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Improving students' ability in learning mathematics by using the science, technology, engineering, and mathematics (STEM) approach

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The science, technology, engineering, and mathematics (STEM) approach is a leading and important learning approach to analyze thinking ability and learning motivation. Accordingly, this study attempts to elaborate a STEM approach to analyze the critical thinking ability and motivation of high school students in Indonesia, especially in Palopo City, South Sulawesi, Indonesia. The current research applied pre-experimental treatment on research objects involving a group of experimental classes. Pre-experimental was used in testing the STEM approach in an experimental class with a one-group pretest–posttest design with 176 students divided into five classes. The results show: (1) improvement in students' critical thinking ability indicated by an average pretest score of 13.90 and posttest score of 70.67; (2) an increase in student learning motivation shown by an average of 71.57–80.83. The analysis results show an increase in students' critical thinking ability and learning motivation after applying the STEM approach. Conclusively, STEM functions as one of the practical learning methods for improving students' critical thinking skills and learning motivation.

KEYWORDS

STEM approach, critical thinking ability, learning motivation, South Sulawesi, Indonesia

Introduction

This study is aimed at analyzing and measuring the science, technology, engineering, and mathematics (STEM) approach by elaborating on the ability to learn mathematics to improve critical thinking and student learning motivation in Palopo City, South Sulawesi, Indonesia. STEM is a modern approach used as a communication and information technology applied to mathematics learning (Changtong et al., 2020).

The approach taken by integrating STEM aspects is carried out to see the extent of students' critical thinking ability and learning motivation toward effective learning methods (Carlson et al., 2016). The STEM approach is a current approach taken to change students' abilities (Blecking, 2018). As a result, this study elaborates on the implementation of mathematics learning methods through a STEM approach to optimally improve students' critical thinking skills and learning motivation.

The change in optimal ability intended by the STEM approach can ideally change the critical ability and motivation of student learning, so that students have incredibly fast and varied latitudes for learning mathematics (Blecking, 2018). Students in educational institutions, mainly formal education, certainly have a significant role in educating their students with the right approach (Graham et al., 2013). Consequently, a STEM approach is needed to encourage basic literacy and students' main competencies, namely critical thinking skills and learning motivation in solving problems. Therefore, educational actors, especially teachers at schools, must be able to formulate a STEM approach to instill good character values in the students (Theobald et al., 2020). Teachers should try to find various approaches so that can provide students with good basic literacy and the ability to solve simple and more complex problems once they graduate from school (Logan et al., 2019).

In the Indonesian context, especially in Palopo City, South Sulawesi, a learning method that teachers can implement to improve students' critical thinking skills and learning motivation is the STEM approach (Wahono et al., 2020). Burke et al. (2020) states that STEM approaches can make STEM a more effective learning method. In addition, critical thinking skills and high learning motivation are among the critical aspects that students need to have (Li and Schoenfeld, 2019). Therefore, this study will have a considerable impact and substantially contribute to the application of STEM approaches in Indonesia, especially the South Sulawesi region.

South Sulawesi was chosen as a case study on account of the fact that the quality of education in South Sulawesi remained low compared to other regions in Indonesia (I PATTA, 2012). It is essential to investigate the effectiveness of STEM approach in the Sulawesi region, which consists of several different regions (Hasbi, 2013). Nonetheless, many of the education related problems faced in South Sulawesi are similar to the western regions of Indonesia. In addition, it is important to know whether the STEM approach is a fundamental tool for improving learning outcomes in Indonesia (Harun, 2018).

An effective learning program is temporarily introduced to teachers through educational institutions to prepare quality students through various approaches, one of which is using a STEM approach (Hora and Oleson, 2017). All students need the learning program to develop self-capacity and participate positively in society (Theobald et al., 2020). Educational programs, teachers, and stakeholders in the field of education are oriented to improve students' ability to achieve learning success according to the standards of the national assessment component (Suchman, 2014). This learning is in line with improving critical thinking skills and learning motivation. Students must have literacy and numeracy competencies (Sanders, 2008). Both competencies are closely related to students' critical thinking ability and learning motivation (Kelley and Knowles, 2016). Thinking critically is not an ability that students can instantly have as it requires process and habituation (Erdmann et al., 2020).

Implementing process and habituation for learning mathematics at schools builds critical thinking skills and fosters student learning motivation (Freeman et al., 2014). Applying STEM approaches to learning methods makes students not only understand the content (Wahono et al., 2020), but it also helps them have applicative skills mainly used to solve problems. Learning that merely entails mastery of content would not be able to develop students' critical thinking skills. Students may even feel bored and disinterested because they only continuously learn about theories (Wang et al., 2017). These questions can serve as a basis for teachers to create more innovative learning plans that can improve students' critical thinking skills and learning motivation.

In addition to developing students' critical thinking skills, having more meaningful learning at schools is crucial to foster student learning motivation. Motivation is fundamental in learning (Li and Schoenfeld, 2019). Motivation directs learning activities correctly. Motivation provides students the zeal to carry out their learning activities (Dziuban et al., 2018). By driving the students' learning motivation, they should be able to learn well without having to feel compelled to carry out their learning activities. Especially in learning mathematics, given the student's motivation to learn both internally and externally, mathematics would no longer be considered an intimidating subject but an exciting one instead (Falco and Summers, 2019).

Science, technology, engineering, and mathematics has an important role in student learning outcomes because this is a central topic in the field of education in general (Silvia and Simatupang, 2020). Studies argue that research in STEM education is increasing globally and is becoming an international field (Wang et al., 2017). Asian regions with challenging educational problems require new teaching and learning changes (Erdmann et al., 2020). Therefore, it is no surprise that over the past decade, researchers and teachers in Asia have been conducting numerous studies, mainly related to the application of STEM in the classroom (Wang et al., 2017). However, no studies have revealed the effectiveness of STEM applications in the Asian sphere with existing characteristics, including in Indonesia, especially in Palopo City, South Sulawesi.

The statement above shows that the key consideration is that local governments, especially in Palopo City, South Sulawesi Province, has not shown interest in designing, implementing, and evaluating the distribution of curriculum in Asia with

methods that accommodate STEM approaches. This review is the fundamental reason for carrying out the research, reviewing effective learning methods in integrating STEM approaches for various purposes, including student learning outcomes (Trevallion and Trevallion, 2020). On the other hand, this study emphasizes aspects of learning mathematics associated with critical thinking ability and motivation to learn mathematics (Manzanares et al., 2020).Therefore, the current research attempts to see how students' abilities can be improved by considering that a study needs to be carried out by implementing a particular approach, especially in mathematics learning to improve students' critical thinking skills and motivation in Palopo City, Sulawesi Selatan, Indonesia. As such, this study employed a student-centered learning model, namely a project-based learning model with a STEM approach.

Literature review

Science, technology, engineering, and mathematics approaches to effective learning methods

Science, technology, engineering, and mathematics are taught in schools to help students understand how to solve problems to improve human life. STEM-based learning helps students understand how to design a method (technique) through analyses and based on mathematical data calculations (mathematics) to find solutions to problems (Akiha et al., 2018). STEM approaches refer to a framework that includes (Carlson et al., 2016; Jensen et al., 2017; Blecking, 2018): (1) identify learning and (2) predict student behavior. Both can be modulated by various interventions and multiple STEM retention initiatives. Accordingly, STEM can be assumed to be most successful at paying attention to both elements. In addition, student learning and behavior improve critical thinking abilities and motivation, which spurs student learning success. The improvement of ability is seen against both factors in student learning success, indicating that students experience an adequate learning condition (Graham et al., 2013).

Some researchers suggest that through STEM learning, obtained analysis results indicate that students' critical thinking skills could develop well. Developing critical thinking is a skill students should have for compiling systematic practice plans and solving contextual problems (Margot and Kettler, 2019). Other studies argue that implementing STEM learning approaches can improve students' critical thinking skills (Erdogan and Stuessy, 2015; Kelley and Knowles, 2016; Changtong et al., 2020; Trevallion and Trevallion, 2020). In addition, an educational journal written by Akiha et al. (2018) states that implementing student worksheets developed using a STEM approach can improve students' critical thinking skills.

Mu'minah (2021) states that STEM could support and implement several things in learning, including 21st century (4C) skills, namely collaboration, critical thinking, communication, and creativity. Based on this statement, it is acceptable to say that students' critical thinking skills can be developed through a STEM approach. Other studies (Erdogan and Stuessy, 2015; Margot and Kettler, 2019) state that STEM learning collaboration helps students collect, analyze, and solve occurring problems and understand the relationship between one problem and another. The ability to collect, analyze, and solve problems is part of the critical thinking process (Erdogan and Stuessy, 2015; Margot and Kettler, 2019). This means that efforts to improve student's critical thinking skills can be carried out through a STEM approach.

Besides improving critical thinking skills, STEM approaches can also improve students' learning motivation. As shown in research articles that examined the development of STEM-based student worksheets, the use of STEM-based student worksheets was found to be able to increase students' learning motivation (Burke et al., 2020). In another educational journal article by Farwati et al. (2021), it was revealed that in STEM-based learning, overall, students are highly motivated to learn science. According to the article, the researchers consider that the STEM approach can be a solution to increase student learning motivation.

Armaludin et al. (2021) posit that motivation could be driven by external stimulation. However, motivation comes from within, as we can observe in various activities. In learning activities, teachers have a vital task of making various efforts to encourage students to actively engage in learning or carry out their learning activities (Li and Schoenfeld, 2019; Erdmann et al., 2020). This is in line with the STEM approach, which, in its learning activities, focuses on how students can execute problem-solving skills in real life (Armaludin et al., 2021). If students are encouraged to conduct an activity while learning, they will not feel bored, and learning becomes more meaningful. The higher a person's motivation, the higher the interest in learning. Puspita et al. (2020) in their research, revealed that with a STEM approach, students' interest in learning mathematics is categorized as very high. This fact supports efforts to increase student learning motivation by using a STEM approach.

Effective learning methods are used in the learning process in today's era, wherein teachers have various selections of learning methods they can use on the students in order to effectively and efficiently achieve the learning objectives (Carlson et al., 2016; Theobald et al., 2020). One of the key aspects is the issue of how teachers create an active atmosphere. This STEM method has proven to be effective in optimizing student learning activities in high school (Margot and Kettler, 2019). Practical methods are needed to meet the requirements for achieving optimal learning (the feasibility of ideal learning methods) with teaching materials that are compiled to improve

critical thinking skills and student learning motivation in the field of study or subject of mathematics (Gao et al., 2020; Manzanares et al., 2020).

A practical learning approach through STEM is oriented toward increasing the effectiveness of learning implementation to improve students' critical thinking skills and motivation (Manzanares et al., 2020). The effectiveness of learning implementation triggers the achievement of high learning outcomes (Wahono et al., 2020). Through STEM effectiveness, students are also required to be able to solve problems, become inventors of science, be technologically literate, understand techniques, and think mathematically (Freeman et al., 2014). The integration of STEM in effective learning is used as the dominant source of learning (Dischino et al., 2011).

Science, technology, engineering, and mathematics education approach

There are, currently, three methods or approaches of teaching in STEM education frequently carried out. These approaches are believed to be capable of meeting STEM content, supporting proper execution of STEM learning, and making STEM learning useful for facing industrial revolution 4.0 (Kelley and Knowles, 2016; Akiha et al., 2018; Erdmann et al., 2020). The STEM education approaches are as follows.

The silo approach

Carr et al. (2012) state that the silo approach is a STEM education approach in which STEM subjects are taught separately or are not integrated. This approach allows students to understand each subject's content in depth (Erdogan and Stuessy, 2015). The silo approach emphasizes how STEM education are in the design of school curricula (Jensen et al., 2017). Harahap et al. (2019) outlines the weaknesses associated with the silo approach as follows: (a) has a tendency of minimizing the benefits of STEM learning due to the possibility of students' lack of interest in one of the STEM areas (e.g., female students like science and mathematics subjects but have no interest in engineering); (b) without practice, students may fail to understand the natural integration between STEM lessons in the real world, hindering academic growth because, in this approach, teachers only prioritize mastery of each STEM field content; and (c) only focus on mastering the content, which, consequently, leave students unaware of the relationships among each STEM field in real life applications.

The embedded approach

Bahrum et al. (2017) state that an embedded approach teaches each stem discipline by focusing more on one or two STEM disciplines. The embedded approach is an educational approach in which knowledge is obtained through an emphasis on real-world situations and problem-solving techniques in social, cultural, and functional contexts (Dischino et al., 2011). This approach focuses on one area of science or primary material by relating it to other embedded materials, but the other materials are not assessed or evaluated (Margot and Kettler, 2019). The disadvantage of the embedded approach is that it can result in splitting student learning into several pieces (Bahrum et al., 2017). Suppose a student is unable to associate embedded content with the main content. In that case, the student risks only learning part of the lesson rather than benefiting from the whole (Karimah et al., 2022).

The integrated approach

An integrated approach focuses on integrating different STEM fields and making them one subject (Sanders, 2008). This approach combines various cross-curricular contents such as critical thinking skills, problem-solving, and scientific information that can lead to a solution to a problem through the combination of materials taught in the classroom (Tanjung and Aminah Nababan, 2019). Rossalia et al. (2019) state that an integrated approach to STEM learning can be applied in schools and society by combining two, three, or all aspects of STEM (Burke et al., 2020). In this integrated approach, STEM learning occurs when two aspects of STEM have been integrated in learning (Wang et al., 2017). For example, if mathematics is integrated with physics in learning, then such learning can already be considered STEM learning (Akiha et al., 2018). Here is an overview of the integrated approach model. Introducing students to the interrelationships among all STEM subjects from a young age and inviting students to apply those linkages for solving problems in the real world will require students to work more actively (Carlson et al., 2016). Therefore, supporters of STEM education are increasingly enthusiastic about successfully supporting and continuing to develop the nature of interrelationships among all STEM subjects.

Research methods

To answer the research question, a field study was designed with a pre-experimental approach. The researchers subsequently describes the design, sample, instrument, and data analysis used in this study. The research method used is able to answer the research hypothesis by using the statistics of the one-sample *t*-test and the Pearson correlation test (Ilyas et al., 2015).

This study used the STEM approach to learning mathematics by employing a pretest–posttest one-group design using an experimental class to evaluate students' critical thinking abilities during the learning process. Accordingly, the STEM learning stages—reflection, inquiry, discovery, application, and communication—were included in the classroom intervention.

The STEM method was implemented over around 6 weeks. In the first 4-weeks, the STEM approach intervention took place

while the students were learning. Two observers attended each meeting to monitor how lessons are being taught and how students participate in class activities. The other 2 weeks were used to review the pretest and posttest results to see how have the students' critical thinking abilities improved. In a sense, students responded to questions assessing their critical thinking abilities before and after the intervention (Utami and Yuliyanto, 2020). This type of research is pre-experimental by applying a treatment on the object of study involving only one group of classes as an experimental class. The treatment refers to the application of a STEM approach to learning mathematics (Ma'rufi et al., 2021).

This research involved a total of 176 students. They are mentioned as participants in various classes. Most of them were 16 years old. According to statistical data, 46% of them were enrolled in science programs. The tool we offered was suitable for evaluating the STEM approach to critical thinking abilities since they were at the time learning trigonometry-related content. Most of the background information of the research participants is summarized in **Table 1**.

Table 1 shows the Participant Demographic Information used in this study. In addition, 35 of the 176 students were selected to take the STEM test in the classroom. The 35 students with an average math score of 76 were enrolled in the same class. Additionally, the class was selected based on the advice of the mathematics teacher, due to the consideration that some of the students were capable of expressing their thoughts during the learning process. This type of research is pre-experimental by applying treatment on the object of study by involving only one group of classes as an experimental class. The treatment in question is the application of STEM approaches in learning mathematics (Ilyas et al., 2018). This study used one treatment, the STEM approach, in one experimental class. The design of the present study was in the form of One Group Pretest–Posttest Design, as presented in **Table 2** (Utami and Yuliyanto, 2020).

TABLE 1 Demographic information of participants.

Item	Total
Participants	176
Gender	
Male	57
Female	119
Program	
Science	81
Social studies	96
Ethnicity	
Bugis	112
Toraja	29
Makassar	35
Age	
15 years old	23
16 years old	119
17 years old	34

This study employed three research instruments. First, the learning implementation observation sheet, which is intended to measure the implementation of the learning implementation plan. The observer filled in this observation sheet during the learning process. The learning implementation observation sheet contains statements allowing the observer to check the answer choices under the ongoing learning activities. The number of statements on this observation sheet was adjusted to the learning implementation plan. The second instrument is the critical thinking ability test, which consisted of a pretest (initial test) and a posttest (final test) in the form of a description or essay. This test measured students' critical thinking skills in learning mathematics. The critical thinking ability test was made as a test for solving math problems. Third, three questionnaires were used in the study, namely: student activity questionnaires (for the purpose of determining how students' activities during mathematics learning with the STEM approach are used); student response questionnaire (for the purpose of finding out how students describe their response after taking part in learning mathematics); and student learning motivation questionnaire (aimed at finding explanation about and improvement in students' learning motivation after participating in the learning process). Each questionnaire was given with a STEM approach before and after the learning process.

The current research was conducted in the Mathematics and Science class (*MIA-Matematika dan Ilmu Alam*) of 10th grade students at Senior High School-*Sekolah Menengah Atas (SMA) 6 Palopo* City, South Sulawesi. This study used data collected from surveys and studies of students enrolled in all 10th grade classes (also mentioned as class X) who served as the population in this study, located at *SMA 6* in the *Palopo* City area of South Sulawesi Province (Winda Fronika, 2019). The study was conducted using one treatment group with two measurements of research data (Permatasari et al., 2018). Pretest: measurement of the Y variable of the treatment group taking place in the 2020/2021 academic year. The subjects or objects of study consisted of five homogeneous classes (class *X MIA-1*, class *X MIA-2*, class *X*

TABLE 2 Frequency distribution of students' critical thinking ability.

Interval	Category	Pretest		Posttest	
		f	Percentage (%)	*f*	Percentage (%)
85≤ x≤ 100	Very high	0	0.00	4	11.43
75≤ x< 85	High	0	0.00	5	14.29
60≤ x< 75	Moderate	0	0.00	23	65.71
55≤ x< 60	Low	0	0.00	3	8.57
x≤ 55	Very low	35	100.00	0	0.00
Sum		35	100.00	35	100.00

Source: Primary data after processing (2022).

MIA-3, class *X MIA-4*, and class *X MIA-5*). Since the population is considered homogeneous, one class was randomly selected (simple random sampling) from five existing classes as a sample in this study. The selected class was an experimental class that was taught using a STEM approach. A total of 176 experimental unit students as research subjects with a total of 35 selected students who's each class can be seen based on the following percentage.

Figure 1 showcases the primary data used in the study, which were obtained from pretest data and posttest data. Pretest data consist of the scores or results obtained before applying STEM in learning, and posttest data refer to the scores or results obtained after applying the STEM approach in learning (Dywan and Airlanda, 2020). Meanwhile, data collection was carried out using: (1) testing tools to collect data on the critical thinking ability of high school students; and (2) questionnaires to find out the learning motivation of high school students. In this study, observation, administering exams, and questionnaires were the primary methods of data collection. Observations were made to gather information on the execution of the instructions and student learning activities. Two observers examined the learning process and recorded their observations. Additionally, test results were used to gather information on students' critical thinking abilities. The tests were administered twice, once before the STEM-based learning process (pretest) and another after the STEM-based learning process (posttest). Two professionals with expertise in teaching mathematics verified the tests that were given. Indicators of critical thinking skills from this study were used to create a modified scoring grid. For interpretative purposes, the students' critical thinking ability level was categorized based on the scores they obtained, which were divided by the highest score the students achieved.

Data were collected from the testing instruments developed to measure students' critical thinking ability. The testing instruments we used, both pretest and posttest, were the same. A questionnaire was developed to measure student learning motivation. This data collection was developed based on a previously described conceptual framework that describes the framework of (1) identifying learning and (2) predicting student behavior (Ilyas et al., 2020; Ma'rufi et al., 2020). Both can be modulated by various interventions and multiple STEM retention initiatives. The framework describes the application of STEM factor approaches in learning mathematics, including critical thinking ability and student learning motivation factors related to the application (Dywan and Airlanda, 2020).

The SPSS software package ver. 25 was used for all data analyses. Two stages were employed in data analysis: (1) prerequisite analysis test; and (2) hypothesis testing. The feasibility and reliability test of the instrument involved testing the validity and reliability (Tamur et al., 2021). Since the acquired data was ordinal, we performed the Method of Successive Interval (MSI) to transform ordinal data into interval data as a prerequisite for inferential testing (Kutner et al., 2004). In this case, MSI used Microsoft Excel software to transform the variable data in the study. Furthermore, the first research question refers to the extent of students' critical thinking skills in learning mathematics with the STEM approach. Thus, the one-sample *t*-test analysis was used to determine the students' improvement in critical thinking skills before and after implementing the STEM approach.

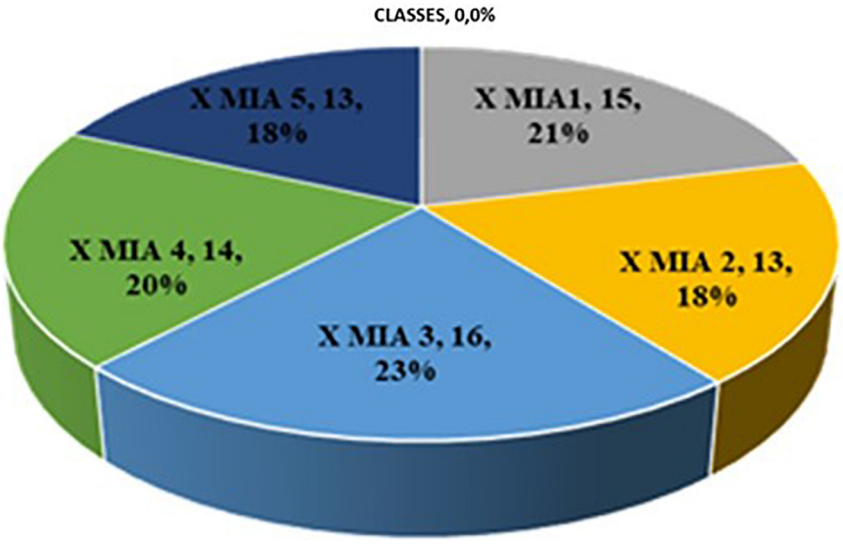

FIGURE 1
Data of 10th grade *mathematics and science* students at Senior High School-*SMA Negeri 6* Palopo. Source: Primary data after processing (2022).

Furthermore, the second research question was raised to assess the extent of student motivation before and after implementing the STEM approach. In this case, a one-sample *t*-test analysis was also used. As a prerequisite, a normality test was carried out by referring to the residual value, whether it has a normal distribution or otherwise, by identifying the Normal P–P Plot of Regression Standardized Residual graph and the significance value on the Kolmogorov–Smirnov test. A good regression model has an average residual value or is at least close to normal. Finally, we used a hypothesis test (*t*-test) to determine the effect of the independent variables (critical thinking skills and motivation), whether they have partially significant effect on the STEM approach.

Descriptive statistical analysis was carried out using the percentage of learning implementation achievement in this research based on certain categories (Ilyas et al., 2018). Inferential statistical analysis was applied by testing analysis requirements and hypothesis testing. Data analysis in this study consists of the results of analysis prerequisite test and hypothesis test. The analysis prerequisite test consists of a normality test on pretest and posttest data. The hypothesis test used *t*-test to determine whether any differences in pretest and posttest data were apparent to demonstrate differences in students' critical thinking ability and learning motivation before and after application of the STEM approach (Wahono et al., 2020).

Results

Students' critical thinking ability through learning methods using a science, technology, engineering, and mathematics approach

Based on the results of data analysis, an overview of students' critical thinking skills taught using a STEM approach is presented in **Table 2**.

As shown in **Table 2**, 35 out of 35 students (100%) were lacking critical thinking skills before the STEM approach was applied. The STEM approach resulted in the identification of 4 students (11.43%) with very high critical thinking ability, 5 students (14.29%) with high critical thinking ability, 23 students (65.71%) with moderate critical thinking ability, and 3 students (8.57%) with low critical thinking ability (Theobald et al., 2020).

Students' critical thinking ability scores after being taught by applying a STEM approach had changed. This can be seen in the change in scores that occurred in each value from pretest to posttest. The results of the pretest of critical thinking ability show that the lowest score was 3, while the highest score was 25. A total of 100% of students were able to think critically in the lower task. As for the posttest results, the lowest score was 55, while the highest was 100. Conclusively, the students' critical thinking ability was in the students that's categorized middle and above. Given an average pretest of 13.90 indicates that the students' critical thinking ability was in the deficient category. Meanwhile, the average posttest score was 70.67, which is in the high category. The median score ranged from 14 to 70. According to the category of students' critical thinking ability, it can be stated that before being given treatment, the average student's critical thinking ability was in the deficient category, with scores ranging from 0 to 20 (Ma'rufi et al., 2021). After the students were given treatment, the average student's critical thinking ability was in the high category ranging between 60 and 80. The rate of the increase in students' critical thinking skills after being taught using a STEM approach is shown in **Table 3**.

As presented in **Table 3**, the average gain from the low, medium, and high classifications, showing 0.65 points, is in the medium category, implying that the average increase in students' critical thinking ability after the application of the STEM approach lies in the medium category.

Student learning motivation through learning motivation using a science, technology, engineering, and mathematics approach

Based on the results of data analysis, an overview of the learning motivation of students taught with a STEM approach can be seen in **Figure 2**.

As shown in **Figure 2**, there was an increase in student learning motivation following the application of the STEM approach. The average student learning motivation prior to the application of the STEM approach was 141.14, with 115.00 as the lowest score and 178.00 as the highest. After the application of the STEM approach, the average student learning motivation increased to 162.17, with 124.00 as the lowest score and 193.00 as the highest. In addition, the frequency distribution of learning motivation of students who were previously taught using the STEM approach is specified into five categories as shown in the following table.

As showcased in **Table 4**, before the application of the STEM approach, out of 35 students there were 13 students (37.14%) who had high learning motivation and 22 students (62.86%)

TABLE 3 Normalized acquisition classification of students' critical thinking ability.

Acquired normalization coefficient	*f*	Percentage (%)	Classification
g< 0.3	0	0.00	Low
0.3≤ g< 0.7	26	74.29	Medium
g≥ 0.7	9	25.71	High
Average	0.65		Medium

Source: Primary data after processing (2022).

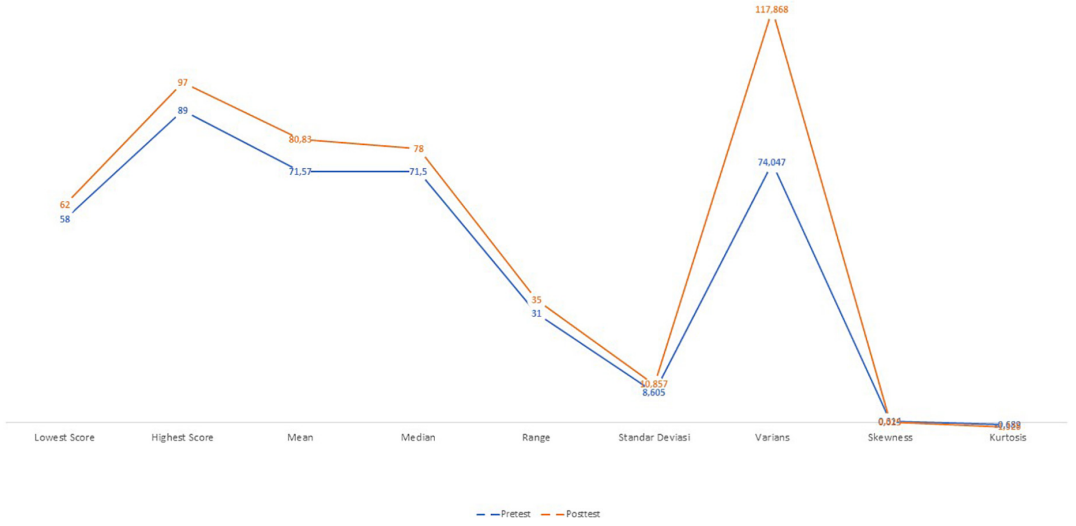

FIGURE 2
Recapitulation of student learning motivation using a STEM approach. Source: Primary data after processing (2022).

who had very high learning motivation. Meanwhile, after the application of the STEM approach, out of 35 students, there was 1 student (2.86%) who had high learning motivation and 34 students (97.14%) who had very high learning motivation (Blecking, 2018).

Hypothesis testing

In the current study, two hypotheses were tested, hypothesis 1 is aimed at finding out whether there is an increase in students' critical thinking skills after being taught using a STEM approach (Ilyas et al., 2020). Meanwhile, hypothesis 2 is aimed at finding out whether there is an increase in student learning motivation after being taught using a STEM approach.

Hypothesis 1

> H_0: There is no improvement in students' critical thinking skills after being taught using a STEM approach.

> H_1: There is an increase in students' critical thinking skills after being taught using a STEM approach.

Hypothesis 1 was tested using one sample *t*-test. However, before conducting a hypothesis test, a prerequisite test was carried out, namely the normality test. The results of the normality test showed that the probability value of students' critical thinking ability obtaining data after the application of the STEM approach was $0.118 > 0.05$, this means that the data acquisition of students' critical thinking ability came from a normally distributed population (Logan et al., 2019).

The results of the prerequisite test show that the data acquisition of critical thinking skills was at a normal distribution. Furthermore, a hypothesis test was carried out. The results of hypothesis test 1 are presented in the following table.

As shown in **Table 5**, it is apparent that the *P*-value of the (two-tailed) test hypothesis 1 is $0.001 < 0.05$, subsequently, H_0 is

TABLE 4 Frequency distribution of student learning motivation.

Interval	Category	Pretest		Posttest	
		f	Percentage (%)	*f*	Percentage (%)
40.00≤ X< 53.33	Very low	0	0.00	0	0.00
53.33≤ X<80.00	Low	0	0.00	0	0.00
80.00≤ X<106.67	Moderate	0	0.00	0	0.00
106.67≤ X<133.33	High	13	37.14	1	2.86
133.33≤ X<200.00	Very high	22	62.86	34	97.14
Sum		35	100.00	35	100.00

Source: Primary data after processing (2022).

TABLE 5 Hypothesis test results 1.

One-sample test						
Test value = 0.29						
	t	df	Sig. (two-tailed)	Mean difference	95% confidence interval of the difference	
					Lowest Score	Highest Score
Gain	19.437	34	0.001	0.36219	0.3243	0.4001

Source: Primary data after processing (2022).

rejected and H_1 is accepted. This means that there is an increase in students' critical thinking skills after being taught using a STEM approach.

Hypothesis 2

> H_0: There is no increase in student learning motivation after being taught using a STEM approach.

> H_1: There is an increase in student learning motivation after being taught using a STEM approach.

Hypothesis 2 was tested using paired sample *t*-test. However, before conducting a hypothesis test, a prerequisite test was carried out, namely the normality test. The results of the normality test showed that the probability value of student learning motivation data before the application of the STEM approach was $0.200 > 0.05$ and the student learning motivation data after the application of the STEM approach was $0.200 > 0.05$. This implies that the student learning motivation data before and after the application of the STEM approach came from a normally distributed population (Ilyas et al., 2018).

The results of the prerequisite test show that students' learning motivation before and after the application of the STEM approach was at normal distribution. Furthermore, a hypothesis test was carried out. The results of hypothesis test 2 are presented in the following table.

As indicated in **Table 6**, the *P*-value of the (two-tailed) test of hypothesis 2 is $0.001 < 0.05$, subsequently, H_0 is rejected and H_1 is accepted. This implies that there was an increase in students' learning motivation after being taught using a STEM approach.

Discussion

Based on the results of the study, learning using a STEM approach can improve students' critical thinking skills, as observed from the average increase in students' thinking ability in the moderate category. Improvement in students' critical thinking skills was due to the application of the STEM approach wherein students are directed to integrate STEM in solving problems to train students' critical thinking skills (Alzen et al., 2018). The STEM approach to learning provides space for students to ask critical and relevant questions about the materials they study, thus training students' critical thinking skills. According to Tamur et al. (2021) and (Supardi et al., 2021), the STEM approach can produce student thinking activities that help bring out students' critical thinking, which is characterized by the capacity to solve problems, make decisions, analyze assumptions, evaluate, and conduct investigations. This causes students to think more critically and understand the study materials because students solve the problems they face by linking scientific knowledge with technology, mathematics, and engineering (Putri et al., 2020).

The results of the study also indicate that using the STEM approach increases student learning motivation; as observed, the average student learning motivation before the application of the STEM approach was 141.14, while after the application of the STEM approach, the average increased to 162.17. This increase in learning motivation was afforded to learning using a STEM approach linking STEM in learning. Consequently, learning became interesting for students, the materials taught were not only limited to theory but also practice (Johnson and Elliott, 2020). This is in line with the argument posited by (Erdmann et al., 2020) stating that in learning using a STEM approach, students are taught both theory and practice in the form of project work. As a result, the students experience the learning process firsthand. Further, according to (Purwaningrum and Faradillah, 2020), using technology in mathematics can increase student engagement and learning motivation.

This study's STEM integrated approach was designed to promote mathematics learning in compliance with curricular requirements. Accordingly, STEM was prioritized in the production of instructional materials (Graham et al., 2013). Such an integrated approach to STEM learning is more accessible to implement than a thematic approach. An integrated STEM strategy eliminates the dividing wall between the various STEM disciplines (Carlson et al., 2016). Indirectly, the integrated application of STEM necessitates a STEM methodology to determine the amount to which students' critical thinking abilities and learning motivation grow when utilizing an

TABLE 6 Hypothesis test results 2.

Paired samples test								
	Paired differences					*t*	df	Sig. (two-tailed)
	Mean	SD	SEM	95% confidence interval of the difference				
				Lowest Score	Highest Score			
Pretest–posttest	−21.02857	17.09229	2.88912	−26.89998	−15.15717	−7.279	34	0.001

Source: Primary data after processing (2022).

integrated approach (Blecking, 2018). Therefore, an integrated STEM strategy is aimed at providing students with inter-disciplinary knowledge to fulfill the demands of the workplace (Johnson and Elliott, 2020). The stem integrated approach is an interdisciplinary method for understanding the effect that critical thinking capacity has on student motivation.

This technique mixes diverse cross-curricular knowledge, such as critical thinking abilities, problem-solving, and scientific information, to provide a solution to a problem by combining classroom-taught material (Freeman et al., 2014). Trevallion and Trevallion (2020) claim that an integrated approach to STEM education may be implemented in schools and society by merging two, three, or all STEM components. In this integrated method, STEM learning occurs when the two STEM parts interact in learning. For instance, if the subjects of mathematics and physics are incorporated into learning, the learning is already considered STEM learning. The following is a summary of the integrated approach model (Manzanares et al., 2020).

The integrated closeness of STEM that was used in the learning in the current study, the ideas paired with critical thinking abilities, and student learning motivation facilitated students comprehension of the material (Falco and Summers, 2019). Consequently, the improvement in learning outcomes attained by students in this research is substantial. This integrated approach to STEM education has resulted in increased learning, implementation, and reaction levels and enhanced mathematics learning outcomes based on parameter criteria (Li and Schoenfeld, 2019). Therefore, it can be asserted that STEM is an excellent learning tool for enhancing students' critical thinking skills and motivation, resulting in an integrated method for enhancing student's math learning results (Erdmann et al., 2020). The influence that the application of STEM involving critical thinking ability and student learning motivation has on the improvement of student learning outcome is represented by the research results relating to the measurement of differences, correlations, and effectiveness based on student worksheets, questionnaires, and instrument tests of STEM as an integrated research criteria.

Limitation and future research

Using an integrated STEM strategy eliminates the barriers between each STEM subject. The integration of STEM disciplines implicitly necessitates a STEM mindset. The integrated STEM approach is an endeavor to provide students with the multidisciplinary knowledge necessary to meet workplace demands. In this study, the combination of ideas, critical thinking abilities, and student motivation facilitated pupils in comprehending learning materials, particularly while studying mathematics.

The present study's limitation is that it focused on applying the STEM approach to mathematics education. It was anticipated that the findings of this study would encourage students and researchers to adopt a method that encourages students to solve mathematical issues they encounter while studying. However, we also believe that to accomplish this, students must approach the learning process through the lenses of STEM. This has not yet transpired in its entirety, as the student learning process detailed in this study contained limited material. STEM functions as an effective learning tool that supports students' critical thinking abilities and motivation and an integrated method that enhances students' mathematical learning results. This research has implications on the creation of mathematics education curriculum and enhancing students' mathematics learning results.

Conclusion

The STEM approach is regarded as the primary and most essential method for assessing cognitive ability and learning motivation. The results of the current research indicate that the application of a STEM-based method to learning mathematics with 10th grade students in Mathematics and Science class (*MIA-Matematika dan Ilmu Alam*) at Senior High School-*Sekolah Menengah Atas (SMA) 6* Palopo could increase students' critical thinking skills. Students were taught to solve issues by integrating STEM. With a pretest average of 13.90 and a posttest average of 70.67, the pupils' ability to think critically improved. The results also revealed that a STEM-based strategy enhanced student learning motivation by an average of 71.57–80.83 points. This study demonstrates that the use of a STEM approach to mathematics learning methods can enhance critical thinking skills and learning motivation, hence making STEM an effective learning method that can be implemented across the board in student education.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MI developed the first draft and data analysis. MM helped to get the data and develop literature review. PK supported the method section and final manuscript. EM supported

the final analysis. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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