring the effectiveness and real impact of using AI in mathematics learning is also a challenge. (Kong , Cheung, & Tsang, 2024) stated that evaluating the effectiveness of AI in improving students' mathematical understanding and skills requires sophisticated evaluation methodologies and reliable data. The role of educators in the integration of AI in mathematics learning is also important. Identifying and addressing the challenges of AI implementation in mathematics learning has the potential to result in positive changes in the way we teach and learn mathematics.

Several studies have been conducted to find out whether AI is effective in developing math learning. Research conducted (Dabingaya, 2022) on analyzing the use of AI as a mathematics learning platform provides results that AI provides potential benefits in improving more effective and inclusive mathematics learning in the age of technology. In line with research (Pavlova, 2024) which has the conclusion that learning using AI can provide convenience, not monotonous, and stimulate the quality of students' abilities when searching for learning information. Similarly, research on the effect of AI on student motivation in learning mathematics conducted by (Qawaqneh, Ahmad, & Alawamreh, 2023) found that classes using AI in learning mathematics had better learning motivation

than control classes. In other words, the use of AI has a good impact on students in learning mathematics.

Study results from primary research do not fully guarantee that AI has promising effectiveness in the mathematics learning process. There may be differences between the results of these studies, as well as potentially biased studies. As explained earlier, AI has evolved over time in accordance with the availability of materials in schools. In recent years, there have also been significant changes in the availability of technology, teaching materials, training, and skills. Therefore, it is necessary to conduct a systematic literature review to update the existing literature by examining the last 9 years (2016 - 2024) of research on the integration of AI in mathematics learning.

Based on this condition, the researcher conducted a systematic literature review to find out the integration of Artificial Intelligence in mathematics learning. This research was conducted by synthesizing and reviewing articles that have been published on ScienceDirect and ERIC.

METHOD

This research is a systematic literature review, which is research that utilizes database searches to collect findings from various relevant studies in a particular field of science or topic. (Lame, 2019) stated SLR is a scientific approach to combining evidence from various relevant studies in answering specific research questions by identifying relevant studies, collecting the necessary data and analyzing and integrating the findings to gain a deeper and broader understanding of the research topic. There is a research protocol that must be considered in using SLR research. The SLR research protocol was developed to provide clear, transparent and systematic guidance on the implementation of SLR. With a clear protocol, researchers can ensure consistency throughout the research process, providing a structured and solid framework for producing quality and reliable literature reviews. The protocol applied in this study is PRISMA (The Preferred Reporting Items for Systematic Reviews and Meta-Analyses) as a research guideline to ensure consistency and structure in the research process. In the study (Panic, Leoncini, Belvis, Ricciardi, & Boccia, 2013) the use of PRISMA guidelines has replaced the QUORUM guidelines to adapt to the evolving concepts in reporting systematic reviews and meta-analyses of observational and experimental studies. In this study, a descriptive method was employed for the analysis.

In systematic literature review research, eligibility criteria play an important role in determining which articles or studies to include in the analysis. The eligibility criteria developed in this study have two main components, namely inclusion criteria and exclusion criteria. The PICOC (Population, Intervention, Comparison, Outcome, and Context) framework was used as an eligibility criteria framework to develop answers to research questions focused on this study. The PICOC framework in this study as presented in full in the table 1 below.

Table 1. PICOC Framework

PICOC Framework	Inclusion Criteria	Exclusion Criteria
Population	Mathematics teachers or students who are research subjects related to the use of AI in mathematics learning.	Not including mathematics teachers or students who are the subject of research related to the use of AI in mathematics learning.

Intervention	Primary studies on the use of AI in math learning.	Primary studies that did not address the use of AI in math learning or address other interventions.
Comparation	The comparison group consists of those using other interventions or no intervention.	There were no exclusion criteria.
Outcome	A study explaining the effect of AI-based learning on student learning outcomes.	Does not discuss AI-based learning
Publication Years	Articles published in journals 2016 - 2024.	Articles published in journals before 2016 - 2024
Language	English research articles.	Research articles that use languages other than English.

Information sources for this systematic literature review research were obtained through searches in various electronic databases. The literature sources used are articles from international journals indexed in Scopus. In this systematic literature review research using ScienceDirect and ERIC databases. The results of the database search are as shown in the following table 2.

Table 2. Results of Database

Keyword	**Publication Year**	**Database**	**The number of articles**
("Artificial Intelligence") AND ("mathematics learning" OR "Mathematics") AND ("middle school" OR "junior high school" OR "secondary school").	2016 - 2024	ScienceDirect	33
		ERIC	54
Total			87

The next stage is the selection process of the database search results. The selection process in SLR is carried out to evaluate each article to ensure consistency and accuracy in the selection of literature. This process also aims to ensure that the resulting literature review is reflective, objective, and relevant to the established research objectives. By using the PRISMA protocol as shown below in Figure 1.

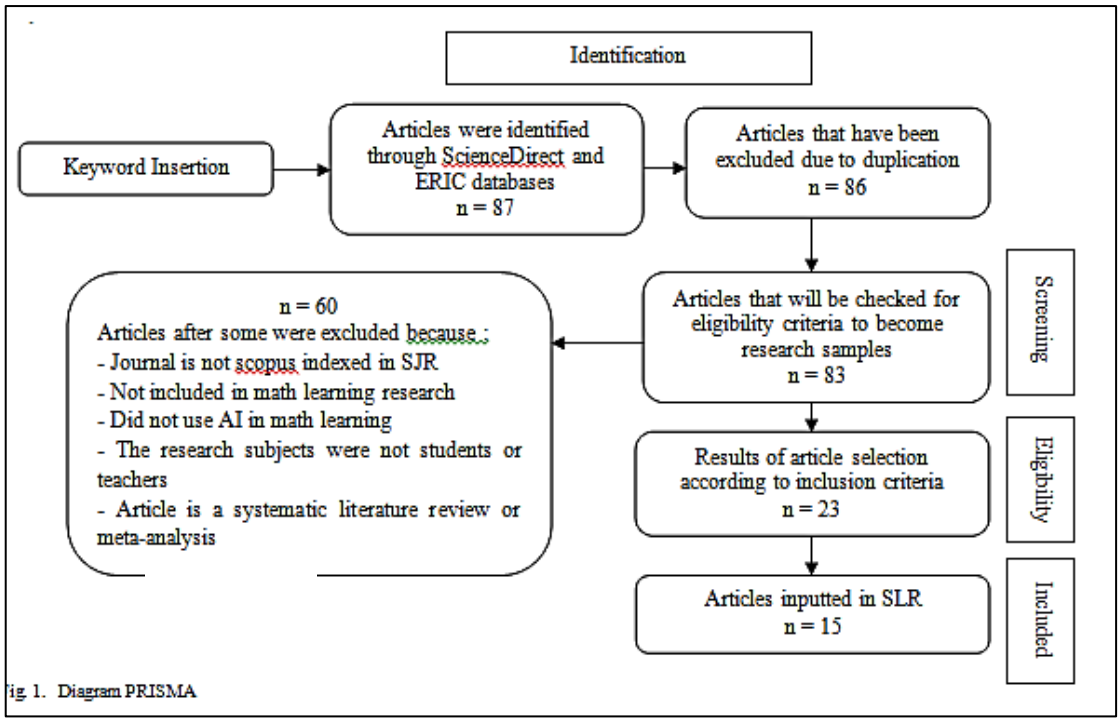

Figure 1. Diagram PRISMA

Based on Figure 1, it is evident that during the identification stage, 87 articles were identified from the ScienceDirect and ERIC databases. However, one article was found to be a duplicate, leaving 86 articles at the identification stage to be screened during the filtering stage. During the filtering stage, not all articles met the journal reputation criteria established for this study. As a result, three articles were excluded from the selection process, leaving 83 articles to proceed to the eligibility stage. At the eligibility stage, articles were assessed based on additional inclusion criteria, resulting in 23 articles qualifying at this stage. Finally, 15 articles were included after the final selection stage.

RESULT AND DISSCUSION

A summary of the coding results, for data extraction from the articles included in this slr, include: Authhor's name, article title, year of publication, and journal name. A summary of the coding data results can be seen in the following table 3

Table 3. Summary Of The Coding Data Results

Author	Title	Journal
Gadanidis George (2017)	Artificial Intelligence, Computational Thinking, and Mathematics Education	International Journal of Information and Learning Technology
Whitney Smith, Rachael Margaret (2023)	The Emergence of Computational Thinking in National Mathematics Curricula: An Australian Example	Journal of Pedagogical Research
LuEttaMae Lawrence, Vanessa Echeverria, Kexin Yang, Vincent Aleven, Nikol	How Teachers Conceptualise Shared Control with an. AI Co-Orchestration Tool: A Multiyear Teacher-Centred Design Process	British Journal of Educational Technology

Rummel (2024)		
Rebolledo-Mendez, Genaro, Huerta-Pacheco, N. Sofia, Baker, Ryan S., du Boulay, Benedict (2022)	Meta-Affective Behaviour within an Intelligent Tutoring System for Mathematics	International Journal of Artificial Intelligence in Education
Koyuncu, Ilhan (2020)	Investigation of Mathematics-Specific Trend Variables in PISA Studies with Neural Networks and Linear Regression	Journal of Curriculum and Teaching
Matsuda, Noboru; Weng, Wenting; Wall, Natalie (2020)	The Effect of Metacognitive Scaffolding for Learning by Teaching a Teachable Agent	International Journal of Artificial Intelligence in Education
Y.Copur-Gencturk (2024)	The impact of an interactive, personalized computer-based teacher professional development program on student performance: A randomized controlled trial	Computers and Education
Y. Zhang (2024)	Multi-Modal Characteristics Analysis of Teaching Behaviors in Intelligent Classroom—Take Junior Middle School Mathematics as an Example	Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST
S. Begum (2023)	Student Performance Analysis using Bayesian Optimized Random Forest Classifier and KNN	International Journal of Engineering Trends and Technology
S. Sun (2023)	A Theoretical Framework for a Mathematical Cognitive Model for Adaptive Learning Systems	Behavioral Sciences
H. Almoubayyed (2023)	Rewriting Math Word Problems to Improve Learning Outcomes for Emerging Readers: A Randomized Field Trial in Carnegie Learning's MATHia	Communications in Computer and Information Science
H. Nguyen (2018)	Student agency and game-based learning: A study comparing low and high agency	Lecture Notes in Computer Science
N. Lubold (2018)	Automated pitch convergence improves learning in a social, teachable robot for middle school mathematics	Lecture Notes in Computer Science
B. McLaren (2017)	Uncovering gender and problem difficulty effects in learning with	Lecture Notes in Computer Science

	an educational game	
I. Arroyo	Collaboration improves student interest in online tutoring	Lecture Notes in Computer Science

In this SLR, 15 research articles analyzed the use of Artificial Intelligence in mathematics learning. The table above can be visualized in the form of a figure as below based on the distribution of article publications in 2016 - 2024.

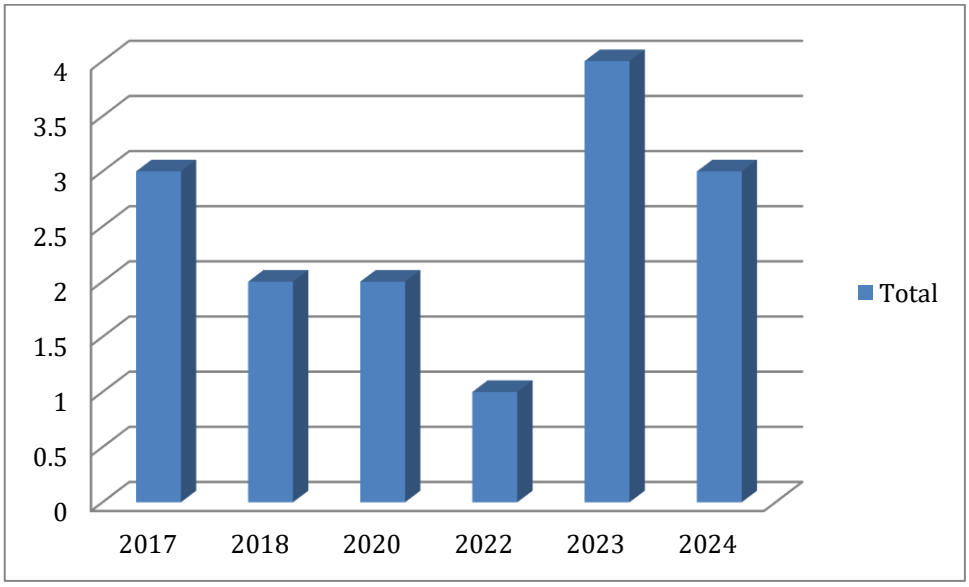

Figure 2. Databased on Publication Year of Article

Based on this figure 2, the distribution of article publications in the range of 2016 - 2024 is unstable and it can be seen that there are no articles that meet the eligibility criteria in 2016, 2019, and 2021. This does not mean that research on AI topics was not found at all during the article selection process but that the research was conducted outside the eligibility criteria such as research (Catherine, Helena, & Lamnina, 2019) which is research outside of mathematics learning or (Jancarik, Michal, & Novotna, 2023) whose research was published in international journals that are not indexed by Scopus. While 2023 was the year with the most publications, namely 4 research articles, which were then found 3 research articles in 2024 in this systematic literature review. Seeing the development of the times that are increasingly advanced, there is a possibility that there will be an increase in research on AI in 2024.

Of the 15 articles from the selected journals, Lecture Notes in Computer Science Journal publishes 4 articles which is the most of all journals, then there are 2 articles published in the International Journal of Artificial Intelligence in Education, as shown in the table 4 below.

Table 4. Summary Of The Journals

Journal	Number of Articles	SJR	Quartil
Behavioral Sciences	1	0.62	Q2
British Journal of Educational Technology	1	2.43	Q1
Communications in Computer and	1	0.2	Q4

Information Science			
Computers and Education	1	3.65	Q1
International Journal of Artificial Intelligence in Education	2	1.84	Q1
International Journal of Engineering Trends and Technology	1	0.19	Q4
International Journal of Information and Learning Technology	1	0.72	Q1
Journal of Curriculum and Teaching	1	0.15	Q4
Journal of Pedagogical Research	1	0.41	Q2
Lecture Notes in Computer Science	4	0.61	Q2
Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST	1	0.16	Q4
Total	15		

The table also shows the quality of the journals that published the selected articles. The distribution of publications of articles on the use of artificial intelligence (AI) in mathematics learning shows an interesting pattern in the analyzed time period. Quarter 2 (Q2) stands out as the period with the highest number of publications, with 6 articles released, indicating a reflection of the deeper research focus or more innovative research methods adopted by researchers in that period. Meanwhile, Quarter 1 (Q1) had 5 articles, and Quarter 4 (Q4) had the least number of publications, with only 4 articles.

This Systematic literature review research also identified several types of AI applied in mathematics learning. One of them is game-learning, the following figure visualizes the various types of AI in mathematics learning that have been adopted in this SLR research.

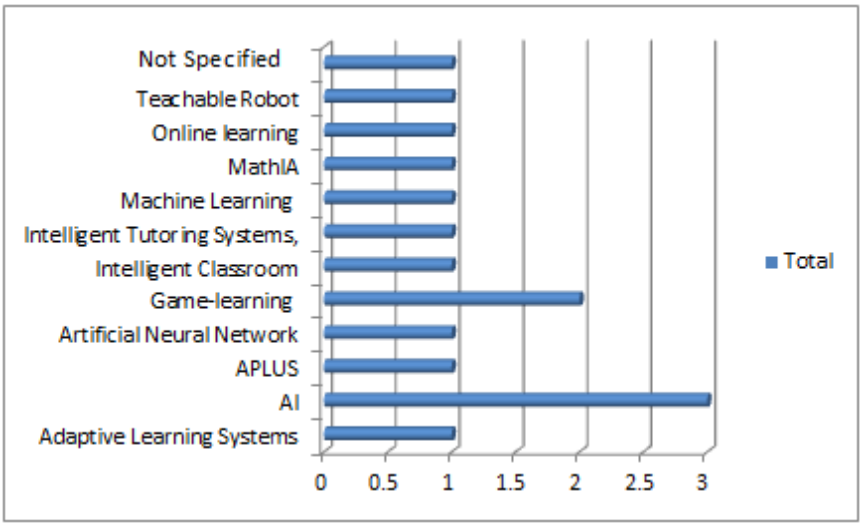

Figure 3. Variations of Artificial Intelligence Used

Game-based learning has become one of the innovative approaches in the application of artificial intelligence (AI) in mathematics learning. In its implementation, AI plays a crucial role in developing educational games that not only attract students' attention but also provide an adaptive and responsive learning experience (Du & Wang, 2023). AI

systems can adjust the game difficulty level, question types, or learning strategies presented based on students' individual learning needs and abilities, ensuring that each student is challenged at an appropriate level. In addition, the instant feedback provided by the AI as students interact with the game allows the learning process to be more dynamic and interactive. Features such as praise, correction or guidance can be provided in real-time, supporting the understanding of the math concepts being learned. Furthermore, in a study (McLaren, 2017) explained that AI-based math games can increase student motivation and engagement through game elements such as points, levels, and rewards, encouraging them to continue participating and achieving learning targets.

AI enables the presentation of material tailored to students' level of understanding and learning needs, provides instant feedback, and offers personalized learning solutions. This facilitates a more engaging, relevant, and efficient learning process for students, as well as assisting teachers in monitoring students' learning progress and providing appropriate interventions. In the analysis conducted, it was found that AI has been applied at various levels of education, ranging from primary education to higher education. It looks like the following Figure 4:

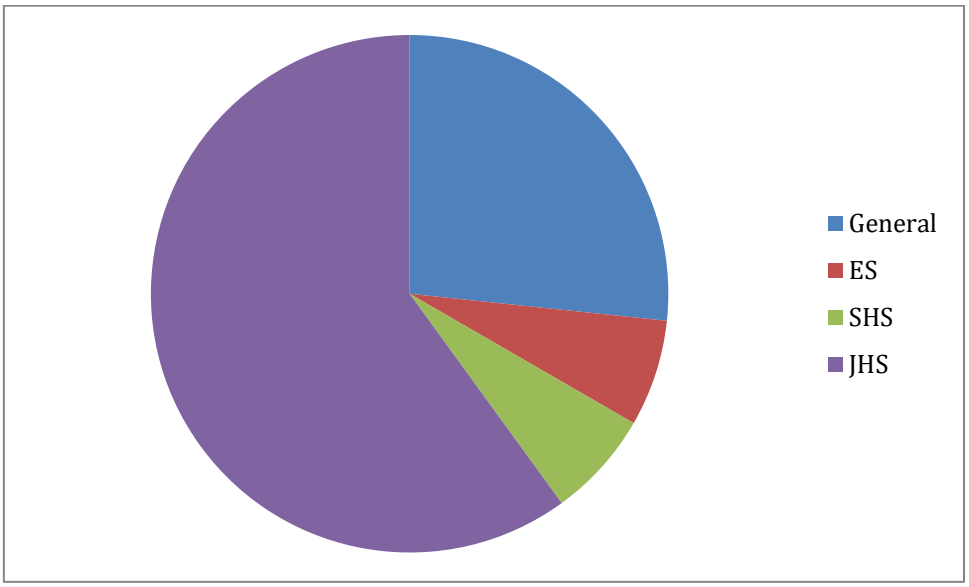

Figure 4. Databased on Educational Research

Based on the figure 4, it can be seen that the largest percentage is at JHS or junior high school. One of the main reasons is that at the junior high school level, students begin to learn more complex mathematical concepts and require a more adaptive and responsive learning approach. AI allows for the presentation of material that can be tailored to students' individual learning abilities and needs, ensuring that each student gets help and challenges that are appropriate to his or her level of understanding. At the elementary school level, the main focus is on building basic skills such as arithmetic operations (addition, subtraction, multiplication, division) and introducing number concepts. AI can be used through interactive applications that adjust the difficulty level of exercises according to the students' abilities (Chassignol, Khoroshavin, Klimova, & Embankment river, 2018). Mathematics material in junior high school begins to include more abstract concepts, such as algebra, geometry and basic statistics. AI can help visualize these concepts through simulations and animations. Apps like GeoGebra allow students to manipulate function graphs and see changes in real-time, helping them understand the

relationship between equations and graphs (Naidoo & Govender, 2014). Moreover, at the junior high school level, the importance of building a strong foundation of mathematical understanding becomes more prominent (Sutomo & Turmudi, 2024) and AI can assist in facilitating a more in-depth and comprehensive learning process. Furthermore, the implementation of AI technology at the junior high school level can also prepare students to enter higher education with better technological skills, preparing them for more complex academic demands in the future. With the proper integration of AI, mathematics learning at the elementary, middle, and high school levels can become more effective, engaging, and relevant to the needs of today's students.

CONCLUSION

The use of Artificial Intelligence (AI) in learning mathematics has changed the paradigm and become one of the innovations in modern education. Based on the publication status, there are 5 research articles examining the use of AI in learning mathematics at all levels of education published in 11 international journals indexed by Scopus. Game learning is one of the AIs used in math learning along with other AIs. Furthermore, this SLR also identifies the various levels of education that are the main focus, with junior high school dominating in the application of this technology. Thus, this SLR provides valuable insights for further development in the field of AI integration in mathematics learning, and confirms the importance of continuing to explore and optimize the potential of technology in improving the quality of education including in mathematics learning.

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