



21st century STEM education: An increase in mathematical critical thinking skills and gender through technological integration

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Abstract

STEM learning is a process of improving one's mathematical critical thinking skills in the twenty-first century. The study aimed to compare the mathematical skills of critical thinking between genders through STEM learning. The researchers employed the quasi-experiment design with 2 x 2 factorial designs and a simple random sampling technique. The research data were collected using tests to assess students' mathematical critical thinking skills. The normality, homogeneity, and hypothesis tests analysis were performed using two-way ANOVA. The research findings are as follows: (1) there were differences between STEM and conventional learning in mathematical critical thinking skills. STEM learning through technological integration is more effective than conventional learning; (2) there was a difference in the mathematical critical thinking skills results between male and female students, with female students having a higher ability to use critical thinking skills. It is expected that STEM learning can be used as a learning solution in the twenty-first century.

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INTRODUCTION

The rapid development of science and technology gives rise to new demands in all life aspects, including the 21st-century education system. The integration of technology is appropriate in teaching and learning. The government has made various efforts to improve the quality of education, of which the 2013 curriculum is one (Syutharidho & Rakhmawati, 2015). It is expected that multidisciplinary training, student-centered, active and critical, interactive study, and groups or teams will be achieved (Keiler, 2018). Mathematics is one topic considered essential in the education world (Lamote, 2017). The facts show that mathematics holds a high position in science because it underpins understanding or thinking about other subjects. However, some students still believe that learning mathematics is difficult (Fadholi et al., 2015). Students are more likely to show low learning interest and low performance motivation when considering the subjects difficult (Suherman, 2015). Given the importance of mathematics, it is hoped that a teacher's role in determining learning approaches can change students' mindsets and views about mathematics (Abdullah et al., 2016; Komarudin et al., 2020; Suherman et al., 2018). Students are expected to show great mathematical interest and develop creativity and learning achievement.

On the other hand, the positive impact of Information and Communication Technologies (ICT) on social life represents a unique opportunity for educational development, as these technologies facilitate and provide meaningful learning opportunities through technological resources. (Nicolete et al., 2017) assert that mathematical abilities are genetically imprinted in our brains and recommend that mathematics be taught using models that include the development of intuitive reasoning, the manipulation of materials, and fun and engaging activities. One possibility is to encourage teachers and schools to incorporate more interactivity and exciting ICT technologies into math classes, exploring playful digital resources, such as educational games, simulators, videos, and images to support the teaching and learning of mathematics and other applied sciences in classrooms across the country (Nicolete et al., 2017).

Mathematics can be considered a science whose system ranges from simple to very complex concepts (Andriani et al., 2019; Depaepe et al., 2013; Syabrina Sarmi, 2019). The concept should appear in the learning process. Critical thinking skill is essential in learning mathematics (Mujib, 2015; Setiawan, 2016; Suherman & Diana, 2019). Students are also helped to develop other skills through

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creative thinking and problem-solving (Mahmuzah, 2015), connection (Eynon et al., 2014), representation (Istemic Starčić et al., 2016), and communication (Surya et al., 2018). In learning mathematics, critical thinking is important to find concepts.

According to the results of international assessments from The Program for International Student Assessment (PISA), Indonesian students' mathematics achievement was low compared to other countries. The PISA assessment consists of basic reading, mathematics, and science tests that are not based on any national curriculum. The PISA process is widely regarded as having strong legitimacy in describing a country's educational quality. Indonesia has taken part in PISA since 2000. In the most recent PISA iteration in 2018, Indonesian students ranked 72 out of 78 countries.

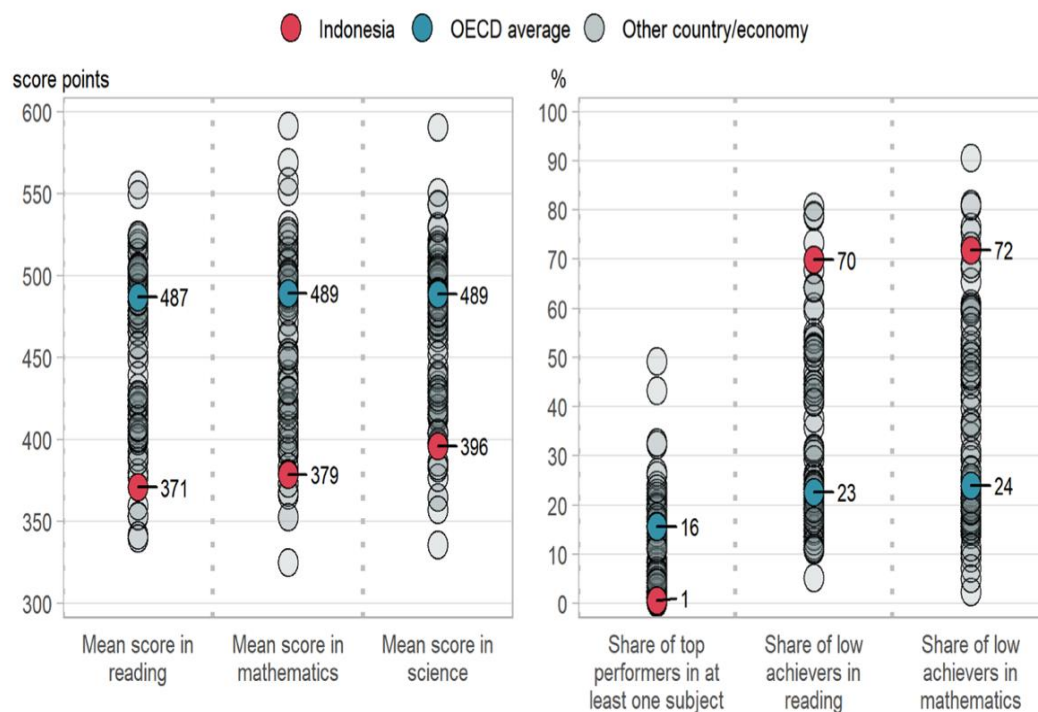


Figure 1. The Results of Indonesian Students in Mathematics, Science, and Reading

Figure 1 shows that Indonesian students, particularly in mathematics, have a lower average score than most Organization for Economic Co-operation and Development (OECD) countries, with an average score of 379 compared to an OECD average score of 489. According to Schleicher (2019), based on PISA results, approximately 28% of Indonesian students achieved level 2 or higher in mathematics, compared to the OECD average of 76%. In short, 72% of Indonesian students are considered low achievers in mathematics, compared to the OECD average of 24 percent (right chart in Figure 1). At level 2, the students can mathematically analyze, acknowledge, and describe simple issues. However, only 1% of Indonesian students score at level 5 (OECD average of 11%). Those students can use mathematical models to solve challenging circumstances and select, compare, and evaluate problem-solving solutions.

The students who learn by only conventional learning mostly cannot understand critical thinking (Happy & Widjajanti, 2014). Therefore, teachers should use a diverse and interesting approach in teaching important abstract subjects (Kariyana & Sonn, 2016; Putra et al., 2020) and encourage students to conduct numerous experiments to better their creative and critical thinking. Furthermore, gender is appropriate to know these factors. Teachers of all skill levels interact more with male students than female students (Canning et al., 2019).

The learning approach can enhance students' understanding of science, technology, engineering, and mathematics (STEM). STEM is an important issue and is recognized internationally as a foundation for economic growth and advancing skills people need in the 21st-century (Chai, 2019; Maass et al., 2019). Two or more fields of knowledge are contained in STEM, and other subjects may be integrated into the STEM approach (Martín-Páez et al., 2019; Shernoff et al., 2017).

Recently, the majority of STEM research has been conducted. The results show that integrating STEM in learning improves the students' accomplishment in algebra, geometry, and probability

(Sunyoung et al., 2016). It also enhances literacy and proficiency in science, math, and technological engineering (Tati et al., 2017). Furthermore, it improves the thinking capacity (Sari et al., 2019). STEM training influences the achievements of science and mathematics. Students are excited about learning. They wish to see more about it in future courses and consider STEM fields for their future professions (Acar et al., 2018). Besides, the findings of a meta-analytic study show that the STEM programs present positive and statistically significant overall effects on students' mathematics achievement (Siregar et al., 2019). The meta-analysis studies contained limitations. Some studies did not provide relevant information for calculating the effect size and detailed information about the STEM program. Also, no explicit or systematic results were presented in the selected studies. Based on the previous article, this research update effectively assesses the STEM approach, students' critical thinking skills, and the gender applied to the 2013 curriculum. A more efficient learning model will increase mathematical thinking skills significantly. The research aims to assess the mathematical abilities of gender-based critical thinking using STEM through technological integration.

METHOD

A quasi-experimental design with a 2 x 2 factorial design was used in this study. The following table depicts the research design.

Table 1. Research Factorial Design

Learning Models (A_i)	Gender (B_j)	
	Male (B_1)	Female (B_2)
STEM model (A_1)	A_1B_1	A_1B_2
Conventional/Expository (A_2)	A_2B_1	A_2B_2

All students at SMK Nurul Islam in South Lampung served as the population, with 53 tenth-grade participants. The research sample was drawn using the simple random sampling technique. The experimental class implemented the STEM approach, while the control class implemented an approach according to the school curriculum. The steps in learning are as follows:



Figure 2. STEM Learning Procedure

An essay test on geometry material was used as the instrument in this study to assess students' critical thinking skills. The following are indicators of critical thinking in mathematics:

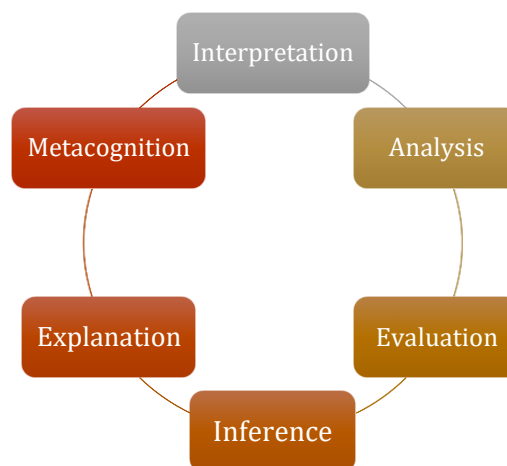


Figure 3. The Indicators of Mathematical Critical Thinking

Normality and homogeneity tests were performed before the analysis. The statistical tests employed a 5% level of significance. The SPSS 17 program was used to perform hypothesis testing, namely the two-way ANOVA test with a 2 x 2 factorial design.

RESULTS and DISCUSSION

The results of the mathematical creative thinking skills test are included in the research data. Table 2 shows the value of mathematical creative thinking skills based on learning and experience. On the other hand, Table 3 shows the value of mathematical creative thinking skills as a function of gender.

Table 2. The Outcome of Mathematical Creative Thinking Skills Based on Learning Model

Group	X_{\max}	X_{\min}	Central Tendency			Variation
			\bar{x}	Mo	Me	Sd
STEM	96	42	70.70	55	50	15.287
Expository	94	36	60.50	45	45	16.525

According to Table 2, the average value of mathematical critical thinking skills using STEM is higher than expository learning. Furthermore, the highest value of STEM learning is greater than the highest value of expository learning.

Table 3. The Outcome of Mathematical Creative Thinking skills Based on Gender

Group	X_{\max}	X_{\min}	Central Tendency			Variation
			\bar{x}	Mo	Me	Sd
Male	98	45	57.04	55	65	16.809
Female	98	50	63.21	45	70	14.707

According to table 3, female students have a higher average test score for critical thinking skills than male students. However, they have the same highest scores. Furthermore, the prerequisite tests were performed using the SPSS 17 program with a significance level of 5%. The tables below show the results of normality and homogeneity tests.

Table 4. The Results of Normality Test

Mathematical Critical Thinking	Group	Sig	Decision
	STEM	0,822	Normal
	Expository	0,330	Normal
	Male	0,440	Normal
	Female	0,628	Normal

Table 5. The Results of Homogeneity Test

Mathematical Critical Thinking	Group	Sig	Decision
	STEM	0,678	Homogeneous
	Expository		
	Male	0,687	Homogeneous
	Female		

According to Tables 4 and 5, the data is normally distributed and has the same variation. The researchers utilized the parametric statistics of the 2×2 factorial two-way ANOVA test assisted by the SPSS program to test the data hypothesis.

Table 6. The Result of Hypothesis Testing

Group	Sig
Teaching Method	$0.047 < 0.05$
Gender	$0.029 < 0.05$
Interaction	$0.907 > 0.05$

According to Table 2, the average value of STEM is 70.70, while the average value of expository is 60.50. The results demonstrate that STEM learning provides students with a better learning experience than expository learning, particularly geometry material. The results are because STEM learning provides students with innovative ideas.

Furthermore, the STEM learning steps combine creativity and learning experiences. Therefore, students become accustomed to using it in everyday situations. The STEM learning steps, such as observation, provide new experiences in geometry learning. Students can participate in discussions to express their ideas and opinions about what they see (observe). These STEM steps will provide students with new information on what has been observed, allowing them to analyze and think critically (Borrego & Henderson, 2014; Hobbs et al., 2018; Kusumah, 2019).

Following the next STEM steps, there is an innovative step in which students will incorporate new ideas into their observations. Through this concept, the student's creativity will be realized, and they can apply the concepts in their daily lives. The final STEM step is to provide students with value (society). It is hoped that students will gain a greater appreciation for what they receive, resulting in increased learning.

The results are consistent with research findings that STEM learning can provide and improve students' critical thinking skills (Struyf et al., 2019). The concept can be implemented using technological integration. This integration is using the Google Classroom platform. Regarding technological integration, the technology can assist the students.

In contrast to expository learning, the researcher explains the learning objectives to be implemented and conveys perceptions about the geometry material. The students will be allowed to comprehend the material in the given book. Furthermore, students will be given problems that can be solved through discussion. The students will then present the outcomes of their discussions.

Expository learning only emphasizes the teacher's role. Students are only given a few opportunities to be less active and less motivated to learn. The conclusion demonstrates a distinction between using STEM and expository learning. It is possible to conclude that STEM is more effective, although the difference is not significant compared to traditional methods. The creative thinking skills using STEM are greater than the expository control class. According to relevant research, STEM learning can provide real learning experiences, increase learning effectiveness, and support future careers and professions (Kelley & Knowles, 2016). As a result, students can benefit from STEM education. Therefore, through STEM learning, students learn the material and practice, which makes learning easier and enjoyable. According to Table 3, the average score of males' mathematical critical thinking skills is 57.04, and females' average level is 63.21. As a result, female students comprehend the concept better than male students. This demonstrates that the gender difference in mathematical critical thinking skills between females and males is distinct.

Gender differences in students' concept understanding are supported by relevant research (Salavera et al., 2017). As a result, rather than expository learning, STEM has creative steps and values that will make students enthusiastic about learning and be motivated. Gender differences in learning outcomes result from a more diligent learning style for female students than male students. Thus, learning outcomes differ between male and female students. Female students outperform male students when learning Mathematics (Meifiani & Prasetyo, 2015). There is no interaction between learning and gender on mathematical critical thinking skills. As a result, STEM and traditional learning that uses scientific learning have a relatively good value of concept understanding seen from the gender perspective.

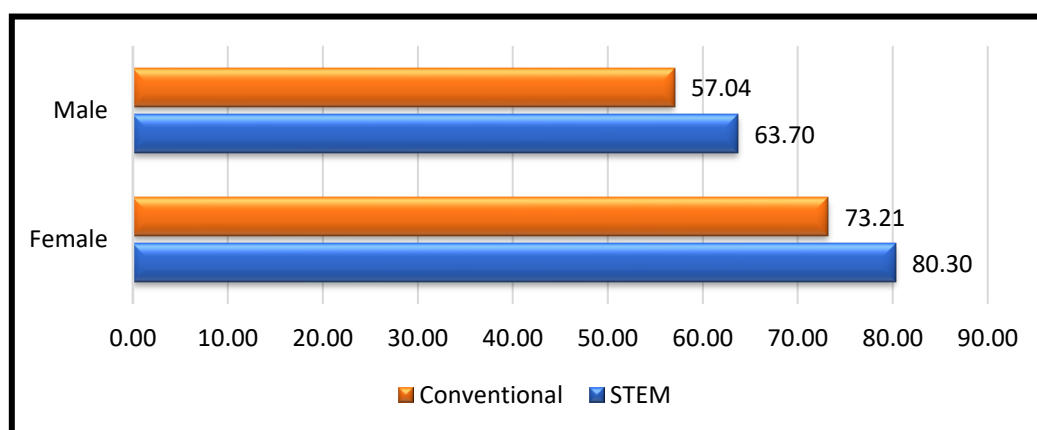


Figure 4. Mathematical Critical Thinking Report

The graph depicts values with insignificant differences. As a result, expository learning does not affect critical mathematical thinking. This research is similar to gender research, concluding that there is no significant difference between cooperative learning and gender. Learning that provides meaning has a positive influence on mathematical critical thinking skills. As a result, it will impact gender differences in STEM learning, making students more critical, active, and creative when compared to expository learning.

However, it was discovered in this study that there was a relationship between the type of learning used (STEM) and gender on mathematical critical thinking skills. Another possible factor is the failure to implement research findings during learning due to a lack of seriousness in the classroom learning process and control over students.

TPACK (Technological Pedagogical Content Knowledge) Framework is used to better understand the interrelationships between science, technology, and pedagogy. This framework was developed by Punya Mishra and Matthew J. Koehler, both of whom worked at the State University of Michigan in the United States, and published their findings (Mishra & Koehler, 2006).

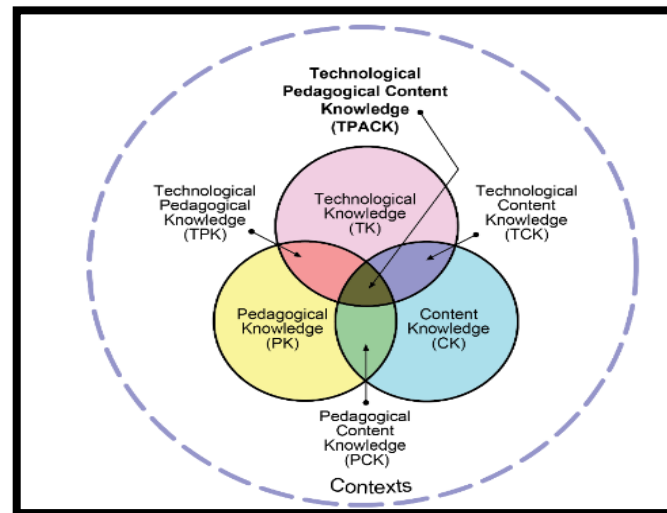


Figure 5. TPACK Model (Nicolette et al., 2017)

A synthesis of this knowledge leads to efficient and effective use of teaching and learning technologies. The combination framework of CK, PK, and TK intersects the association's proposal evaluation concepts (TPK). The Educational Technological Knowledge Content (TPCK) is the ideal knowledge for teachers to integrate technology into their teaching practice after interacting with knowledge first (Mishra & Koehler, 2006).

CONCLUSION

In conclusion, there were differences in learning between STEM and conventional learning, indicating that STEM learning was superior to conventional learning. In terms of gender differences, female students outperform male students in mathematical critical thinking skills. There was no interaction between learning and gender. As a result, STEM was more effective in the learning process and provided female students with higher mathematical critical thinking skills, although there was no interaction between learning and gender.

This study had some limitations, namely only measuring mathematical creative thinking skills in geometry material, limiting its applicability to other materials. By paying attention to time and direction, STEM learning can be used as a learning solution in the twenty-first century.

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Author Contribution Statement:

Suherman: Conceptualized and designed the study, contributed to data collection, performed statistical analysis, and wrote the manuscript. Responsible for revising and finalizing the manuscript.

Revani Husain Setiawan: Assisted in data collection and contributed to the interpretation of the results. Co-wrote the introduction and literature review sections.

Herdian: Contributed to the research design and methodology, supported data collection, and provided critical feedback during the analysis process.

Bambang Sri Anggoro: Assisted with the literature review, provided insights on the implications of the study, and contributed to editing the manuscript.

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