JPII 12 (3) (2023) 482-492

Jurnal Pendidikan IPA Indonesia

http://journal.unnes.ac.id/index.php/jpii

STEM-BASED SCIENTIFIC LEARNING AND ITS IMPACT ON STUDENTS' CRITICAL AND CREATIVE THINKING SKILLS: AN EMPIRICAL STUDY

I. G. Astawan[1], I. M. Suarjana[1], B. R. Werang*[1], S. I. Asaloei[2], M. Sianturi[3], E. C. Elele[4]

[1]Ganesha University of Education, Singaraja, Bali, Indonesia
[2]Sam Ratulangi University, Manado, North Sulawesi, Indonesia
[3]School of Social Sciences, The University of New South Wales, Australia
[4]Abundance Wisdom University, Nigeria

DOI: 10.15294/jpii.v12i3.46882

Accepted: August 19th, 2023. Approved: September 29th, 2023. Published: September 30th, 2023

ABSTRACT

This research aims to investigate the potential impact of STEM-based scientific learning on the critical and creative thinking skills of students at Universitas Pendidikan Ganesha in Indonesia. To achieve this goal, we conducted a quasi-experimental research design to collect data. We provided students with hands-on experiences in conducting scientific experiments to solve real-world problems related to energy and air. Data regarding students' critical thinking skills were gathered through tests, while data about creative thinking skills were obtained by observing students' performance in mind-mapping exercises. The collected data underwent thorough statistical analysis, including descriptive and inferential techniques. The results of this research show that students taught using the STEM-based scientific learning model outperform those taught using the conventional model (lecturing). Furthermore, inferential statistical research shows that using the STEM-based scientific learning model predicts students' critical and creative thinking skills considerably. These results imply that using the STEM-based scientific learning model can help students improve their critical and creative thinking skills. This shows the potential to add to the body of literature on the influence of STEM-based scientific learning in developing students' critical and creative thinking skills. Further, this study can serve as a basic reference for future studies aimed at investigating the influence of STEM-based scientific education on students from various educational backgrounds and cultural settings.

Keywords: creative thinking skill; critical thinking skill; STEM-based scientific

INTRODUCTION

Science education is crucial for today's society because a community's growth is determined, in part, by its scientific skills. Despite the Indonesian government's endless efforts to improve students' ability to master science, the 2018 PISA survey results show that Indonesia ranked 74th overall, out of 79 surveyed countries, with a reading ability score of 371, a mathematics ability score of 379, and a science ability score of 396. In the context of Indonesia's 2019 Human Development Index (HDI) value of 0.718, it is critical to comprehend the consequences of this ranking at 107th out of 189 countries and territories. Indonesia's HDI score of 107 shows a relatively low level of human development, highlighting the primary obstacles the country confronts in improving its overall well-being and development in comparison to its global competition (Soetjipto & Jose, 2020).

The PISA study emphasizes the importance of improving education quality in Indonesia, with a special emphasis on 21st-century skills, including critical and creative thinking. On the one hand, Nuri et al. (2019) emphasize the necessity

***Correspondence Address**
E-mail: werang267@undiksha.ac.id

of boosting Indonesian students' critical thinking through science-integrated teaching. Similarly, Amrilizia et al. (2022) highlight the importance of improving critical thinking through e-modules and contextual teaching. Pursitasari et al. (2022), on the other hand, demonstrate the importance of strengthening students' creative thinking skills through the use of biotechnological modules related to real-world challenges. In a similar vein, Pasaribu et al. (2023) emphasize the significance of nurturing creative thinking through STEM-based worksheets. These latest studies have revealed that critical and creative thinking skills among Indonesian students are in a worrisome situation.

In today's rapidly evolving world, where technological advancements and societal changes are happening at an unprecedented pace, the importance of STEM education in enhancing students' critical and creative thinking skills extends beyond being just an educational trend. It has evolved as a vital avenue for preparing students to flourish in an increasingly complicated and interconnected global context. Traditional educational approaches, which frequently emphasize rote memorization and discipline-specific learning, are no longer sufficient in preparing students for the multifaceted issues they will confront in their personal and professional lives.

The urgency to prioritize STEM-based scientific education is underscored by the growing demand for a workforce capable of driving innovation and economic growth. Industries are becoming increasingly reliant on technology-driven solutions, and the ability to navigate and leverage technology is a skill that cuts across sectors. STEM education not only cultivates technical competence but also fosters critical thinking, analytical reasoning, and creativity – highly transferrable skills and sought after in a wide range of professions.

STEM education has been identified as one of the key priority areas for its crucial role in the country's future economic growth and development (Croak, 2018), and it is becoming even more important in today's world, where technology and innovation are driving progress (Nugroho et al., 2021). STEM is not only essential for students who are interested in pursuing careers in science or technology, but it is also critical for all students, as it provides them with a foundation of skills and knowledge that can be applied to any field. The importance of STEM-based scientific education extends beyond just providing students with the skills they need for future careers. STEM education provides students with a strong foundation in math, science, and technology, which is an essential skill in our rapidly evolving economy. Through STEM-based scientific education, students learn to think critically and systematically, analyze data, and solve complex problems. By incorporating STEM-based scientific education into the curriculum and providing students with the necessary resources and tools, Indonesia can improve its position in PISA and enhance its global competitiveness.

STEM education has been recognized as linked to students' critical thinking (A'yun et al., 2020; Hacioglu & Gulhan, 2021; Octafianellis et al., 2021; Parno et al., 2021; Widiasari, 2021; Ilma et al., 2023; Khotimah et al., 2023). Historically, the concept of critical thinking was first introduced by an American philosopher, John Dewey, in 1910 (Hitchcock, 2017). Dewey called it "reflective thinking." Over the next 40 years, the concept of critical thinking gained momentum, and the progressive education movement in the United States endorsed it (Hitchcock, 2017). In 1925, Edward Glaser and Goodwin Watson's revolutionary work was another extension of the progressive education movement's emphasis on critical thinking. Critical thinking has since been widely applied in a variety of sectors, including education.

Critical thinking entails more than just thinking; it also includes what a person believes or acts. Making informed decisions and tackling complicated challenges in a variety of professions and circumstances requires critical thinking. As a result, it is necessary to use critical thinking while making decisions and to verify that the judgments made are well-justified. Developing critical thinking skills provides students with the resources to assess information correctly, present compelling arguments, and manage their thoughts in a clear, rational, and systematic manner. Students can improve their academic performance and expand their grasp of the topic by examining and critiquing concepts. Furthermore, critical thinking encourages problem-solving creativity, which includes not just originating new ideas but also coming up with effective solutions (Bailin et al., 2010; Duran & Şendağ, 2012)

STEM education has also been recognized as linked to students' creativity (Kristiani et al., 2017; Sirajudin et al., 2020; Widiasari, 2021; Doyan et al., 2022; Karmila, 2022). The ability to develop new and original ideas or solutions to issues is known as creative thinking, and it is a fundamental skill that is becoming increasingly important in today's environment. Individuals in today's quickly changing environment are constantly confronted with new difficulties and opportunities. To keep up, someone must be able to think creatively and come up with fresh and creative solutions to challenges (Forster, 2014).

The ability to approach problems from several perspectives is one of the most fundamental components of creative thinking. By looking at a problem from a variety of perspectives, it is possible to come up with new and innovative solutions that might not have been apparent otherwise (Forster, 2014). This requires a willingness to explore different ideas and challenge assumptions about the problem at hand. From this viewpoint, creative thinking encompasses more than just the use of imagination. It involves the production of a novel, original, and treasured outcome for either an individual or a society (Suciu, 2014).

The 4.0 industry transforms the way people work, requiring new skills to succeed in this innovative field. Students today must develop critical and creative thinking skills in order to keep up with the swiftness of change (Islam, 2015). Both critical and creative thinking are vital forms of thinking. Critical thinking, on the other hand, goes beyond creative thinking in terms of its level of analysis and assessment of information and ideas (Hitchcock, 2017). Critical thinking entails systematically and logically assessing and evaluating information, arguments, and claims. It involves assessing evidence, identifying biases and assumptions, and drawing conclusions based on reasoned judgment. Critical thinking is often used to identify problems, find solutions, and make decisions.

On the other hand, creative thinking requires a more open and flexible mindset that allows for unconventional and original ideas (Bailin et al., 2010). The process of developing fresh and unique ideas or solutions is known as creative thinking. It often involves thinking outside the box, taking risks, and challenging conventional thinking (Werang et al., 2023a. 2023b). Creative thinking is often used in areas such as art, design, and invention, but it can also be applied to problem-solving in other fields.

The purpose of this study is to describe the impact of STEM-based scientific education on critical and creative thinking skills in fourth-semester Elementary School Teacher Education Program students. Students can engage in holistic problem-solving and get a deeper grasp of real-world applications by combining principles from multiple STEM fields.

As displayed earlier, a huge number of studies have investigated the impact of STEM education on critical thinking skills (A'yun et al., 2020; Hacioglu & Gulhan, 2021; Octafianellis et al., 2021; Parno et al., 2021; Widiasari, 2021) and creative thinking skills (Kristiani et al., 2017; Sirajudin et al., 2020; Widiasari, 2021; Doyan et al., 2022; Karmila, 2022). However, within this set of existing studies, only the study conducted by Sirajudin et al. (2020) took place at the higher education level, while the remaining ones were carried out in junior and senior secondary schools. Despite these current studies, there is a significant gap in the assessment of the impact of STEM-based scientific learning on prospective teachers' critical and creative thinking skills. This study highlights fourth-semester Elementary School Teacher Education Program students to bridge this gap. Its goal is to shed light on the effectiveness of STEM education in improving critical and creative thinking skills among university-level students aspiring for careers in education.

University students are often required to think critically and creatively in their coursework and their future careers. Therefore, understanding the impact of STEM education on these cognitive skills in university students is crucial for designing effective STEM-based scientific education curricula and preparing students for success in the workforce. We probed two research questions to guide this study as the following: (1) Does the use of STEM-based scientific learning significantly impact students' critical thinking skills? and (2) Does the use of STEM-based scientific learning significantly impact students' creative thinking skills? To answer these research questions, we employed a quantitative research approach using a quasi-experimental research design.

Based on the existing literature examining how the utilization of STEM learning affects students' critical and creative thinking, the hypothetical model of the study is presented in Figure 1.

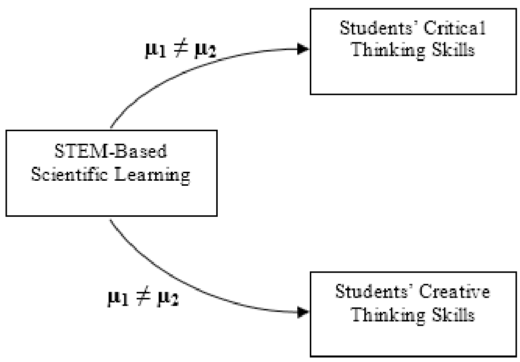

Figure 1. The Hypothetical Model of the Study

The study's hypothetical model emphasizes the potentially transforming benefits of STEM education on students' critical and creative thinking skills. It demonstrates that kids who are exposed to STEM education have better critical and creative thinking skills than students who are not exposed to STEM education. By presenting the hypothetical model as depicted in Figure 1, the study anticipates finding evidence that students exposed to STEM education will demonstrate higher levels of critical and creative thinking compared to their counterparts who have not received such exposure. STEM education empowers learners to face the challenges of an increasingly complex and innovative world by instilling in them valuable lifelong tools of critical and creative thinking that extend beyond the classroom. However, it is essential to note that further research and empirical evidence are required to validate this hypothetical model and draw concrete conclusions about the causal relationship between STEM education and enhanced critical and creative thinking skills in students.

METHODS

As previously stated, this research aimed to examine the potential impact of STEM education on students' critical and creative thinking skills. To achieve this goal, we adopted an experimental research approach with a quasi-experimental research design. The experimental research design refers to the systematic approach of conducting research in an unbiased and regulated manner to enhance accuracy and derive definite conclusions regarding the postulated hypothesis (Bell, 2009). The experimental research design is a scientific method that involves changing one or more independent variables to see if the changes affect a second variable (Loewen & Plonsky, 2017). This method allows researchers to look into the cause-and-effect relationship between variables. In general, the impact of the independent variable on the dependent variable is observed over time in order to draw a reasonable conclusion regarding the causal relationship between the variables (Cherry, 2022).

We used an experimental research approach in our study for two reasons. For initial reasons, it is a widely employed strategy in our sector of expertise, education. Second, the experimental study design is especially beneficial when time restrictions make it impossible to establish cause-and-effect correlations using other research methodologies (Agung et al., 2022). We were able to change the independent variables and see the influence on the dependent variables over a certain time period by employing this design. This allowed us to make logical conclusions about the causal relationship between the variables we studied.

There exist three distinct categories of experimental research, namely: (a) pre-experimental research design, which encompasses one-shot case study research design, one-group pretest-posttest research design, and static-group comparison; (b) quasi-experimental research design, which includes nonequivalent group, discontinuity in regression, and natural experiments; and (c) true experimental research design (Tanner, 2018; Zubair, 2022). For this study, we employed a quasi-experimental research approach, utilizing a posttest-only nonequivalent groups design, as conducting a true experimental study is neither feasible nor ethically viable. The posttest-only nonequivalent groups' design is a quasi-experimental research framework that involves comparing two groups that were not randomly assigned and thus are not equivalent in their composition. Within this design, both groups undergo a posttest assessment after exposure to a treatment or intervention aimed at discerning whether the treatment yielded a significant difference in the outcome variable (Krishnan, 2018). The selection of study participants was accomplished using a purposive sampling technique, wherein specific characteristics were taken into account to determine the subjects (Campbell et al., 2020).

Data pertinent to the study's topic were collected through two distinct measurement techniques. To gauge students' critical thinking skills, we administered a standardized test designed to evaluate participants' proficiency in comprehending and mastering learning materials. We assessed students' creative thinking skills in tandem by measuring their performance in an activity that required the production of unique ideas or solutions in response to a given topic. Our goal was to determine the extent to which this pedagogical method may effectively boost critical and creative thinking skills among participants by measuring these skills both before and after the application of STEM-based scientific learning.

Using STEM-based scientific learning, we provided students with hands-on experiences in conducting scientific experiments to solve real-world problems related to energy and air. The obtained data were subjected to both descriptive (Loeb et al., 2017) and inferential statistical analyses (Hydayatsyah, 2021). The mean value and standard deviation were determined using descriptive statistics, while the model's influence was evaluated using inferential statistics and a one-way MANOVA test. We used the Statistical Package for the Social Sciences (SPSS) version 16 to assure the accuracy of our results.

RESULTS AND DISCUSSION

It is crucial to consider the assumptions when interpreting parametric tests in statistical analysis to avoid drawing erroneous conclusions. In this study, we utilized two assumption tests - normality and homogeneity assumption tests. The majority of parametric tests require normality assumption, which we tested using Kolmogorov-Smirnov's Test. The data distribution needs to be normal, indicated by a non-significant Kolmogorov-Smirnov test. The outcomes of the normality test are provided in Table 1.

Table 1. The Outcomes of the Normality Test

Dependent Variables		Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistics	df	Sig.	Statistics	df	Sig.
Critical thinking skills	1	0.141	32	0.107	0.940	32	0.075
	2	0.141	32	0.104	0.957	32	0.222
Creative thinking skills	1	0.150	32	0.953	0.953	32	0.175
	2	0.144	32	0.970	0.970	32	0.513

Data is considered to be normally distributed if the obtained significance level is higher than 0.05. The analysis technique used in this study was SPSS 16.0 for Windows software. The results of the normality analysis indicate that all data, both from the experimental and control groups for critical and creative thinking skills data, are normally distributed, as evidenced by the Kolmogorov-Smirnov and Shapiro-Wilk statistical values that exhibit significance levels greater than 0.05. Therefore, overall, the data is normally distributed.

To test the homogeneity of variance between groups, we employed Levene's Test of Equality of Error Variances, a commonly used statistical method to assess whether the variance of the dependent variable is similar across the groups being compared. The outcomes of the homogeneity test, as presented in Table 2, provide valuable information concerning the validity of the one-way MANOVA test results, allowing for a more accurate interpretation of the statistical findings.

Table 2. The Outcomes of the Homogeneity Test

		Levene Statistics	df1	df2	Sig.
Critical thinking skills	Based on mean	0.134	1	62	0.715
	Based on median	0.084	1	62	0.773
	Based on the median and with adjusted df	0.084	1	60.471	0.774
	Based on trimmed mean	0.122	1	62	0.728
Creative thinking skills	Based on mean	0.572	1	62	0.452
	Based on median	0.432	1	62	0.514
	Based on the median and with adjusted df	0.432	1	60.394	0.514
	Based on trimmed mean	0.525	1	62	0.472

Data is considered to have the same variance if the resulting significance level is higher than 0.05. The analysis technique employed in this study was the SPSS 16.0 for Windows software. The results of the homogeneity of variance analysis among the learning model groups indicate that all Levene statistical values exhibit significance levels above 0.05. This implies that the variance between the learning model groups is homogenous. The general description of the research findings comprises the distribution of mean scores ($\bar{X}$) and standard deviation (S.D.) based on the learning approach (STEM-based scientific learning and conventional) administered to each treatment group. The mean scores ($\bar{X}$) and standard deviation (S.D.) obtained from the research for each learning approach group are presented in Table 3.

Table 3. The Mean Score and Standard Deviation of Dependent Variables

Dependent Variables	Experimental Group		Nonexperimental Group		Sum	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Critical Thinking Skills	82.50	6.95	69.69	7.61	76.09	9.70
Creative Thinking Skills	82.09	6.00	69.40	5.20	75.75	8.48

If depicted in a bar chart, the mean score ($\bar{X}$) and standard deviation (S.D.) obtained from the research for each learning approach group are presented in Figure 2.

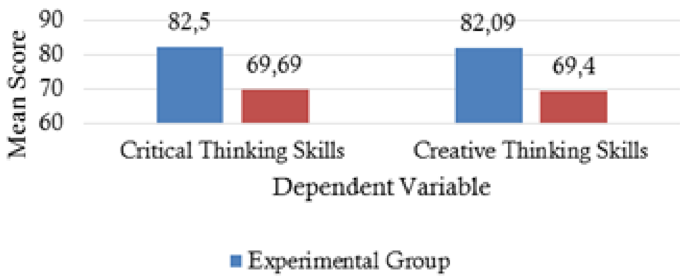

Figure 2. The Mean Score and Standard Deviation of Dependent Variables within Each Group

Data in Table 3 and Figure 2 display the mean score ($\bar{X}$) and standard deviation (S.D.) of critical thinking for the experimental group, which are 82.50 and 6.95, respectively, while the nonexperimental group has a mean score ($\bar{X}$) of 69.69 and a standard deviation of 7.61. These findings suggest that the use of STEM-based scientific learning is more effective in promoting critical thinking skills compared to the conventional approach. Data in Table 3 also displays the mean score ($\bar{X}$) and standard deviation (S.D.) of creative thinking skills for the experimental group, which are 82.09 and 6.00, respectively, while the nonexperimental group has a mean score ($\bar{X}$) of 69.40 and a standard deviation of 5.20. These findings suggest that the use of STEM-based scientific learning is more effective in promoting creative thinking skills compared to the conventional approach.

Based on data displayed in Table 3 and Figure 2, the results suggest that the use of STEM-based scientific learning is more effective in promoting both critical thinking and creative thinking skills when compared to the conventional approach. The experimental group has higher mean scores for both critical thinking and creative thinking skills, and the standard deviation is smaller in the experimental group, suggesting that the STEM-based approach is consistently effective in improving these skills. These findings suggest that implementing STEM-based scientific learning can be a valuable strategy for educators seeking to enhance students' critical and creative thinking skills.

To test the proposed hypothesis, we utilized a one-way multivariate analysis of variance (MANOVA). The summary of the results obtained from the MANOVA is presented in Table 4.

The results of the analysis, as presented in Table 4, indicate that there is a statistically significant impact of STEM-based scientific learning on students' critical and creative thinking skills. This is demonstrated by the F coefficient values of 48.394 and 81.769, respectively, with significance coefficients of .000 for both. The F coefficient value represents the ratio of between-group variability to within-group variability, and a higher F coefficient value indicates a greater difference between the groups being compared. In this case, the high F coefficient values suggest that there is a significant difference in the critical and creative thinking skills of students who have been exposed to STEM-based scientific learning compared to those who have not.

Table 4. Summary of the Results of the One-Way MANOVA Test

Source	Dependent Variable	Type III Sum of Squares	DF	Mean Square	F	Sig.
Corrected Model	Critical thinking skills	2626.563	1	2626.563	49.394	0.000
	Creative thinking skills	2578.735	1	2578.735	81.769	0.000
Intercept	Critical thinking skills	370576.562	1	370576.562	6.969	0.000
	Creative thinking skills	367228.425	1	367228.425	1.164	0.000
STEM-Based Scientific Learning	Critical thinking skills	2626.562	1	2626/562	48.394	0.000
	Creative thinking skills	2578.735	1	2578.735	81.769	0.000
Error	Critical thinking skills	3296.875	62	53.175		
	Creative thinking skills	1955.278	62	31.537		
Total	Critical thinking skills	376500.000	64			
	Creative thinking skills	371762.438	64			
Corrected Total	Critical thinking skills	5923.438	63			
	Creative thinking skills	4534.013	63			

Furthermore, the Sig. coefficient value of .000, which is less than the commonly accepted threshold of 0.05, indicates that the impact of STEM-based scientific learning on students' critical and creative thinking skills is statistically significant. This result provides strong evidence to support the two hypotheses proposed in this study and rejects the null hypothesis that there is no significant difference in critical and creative thinking skills between students who receive STEM-based scientific learning and those who do not. The confirmation of these hypotheses highlights the potential benefits of implementing STEM-based scientific learning programs in educational settings to promote the development of critical and creative thinking skills among students.

In the 21st century, education systems, governments, and employers alike are recognizing critical thinking and creativity as fundamental skills for developing innovative cultures and promoting responsible citizenship (OECD, 2008). Through the implementation of a sequence of thinking skills, students can develop a more sophisticated understanding of the processes to use when encountering new ideas, unfamiliar information, or problems, which enhances their problem-solving skills (Retnawati et al, 2018).

Critical and creative thinking is a complex cognitive process that involves the use of various skills, behaviors, and mindsets. These skills include logic, resourcefulness, innovation, imagination, and reason (Pacheco & Herrera, 2021). The application of these skills is not only limited to academic subjects but also extends to everyday situations both within and outside the educational setting. This type of thinking encourages students to approach problems from different angles and to consider multiple perspectives, leading to more innovative solutions and a deeper understanding of the world around them. By engaging in critical and creative thinking, students can develop a more comprehensive and profound thinking process that goes beyond surface-level comprehension (Bauld, 2022).

Effective learning is centered around productive, purposeful, and intentional thinking. This means that students are encouraged to engage in critical and creative thinking to develop a deeper understanding of the concepts they are learning. One approach that emphasizes this type of thinking is STEM-based scientific learning. This approach emphasizes the integration of science, technology, engineering, and mathematics concepts to promote innovative and analytical thinking (Yaki, 2022). By utilizing this approach, students are exposed to real-world problems that require them to apply their knowledge and skills to find solutions. This encourages students to think outside the box and develop unique solutions to complex problems.

STEM-based scientific learning also emphasizes the importance of collaboration and teamwork, as students work together to find solutions to real-world problems (National Center for Education Statistics, 2017). By promoting critical and creative thinking skills, STEM-based scientific learning provides students with the tools they need to succeed in a rapidly changing world. The results of data analysis show that the use of STEM-based scientific learning has a significant impact on students' critical thinking skills, as indicated by the F coefficient value of 49.394 with the Sig. coefficient value of 0.000. It means that the more university teachers utilize STEM-based scientific learning approaches, the more significantly students' critical thinking skills will increase. Conversely, the fewer university teachers use STEM-based learning approaches, the less significant the improvement in students' critical thinking skills will be. This finding is supported by the research findings of Bulu and Tanggur (2021), Hebebci (2022), Mabrurah et al. (2023), Putra et al. (2023), Sastra et al. (2022), Sujanem and Suwindra (2023), and Topsakai et al. (2022) that the utilization of STEM education in the classroom lead to significant improvements in students' critical thinking skills. Since creative thinking skills are classified as both 21st-century learning skills and higher-order thinking skills, this finding is also in line with the research findings of Ichsan et al. (2023), Martawijaya et al. (2023), Suradika et al. (2023), and Yerimadesi et al.'s (2023) research findings that the utilization of STEM-based scientific learning led to the improvements in students' higher order thinking skills. The study shows that students who participate in STEM-based scientific learning activities have higher scores in critical thinking than those who do not engage in such activities. The results of these previous studies suggest that STEM education can be beneficial for all students, regardless of their academic background or prior knowledge of STEM subjects.

The results of data analysis also show that the use of STEM-based scientific learning has a significant impact on students' creative thinking skills, as indicated by the F coefficient value of 81.769 with the Sig. coefficient value of 0.000. It means that the more university teachers utilize STEM-based scientific learning approaches, the more significantly students' creative thinking skills will increase. Conversely, the fewer university teachers use STEM-based learning approaches, the less significant the improvement in students' creative thinking skills will be. This finding is in line with the research findings of Aguilera and Ortis-Revilla (2021), Amiruddin et al. (2019), Eroğlu and Bektaş (2022), Hebebci (2022), Iskandar et al. (2020), Izzah et al. (2023), Kencana et al. (2020), Preca et al. (2023), Sastra et al. (2022), and Sutaphan and Yuenyong's (2023), that incorporating STEM education in the classroom lead to significant improvements in students' creative thinking skills. Since creative thinking skills are classified as both 21st-century learning skills and higher-order thinking skills, this finding is also in line with Ichsan et al.'s (2023), Ilma et al.'s (2023), Martawijaya et al.'s (2023), Suradika et al.'s (2023), and Yerimadesi et al.'s (2023) research findings that the utilization of STEM-based scientific learning affect the students' higher order thinking skills significantly. The study shows that students who participate in STEM-based scientific learning activities have higher scores in creative thinking than those who do not engage in such activities.

In light of the findings of previous studies and this study, it is clear that incorporating STEM-based scientific learning in the classroom can have a significant positive impact on both critical and creative thinking skills in students. By promoting the integration of STEM education within educational institutions, educators can equip students with the means to conjure innovative solutions to problems impacting their communities and the global sphere. Furthermore, as the demand for adept technologically skilled workers continues to rise, endowing students with opportunities to refine these skills through STEM education enhances their readiness for future careers.

These findings are noteworthy as they underscore STEM education's capacity to assist students in cultivating essential skills that can prove advantageous in both academic and non-academic domains. The favorable influence of STEM-based scientific learning on critical and creative thinking skills is poised to yield enduring ramifications, given that students who nurture these proficiencies are likely to perpetually employ and hone them across the course of their lives. These findings substantiate the idea that STEM-based scientific learning can serve as a feasible avenue for enhancing critical and creative thinking skills. These skills are imperative for tackling intricate challenges prevalent in contemporary society.

The outcomes of this study carry substantial theoretical implications for the existing body of knowledge concerning STEM education and the cultivation of critical and creative thinking skills. While previous studies have explored this area, only a few studies have delved into the context of Indonesian Higher Education Institutions. Therefore, these current findings have the potential to fill the gap and provide a more comprehensive understanding of how STEM-based scientific learning impacts critical and creative thinking skills within this particular context.

Despite its theoretical contributions, this study does possess limitations. It primarily pertains to its narrow focus on a singular department and university, potentially constraining the applicability of the results to broader contexts. Future research endeavors should aim to replicate and extend these findings in diverse settings, encompassing larger and more heterogeneous participant samples. Additionally, the study's reliance on self-report measures of critical and creative thinking skills introduces potential biases like social desirability, warranting future investigations to incorporate objective measures or multiple data sources to overcome this limitation.

CONCLUSION

Based on the results of this study, it can be concluded that implementing STEM-based scientific learning has a positive impact on the critical and creative thinking skills of students at Universitas Pendidikan Ganesha, Indonesia. This highlights the potential of STEM-based scientific learning in transforming the way we approach teaching and learning. The study suggests adding STEM-based scientific learning to the curriculum to improve students' higher-order thinking skills, which are essential for future careers in science, technology, engineering, and mathematics. The study also highlights the importance of teachers receiving proper training to effectively use the STEM model in teaching and nurturing students' critical and creative thinking. The theoretical rationale underlying these outcomes lies in the cognitive development theories that support the idea that active, experiential, and interdisciplinary learning enhances higher-order thinking skills. STEM education aligns with Vygotsky's and Dewey's theories on the importance of social interaction and practical experiences in cognitive development by providing a rich and dynamic learning environment where students engage in meaningful, collaborative, and hands-on experiences, leading to the development of critical and creative thinking skills.

REFERENCES

Agung, A. A. G., Sri, A. G. P., & Werang, B. R. (2022). Project-based e-learning and its impact on students' academic achievement in curriculum development lectures. *Mimbar Ilmu, 27*(3), 362-369.

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM Education and Student Creativity: A Systematic Literature Review. *Education Sciences,* 11, 331.

Amiruddin, B., Juwairiyah, A., & Subhan, S. (2019). STEM education in integrated thematic learning to improve students' creative thinking skills in elementary schools. *Proceedings of the 1st International Seminar on Science, Technology, Engineering, and Mathematics*.

Amrilizia, N., Habiddin, H., & Marsuki, M. F. (2022). Improving students' critical thinking skills using e-modules-contextual teaching and learning (CTL) on the interaction of living organisms with their environment. *JODLI: Journal of Disruptive Learning Innovation, 3*(2), 65–82.

A'yun, Q., Rusilowati, A., & Lisdiana, L. (2020). Improving students' critical thinking skills through the STEM digital book. *Journal of Innovative Science Education, 9*(2), 237-243.

Bailin, S., Case, R., Coombs, J. S., & Daniels, L. B. (2010). Conceptualizing critical thinking. *Journal of Curriculum Studies, 31*(3), 285–302.

Bauld, A. (2022). *Encouraging higher-order thinking skills in students.*

Bell, S. (2009). Experimental design. In *International Encyclopedia of Human Geography.*

Bulu, V. R., & Tanggur, F. (2021). The effectiveness of STEM-based PjBL on student's critical thinking skills and collaborative attitude. *Al-Jabar: Jurnal Pendidikan Matematika, 12*(1), 219-228.

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., & Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of Research in Nursing, 25*(8), 652–661.

Cherry, R. (2022). *How the experimental method works in psychology.* Verywell Mind.

Croak, M. (2018). The effects of STEM education on economic growth. *Honors Theses.* 1705.

Dewey, J. (1910). *How we think*. Lexington, Massachusetts: D.C. Heath and Company.

Doyan, A., Wahyudi, W. & Aulia, L. D. (2022). Pengaruh model STEM terhadap kreativitas sains peserta didik pada materi suhu dan kalor. *Jurnal Penelitian dan Pembelajaran Fisika Indonesia, 4*(1), 1-5.

Doyan, A., Melita, A. S., & Makhrus, M. (2023). Increasing critical thinking skills through the development of stem-based physics learning media on temperature and heat. *Jurnal Penelitian Pendidikan IPA, 9*(6), 4096-4102.

Duran, M., & Şendağ, S. (2012). A preliminary investigation into critical thinking skills of urban high school students: Role of an IT/STEM program. *Creative Education, 3*(2).

Eroğlu, S., & Bektaş, O. (2022). The effect of 5E-based STEM education on academic achievement, scientific creativity, and views on the nature of science. *Learning and Individual Differences, 98*, 102181.

Forster, J., (2014). The significance of creativity in our lives. *International Journal for Talent Development and Creativity, 3*(1), 53–68.

Hacioglu, Y., & Gulhan, F. (2021). The effect of STEM education on the students' critical thinking skills and STEM perceptions. *Journal of Education in Science, Environment, and Health, 7*(1), 139-155.

Hebebci, M. T. (2022). The effect of integrated STEM education practices on problem-solving skills, scientific creativity, and critical thinking dispositions. *Participatory Educational Research, 9*(6), 358-379.

Hitchoock, D. (2017). Critical thinking as an educational ideal. On Reasoning and Argument, pp. 477-497

Ichsan, I., Suharyat, Y., Santosa, T. A., & Satria, E. (2023). The effectiveness of STEM-based learning in teaching the 21st Century skills in Generation Z in science learning: A meta-analysis. *Jurnal Penelitian Pendidikan IPA Indonesia, 9*(1), 150-166.

Ilma, A. Z., Wilujeng, I., Widowati, A., Nurtanto, M., & Kholifah, N. (2023). A systematic literature review of STEM education in Indonesia (2016-2021): Contribution to improve skills in 21st-century learning. *Pegem Journal of Education and Instruction, 13*(2), 134-146.

Iskandar, I., Sastradika, D., Jumadi, J., & Defrianti, D. (2020). Development of creative thinking skills through STEM-based instruction in senior high school student. *Journal of Physics: Conference Series, 1567*, 1-7.

Islam, S. M. R. (2015). *What are the importance and benefits of 'critical thinking skills'*.

Izzah, S. N., Sudarmin, S., Wiyanto, W., & Wardani, S. (2023). Analysis of sciences concept mastery, creative thinking skills, and environmental attitudes after ethno-STEM learning implementation. *International Journal of Instruction, 16*(3), 777-796.

Karmila, K. (2022). *Pengaruh pembelajaran STEM (Science, Technology, Engineering, Mathematics) pada materi fluida terhadap keterampilan berpikir kreatif peserta didik.* Graduate Thesis presented to Universitas Muhammadiyah Makasar.

Kencana, M. A., Musri, M., & Syukri, M. (2019). The effect of science, technology, engineering, and mathematics (STEM) on students' creative thinking skills. *Journal of Physics: Conference series, 1460*, 1-6.

Khotimah, R. P., Adnan, M., Ahmad, C. N. C., & Murtiyasa, B. (2023). The effectiveness of the STEMDISLEARN module in improving students' critical thinking skills in the differential equations course. *Cogent Education, 10*, 2220233.

Krishnan, P. (2018). A review of the nonequivalent control group post-test-only design. *Nurse Researcher, 26*(2), 37–40.

Kristiani, K. D., Mayasari, T., & Kurniadi, E. (2017). Pengaruh pembelajaran STEM-PjBL terhadap keterampilan berpikir kreatif. *Prosiding Seminar Nasional Pendidikan Fisika,* 266-274.

Loeb, S., Morris. P., Dyanarski, S., Reardon, S., McFarland, D., & Reber, S. (2017). *Descriptive analysis in education: A guide for researchers*.

Loewen, S., & Plonsky, L. (2017). *An A–Z of applied linguistics research methods.* Bloomsbury Publishing

Mabrurah, F. F., Qadar, R., & Sulaeman, N. F. (2023). Enhancing high school students' critical thinking skills through STEM-PjBL in optics topic. *Berkala Ilmiah Pendidikan Fisika, 11*(1), 1-8.

Martawijaya, M. A., Rahmadhanningsih, S., Swandi, A., Hasyim, M., & Sujiono, S. H. (2023). The effect of applying the ethno-stem-project-based learning model on students' higher-order thinking skills and misconception of physics topics related to Lake Tempe, Indonesia. *Jurnal Pendidikan IPA Indonesia, 12*(1), 1-13.

National Center for Education Statistics. (2017). Collaborative problem solving: Considerations for the national assessment of educational progress.

Nugroho, O. F., Permanasari, A., Firman, H., & Riandi, R. (2021). The urgency of STEM in Indonesia. *Jurnal Penelitian dan Pembelajaran IPA, 7*(2), 260-279.

Nuri, A. R. U., Sajidan, S., Oetomo, D., Prasetyanti, N. M., & Parmin, P. (2019). Improving Indonesian senior high school students' critical thinking skill through science integrated learning model. *Tadris: Jurnal Keguruan dan Ilmu Tarbiyah, 4*(2), 145-158.

Octafianellis, D. F., Sudarmin, S., Wijayanti, N., & Panca, H. (2021). Analysis of student's critical thinking skills and creativity after problem-based learning with STEM integration. *Journal of Science Education Research, 5*(1), 31-37.

OECD. (2008). *21st-century skills: How can you prepare students for the new global economy?*

Pacheco, C. S., & Herrera, C. I. (2021). A conceptual proposal and operational definitions of the cognitive processes of complex thinking. *Thinking Skills and Creativity, 39,* 1-10.

Parno, P., Supriana, E., Widarti, A. N., & Ali, M. (2020). The effectiveness of STEM approach on students' critical thinking ability in the topic of fluid statics. *Journal of Physics: Conference Series,* 1882, 1-8.

Pasaribu, K., Khairuna, K., Adlini, M. N., & Abrori, F. M. (2023). Developing STEM students' worksheet to improve students' creative thinking ability. *Research and Development in Education, 3*(2), 127-136.

Preca, B. C., Baldacchino, L., Briguglio, M., & Mangion, M. (2023). Are STEM Students Creative Thinkers? *Journal of Intelligence, 11*, 106.

Pursitasari, I. D., Alfitriyani, N., & Kurniasih, S. (2022). Enhancing students' critical thinking skills through biotechnology module-based socio-scientific issues. *Jurnal Penelitian Pendidikan IPA, 8*(2), 939-948.

Putra, M., Rahman, A., Ilwandri, I., Suhayat, Y., Santosa, T. A., Putra, R., & Aprilisia, S. (2023). The effect of STEM-based REACT model on students' critical thinking skills: A meta-analysis study. *Literacy: International Scientific Journal of Social, Education, and Humaniora, 2*(1), 207–217.

Retnawati, H., Djidu, H., Kartianom, A., & Anazifa, R. D. (2018). Teachers' knowledge about higher-order thinking skills and its learning strategy. *Problems of Education in the 21st Century*, *76*(2), 215.

Sastra, P. Z. M., Putri, Y. L. J., Pratama, F., & Desnita, D. (2022). Meta-analysis of the effect of STEM approach on students' critical and creative thinking skills in Physics learning in senior high schools. *Journal of Geliga Sains, 10*(1), 61-73.

Sirajudin, N., Suratno, J., & Pamuti, P. (2020). Developing creativity through STEM education. *Journal of Physics: Conference Series.* 1806, 1-5.

Soetjipto, T., & Jose, R. (2020). *In latest UNDP report, Indonesia retains standing in high human development category*.

Suciu, T. (2014). The importance of creativity in education. *Bulletin of the Transilvania University of Braşov: Series V Economic Sciences, 7*(2), 151–158.

Sujanem, R., & Suwindra, I N. P. (2023). Problem-based interactive physics e-module in physics learning through blended PBL to enhance students' critical thinking skills. *Jurnal Pendidikan IPA Indonesia,12*(1), 135-145.

Suradika, A., Dewi. H. I., & Nasution, M. I. (2023). Project-based learning and problem-based learning models in critical and creative students. *Jurnal Pendidikan IPA Indonesia, 12*(1), 153-167.

Sutaphan, S., & Yuenyong, C. (2023). Enhancing eighth-grade students' creative thinking in the water STEM education learning unit. *Cakrawala Pendidikan, 42*(1), 120-135.

Tanner, K. (2018). *Research methods: Information, systems, and context.* Chandos Publishing.

Topsakai, I., Yalçın, S. A., & Çakır, Z. (2022). The effect of problem-based stem education on the students' critical thinking tendencies and their perceptions for problem-solving skills. *Science Education International*, *33*(2), 136-145.

Werang, B. R., Agung, A. A. G., Jampel, I N., & Sujana, I W. (2023a). Outside the box leadership pada SMP Negeri Buti, Merauke, Papua: Perspektif guru. *Kelola: Jurnal Manajemen Pendidikan,* in print.

Werang, B. R., Agung, A. A. G., Jampel, I N., & Sujana, I W. (2023b). Exploring the outside-the-box leadership of an Indonesian state junior high school principal: A qualitative case study. *Cogent Education, 10*(2), 2255091.

Widiasari, B. (2021). Pengaruh pembelajaran STEM berbantuan google classroom terhadap berpikir kreatif. Graduate Thesis presented to Universitas Islam Negeri Raden Intan.

Yaki, A. A. (2022). Fostering critical thinking skills using integrated STEM approach among secondary school biology students. *European Journal of STEM Education, 7*(1), 1–10.

Yerimadesi, Y., Warlinda, Y. A., Rosanna, D. L., Sakinah, M., Putri, E. J., Guspatni, G., & Andromeda, A. (2023). Guided discovery learning-based chemistry e-module and its effects on students' higher order thinking skills. *Jurnal Pendidikan IPA Indonesia, 12*(1), 168-177.

Zubair, A. M. (2022). *Experimental research: Design - types and process*.