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The utilization of metaverse technology applications based on science, technology, engineering and mathematics (Meta-STEM) to improve critical thinking skills

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Abstract

The existence of digital technology is currently seen as a system that helps teachers satisfy the needs of their students. The utilization of technology facilitates teachers' ability to address students' low critical thinking abilities. Therefore, this research studied the utilization of Metaverse technology applications based on Science, Technology, Engineering and Mathematics (Meta-STEM) to improve critical thinking skills. The study used a quantitative research approach and adopted the true experimental design method. A pre- and post-tests control group design was used in this study. The research findings revealed a significant difference between the average outcomes of using Metaverse technology applications in the experimental group compared to the control group. Meta-STEM technology supported by the internet provides a fresh perspective on teaching methods especially in education. The present teaching methods use both virtual learning platforms and conventional face-to-face classrooms. The interaction process is becoming more dynamic and obtaining and searching for information is more accessible without spatial or temporal limitations. The implications of Meta-STEM for supporting learning can increase students' ability to gain information. In addition, there are numerous advantages to using Meta-STEM in the field of education for training and education. Providing impressive learning methods for students and teachers, making it easier for teachers to convey complex material, increasing students' level of understanding of the learning material presented by teachers as well as Meta-STEM can provide knowledge to master technology for students.

Keywords: Critical thinking ability, Elementary school, Elementary school, Metaverses STEM.

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Contents

Contribution of this paper to the literature

This research contributes to overcome learning problems in elementary schools namely low critical thinking skills, so new innovations are needed that are in line with current developments in learning technology namely Meta-STEM.

1. Introduction

The advancement of science and digital technology in the Metaverse period of education has motivated modern teachers to adopt and apply these tools in their teaching. The learning process places more emphasis on creativity, innovation, initiative, communication and collaboration (Chua & Yu, 2023; Shurygin, Anisimova, Orazbekova, & Pronkin, 2023). Teachers need to connect the Metaverse with constructivist learning theories. Metaverse technology will stimulate students' critical thinking when facing problems and real-life situations (Rahman, Shitol, Islam, Iftekhar, & Saha, 2023). Visualizing abstract concepts through Metaverse technology helps students understand the structure of an object, making it an effective learning medium for achieving learning goals (Rachmadtullah, Setiawan, Wasesa, & Wicaksono, 2023).

Modern education particularly in elementary schools is based on the idea that teachers have to address personal problems. They have to train students' critical thinking skills in solving problems in science, technology, engineering and mathematics learning activities. Currently, Indonesia is experiencing problems regarding STEM. According to the results of the 2018 Programme for International Student Assessment (PISA), published in March 2019, Indonesia's reading, science and math scores were comparatively low ranking 74th out of 79 countries in the world (OECD, 2015). According to the PISA data report, one of the factors behind students' low critical thinking skills is that they enjoy learning using technology. Therefore, it is important to optimize the use of technology in learning activities (Hasanah, 2023). Additionally, considering the characteristics of today's students who are enthusiastic about technology, teachers should enhance critical thinking skills by using digital-based learning media, including 3D technology like the Metaverse (Marini et al., 2022; Rachmadtullah, 2019).

According to de la Fuente Prieto, Lacasa, and Martínez-Borda (2022), research studies on the Metaverse as a learning medium for STEM are still limited despite its importance in addressing learning issues in schools. The Metaverse issue as an application for educational media provides innovation in educational technology by introducing students to virtual technology and enabling them to learn remotely. The Metaverse is very useful as a learning medium. The use of the Metaverse as a presentation medium for digital educational content helps users gain new knowledge and insights (Singh, Malhotra, & Sharma, 2022).

Technology is widely used in educational activities. It facilitates the delivery of content, particularly for elementary school students learning about STEM subjects. For this reason, researchers are making innovations, namely integrating Metaverse technology with STEM (Meta-STEM). The aim of Meta-STEM is to address issues that impact both teachers and students such as a lack of understanding of the subject matter and insufficient detail in explanations among other challenges.

Meta-STEM technology is a new technology for the development of educational technology. Students can learn in a more interactive way and gain a more in-depth learning experience by using Metaverse technology integrated with the STEM approach. One of the main benefits of Meta-STEM in the learning process for students and teachers in elementary schools is its ability to provide an in-depth learning experience (Rahman et al., 2023). It can make learning more fun and increase student interest in the topic being taught (Chen, Zou, Xie, & Wang, 2023). In addition, meta-STEM technology can also be used to provide realistic simulations of various situations such as laboratory experiments or medical situations that can help students learn in a more effective way without worrying about the risks associated with real situations (Chen et al., 2023; Ho, 2022). The development of science and digital technology in the Metaverse era of education has encouraged today's teachers to adapt and practice them in learning. The learning process places more emphasis on creativity, innovation, initiative, communication and collaboration (Al-Kfairy, Al-Fandi, Alema, & Altaee, 2022).

Meta-STEM technology can also be used to increase learning accessibility for students with physical or cognitive disabilities. Students can study in a modified environment and explore the world by using Meta-STEM (Sin et al., 2023). Meta-STEM can be recommended for schools that support learning with digital technology because it requires the internet and computers as the main means of learning activities. The meta-STEM in this research was designed by the researchers themselves with the help of "The Sandbox" platform. On "The Sandbox" platform, we buy space in virtual worlds, design animations and arrange virtual scenarios.

This research aimed to determine the effectiveness of using Metaverse technology applications based on Meta-STEM in improving critical thinking skills among elementary school students. Theoretically, this study was expected to facilitate teachers in delivering effective education to students through Meta-STEM application technology. In other words, it was anticipated that elementary school teachers could analyze the learning process effectively. Hence, this research was crucial for teachers to observe the strengths and weaknesses of using Meta-STEM application technology during teaching and learning. Meta-STEM technology provides profound benefits to our lives, for example, in the fields of the military, aviation, medicine and sports. Meta-STEM is an innovation in teaching and learning activities because it can increase a person's imagination to design and depict it in real form. In this way, teaching and learning activities will become more interesting. Technology and media have an

important role in the learning process. Various studies on the diffusion of technology and the use of information and communication in education show that there is a tendency for consumers who undertake education to integrate technology into the learning process. The use of Meta-STEM technology in the world of education and training is an example of the use of information and communication and is a creative learning medium for the future.

2. Literature Review

2.1. Metaverse Technology Application based on Science, Technology, Engineering and Mathematics (Meta-STEM)

The current Metaverse technology worldwide is being discussed and scientific studies are continuing to be carried out. Metaverse is a combination of 3D virtual technology and using Augmented Reality (AR) and Virtual Reality (VR) technology where users seem to interact in real life. Metaverse as a new technology has great potential in the future even though it is currently undergoing development and cannot be fully used. If applied to education, the Metaverse technology concept can create a virtual teaching and learning simulation environment so that students have new learning experiences and interact in the virtual world (Moon & Kong, 2023; Yaqoob, Salah, Jayaraman, & Omar, 2023). In terms of the Metaverse potential for use in educational activities, it can serve as a virtual laboratory. Students can learn about practices that have been used in real-world laboratories. The Metaverse can also be used in course activities for educational institutions to make it interesting. Students are interested in taking courses with new experiences namely learning in a 3D virtual world (De la Peña et al., 2010).

The use of the Metaverse in education can facilitate distance learning programs because it can interact in the virtual world and facilitate the learning process. Distance learning with Metaverse collaborates audio, visual and virtual reality learning styles. Students can participate in learning classes in the Metaverse; they do not have to be at school but can study anywhere. The most important thing is to be connected to the internet network and use virtual box glasses (Costa, Lima, & Tamayo, 2019; Mustafa, 2022; Mystakidis & Christopoulos, 2022).

During the COVID-19 pandemic, the Metaverse became one of the solutions to learning activities because during the pandemic, learning activities became long-distance. Metaverse with virtual reality technology provide experiences for teachers and students to learn virtually in addition to experiencing the abilities of teachers and students regarding their abilities. Mastery of technology and technological insight have also increased. Education is currently developing in the field of learning technology especially learning media such as the Metaverse (Li & Xiong, 2022; Purwaningsih et al., 2020; Rahmawati et al., 2021; Suwarma & Kumano, 2019). This study addresses the issue of primary school students' lack of critical thinking abilities because research on STEM-based Metaverse technology applications is still infrequently conducted in Indonesia. The use of digital technology in instructional materials can enhance learning because learning media contribute to children's excitement for learning, their indifference can be overcome through their utilization. Meta-STEM is an effective and efficient method of knowledge transfer to enhance the quality of learning.

2.2. Critical Thinking Ability

The ineffectiveness of teaching and learning activities is one of the factors that reduces students' critical thinking skills. Students with high critical thinking skills can easily solve problems related to mathematics. Critical thinking skills can be enhanced by technology-assisted learning such as in the Metaverse. One of the higher-order thinking skills required for the development of 21st-century skills is the capacity for critical thought. Critical thinking is a natural thinking process that is oriented towards solving problems, making decisions, analyzing, observing, interpreting, developing ideas and scientific behavior (Anggraeni, Prahani, Suprapto, Shofiyah, & Jatmiko, 2023; Dewi & Rachmadtullah, 2019).

According to Ennis (2011), critical thinking skills are rational thinking skills that focus on a person's beliefs about the decisions he makes. However, a student's critical thinking skills are less than optimal. One of the factors is the student's lack of focus on learning. Students who have good critical thinking skills are able to solve problems related to the learning material.

The ability to think critically is needed by students in the process of learning activities especially STEM learning. STEM learning is learning that can provide knowledge for students in everyday life. STEM learning does not only contain knowledge but also concepts, facts and other scientific matters (Deák, Kumar, Szabó, Nagy, & Szentesi, 2021; Duran & Dökme, 2016; Lu & Lin, 2018; Plotnikova & Strukov, 2019; Purnami, Sarwanto, Suranto, Suyanti, & Mocerino, 2021; Zhu & Wang, 2020). According to Rahmawati et al. (2021), the importance of critical thinking skills in STEM learning in elementary schools is needed in everyday life to meet human needs through problem-solving. The application of STEM needs to be done wisely so that it does not have a bad impact on society's environment.

Critical thinking is a complex process. It helps you evaluate complex ideas in a systematic way and making it easier to solve problems. Critical thinking skills have clear goals in solving problems, questioning information, reasoning and perspectives so that problem-solving is clear, concise, precise, relevant logical, reasonable and fair. Critical thinking also requires the ability to consider different assumptions, ask relevant questions, draw conclusions, think continuously and discuss problems. The implementation of this research activity was carried out by studying the use of Meta-STEM. Technology improves the critical thinking skills of elementary school students because various studies have proven that learning technology can help increase student interest and learning outcomes.

In this study, the ability to think critically refers to indicators of critical thinking according to Facione which were adapted by Normaya, namely interpretation, analysis, evaluation and inference. According to Facione and Facione (2013), the other two indicators, namely explanation and regulation were not used in this study. These four indicators fulfill the ability to think critically, while the explanation and self-regulation indicators are only owned by strong critical thinkers.

Table 1. Indicators of success in increasing critical thinking ability.

Indicators	Sub indicators
Interpretation	1. Be able to classify the information received so that its meaning and significance are clear. 2. Be able to clarify the meaning so that it can explain in more detail the statement contained about the problem.
Analysis	1. Check ideas in the form of information or facts contained in the problem and describe them so as to determine the strategy or solution. 2. Identify the relationship between ideas or concepts and arguments so it can provide supporting statements or reasons idea (Completion strategy) to define correct problem solving.
Evaluation	Check the truth of a statement delivered using the right strategy to solve the problem.
Inference	1. Answering more than one answer or solution that is right and proper. 2. Provide logical proof through steps resolution in drawing conclusions.

3. Method

3.1. Research Design

This quantitative research employed a true experimental design systematically administering specific treatments to the experimental group. The design used was the pre-and post-tests control group design as illustrated in Table 1. The treatment was administered after conducting a pre-test followed by post-test assessing critical thinking skills using the Meta-STEM application for the experimental group. On the other hand, the control group received treatment through a multimedia application after the pre-test ended with a post-test.

Table 2. Research design.

Experiment group	O_1	X	O_2
Control group	O_3	Z	O_4

Note: O_1: Pre-test experiment group.
O_2: Post-test experiment group.
O_3: Pre-test control group.
O_4: Post-test control group.

Table 2 illustrates the inclusion of a pre-test to determine the initial state whether there are any differences between the experimental and control groups. A successful pre-test outcome indicates no significant difference between the pre-test scores of the experimental and control groups. The treatment effect is calculated as $(O_2 - O_1) - (O_4 - O_3)$.

3.2. Respondents

The research respondents were all fifth-grade students at the state elementary school of 01 Penggung, Cirebon City comprising two classes with 62 children. The selection of these respondents was based on identifying critical thinking issues among fifth-grade students which necessitated the implementation of Meta-STEM to enhance critical thinking skills. The description of the research respondents can be seen in Table 3.

Table 3. Description of research respondents.

Group	Gender	Amount	Total
Experiment group	Male Female	10 21	31
Control group	Male Female	10 21	31

3.3. Data analysis

The data analysis consisted of three stages. First, a descriptive statistical test was conducted to determine the mean, mode, median and standard deviation. Second, a normality test was performed to ascertain the distribution of scores for each variable and whether the data followed a normal distribution or not. The normality test is the initial statistical analysis in data analysis. Ensuring the fulfillment of normality requirements ensures the accountability of the analysis. Data analysis can proceed if the data is normally distributed. The Kolmogorov-Smirnov test was used to test normality. The third stage involved homogeneity test where the expected F-value is a non-significant F-value determining whether the empirical F-value is smaller than the theoretical F-value. Fourth, a hypothesis test was conducted to determine the significant differences in the utilization of Science, Technology, Engineering, and Mathematics (STEM)-based Metaverse Technology Applications (Meta-STEM) in enhancing critical thinking skills between the experimental and control groups. This hypothesis test used an independent t-test examining the mean differences between the two groups. The hypotheses were as follows:

H_0: There is no significant difference in the average critical thinking ability between the experimental and control groups.
H_a: There is a significant difference in average critical thinking abilities between the experimental and control groups.

4. Results

The results of this research aimed to determine the role of Metaverse technology applications based on Meta-STEM (Science, Technology, Engineering and Mathematics) in enhancing critical thinking skills. The findings of this research are presented in Table 4 which provides a descriptive statistical analysis.

Table 4. Descriptive statistics.

Control group test	N	Mean	Std. deviation	Std. error means
Experiment group test	31	85.77	7.112	1.277
Control group test	31	79.52	7.042	1.265

The control group comprised 31 respondents while the experimental group comprised 31 respondents (see Table 4). The mean concentration score for the control group was 79.52 whereas for the experimental group, it was 85.77. It was observed that the experimental group had a higher mean concentration score based on the statistical calculations.

Table 5. One-sample Kolmogorov-Smirnov test for normality.

Description: One-sample Kolmogorov-Smirnov test for normality			Unstandardized residual
N			31
Normal parameters [a,b]	Mean		0.133
	Std. deviation		0.152
The most extreme differences	Absolute		0.144
	Positive		0.144
	Negative		-0.104
Test statistic			0.144
Asymp. sig. (2-tailed)[c]			0.102
Monte Carlo sig. (2-tailed)[d]	Sig.		0.098
	99% confidence interval	Lowe bound	0.091
		Upper bound	0.106

Note: a) Test distribution is normal.
b) Calculated from data.
c) Liliefors significance correction.
d) This is a lower bound of the true significance.

Table 5 obtained Asymp. sig. (2-tailed)[c] with a value of 0.102 > 0.05. The data on the utilization of Metaverse technology applications based on Meta-STEM to enhance critical thinking skills among students follow a normal distribution.

Table 6. Tests of homogeneity of variances.

Homogeneity test description	Levene statistic	Df1	Df2	Sig.
Based on mean	0.159	1	60	0.692
Based on median	0.020	1	60	0.888
Based on the median and with adjusted df	0.020	1	59.527	0.888
Based on trimmed mean	0.159	1	60	0.691

Table 6 obtained sig. based on the mean value for the mathematics learning outcome variable was 0.691 > 0.05 which leads to the conclusion that the data variance of the utilization of Metaverse technology applications based on Meta-STEM (Science, Technology, Engineering and Mathematics) to enhance critical thinking skills among students in both the experimental and control groups were homogeneous.

Table 7. Independent samples test.

Test Description	F	Sig.	T	Df	Sig. (2-tailed)
Equal variances are assumed	0.159	0.692	3.481	60	0.001
Equal variances are not assumed			3.481	59.994	0.001

In Table 7, the results of the independent samples test under "equal variances are assumed" section, the sig. (2-tailed) value is 0.001 which is less than 0.05. It can be concluded that H0 is rejected and Ha is accepted. based on the decision-making criteria in the independent sample t-test. Thus, it can be inferred that there is a significant difference between the mean scores of the utilization of Science, Technology, Engineering, and Mathematics (STEM)-based Metaverse Technology Application (Meta-STEM) in the experimental group compared to the control group.

5. Discussion

The application of Meta-STEM technology improves critical thinking abilities based on the research results. This finding is in line with research by Sin et al. (2023) which states that Meta-STEM makes learning more interesting and allows students to be more involved in the learning process. Additionally, Metaverse technology can help students acquire the necessary technological skills for the future. Digital skills have grown increasingly important in a world where the workforce is increasingly dependent on technology (Burušić, Simunović, & Sakić, 2021; Kim, Yang, & Ryu, 2022; Wilson, 2021).

The results of research on using Metaverse technology applications based on Meta-STEM to improve critical thinking skills are very important as a reference for elementary school teachers in overcoming learning problems in schools because the use of Metaverse technology is based on Meta-STEM in learning is defined as a digital processing system that encourages active learning, knowledge construction and exploration in students as well as virtual 3D communication, namely distance learning and data sharing that occurs between educators and students in different physical class locations. This is a technological advance in the field of education and teaching especially in Indonesia and worldwide. Today's Metaverse technology has been widely developed in several developed countries which has expanded from information delivery systems and also clarified its wider role and use in different classrooms, whole schools and other learning centers (Rachmadtullah et al., 2023).

Utilization of the Metaverse technology applications based on Meta-STEM can improve the quality of learning. Utilization of various Metaverse-Based Meta-STEM technology applications can overcome students' passivity because learning media play a role in awakening children's enthusiasm for learning. The use of Meta-STEM technology applications has great potential as a solution to improve the quality of learning because virtual reality learning can convey learning material information effectively and efficiently (Hasanah, 2023; Rahman et al., 2023; Sin et al., 2023).

In this era of digital technology, parents can use Metaverse technology applications based on Meta-STEM in providing education. Various considerations must be made by parents and educators in choosing the right media for their children. Errors in choosing media have an impact on the development and formation of children's character. In this paper, we discuss the benefits of digital media for young children and the negative impact of excessive use of technology (Aydoğdu, 2022; Lutfi et al., 2022).

Meta-STEM offers the ability to provide immersive learning experiences. By using Meta-STEM, students can learn more interactively such as by exploring virtual worlds, investigating environments that are not possible in the real world or even experiencing situations that are otherwise impossible in reality. It can make learning more enjoyable and increase students' interest in the topics taught (Rachmadtullah et al., 2023; Suri & Rachmadtullah, 2021).

The critical thinking skills students must master in 21st-century education include creative thinking, critical thinking, problem-solving and decision-making. Working in the global and digital world requires students to communicate and collaborate effectively with individuals, communities and networks (Chu, Reynolds, Tavares, Notari, & Lee, 2016). Students should also be able to master tools and technologies, as applying the Metaverse based on Science, Technology, Engineering and Mathematics (Meta-STEM) facilitates their learning process (Said, 2023).

Meta-STEM in the process of learning activities continues to be researched and developed by experts and researchers to become a 3D and virtual learning media tool to support successful learning. Meta-STEM is currently an interesting discussion by world technology experts, especially in the field of education and teaching because this technology is an innovation that aims to create something new and useful in terms of time, form and materials thereby making the learning media more efficient and effective. Meta-STEM technology supports students' cognitive achievements namely critical thinking skills, problem solving abilities, collaboration skills and students' intellectual abilities.

6. Conclusion

The research on Metaverse technology applications based on Meta-STEM (Science, Technology, Engineering, and Mathematics) in enhancing critical thinking skills for elementary school students has been successfully conducted. The independent t-test results showed that H0 was rejected and Ha was accepted. These results showed a significant difference in the average critical thinking skills between the control and experimental groups. Furthermore, using Metaverse technology applications based on Meta-STEM positively enhances student participation, as students actively engage in learning through the virtual world. The utilization of Meta-STEM involves interactive technology combining 2-dimensional or 3-dimensional virtual objects and integrating them into the natural environment, creating a mixed reality space projected into real-time. Meta-STEM is a technology that combines the natural world and the virtual world making learning more enjoyable and interactive. Additionally, students can actively participate in the learning process by interacting with the virtual environment.

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