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Analysis of Spatial Skills Impact of Science, Technology, Engineering, And Mathematics (STEM) Approach in Cartography Learning

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ABSTRACT

The independent campus curriculum is an effort to increase competition in the 21st century, which requires competent human resources in the fields of science, technology, engineering, and mathematics (STEM). STEM learning responds to the need to increase students' interest and skills in these areas. This study aims to determine the effect of using the STEM approach on spatial thinking skills in cartography learning. This research uses a quasi-experimental method with a one-group pretest-posttest Design, conducted in a single experimental class without a control class. Subjects were selected by random sampling through drawing lots, focusing on 5th-semester B students. Data were analyzed using a t-test with paired samples T-Test. The results showed a sig value. (2-tailed) of 0.000, which is smaller than the significance value of 0.05. Therefore, H_0 is rejected, and H_a is accepted. To conclude, there is an increase in the average pretest and posttest after learning using the STEM approach, indicating that the STEM approach positively affects spatial thinking skills. Each stage of the STEM approach affects the students' spatial abilities. The science stages develop spatial abilities in the form of spatial interaction. The technology stages enhance the ability to apply applications and scale on maps. The engineering stage fosters analytical, representational, and comprehensive skills. The math stage improves the ability to calculate scale and its application in everyday life

INTRODUCTION

The independent campus curriculum aims to increase competitiveness in the 21st century, which requires competent human resources in science, technology, engineering, and mathematics (STEM) fields. Thus, the government will develop it in education in Indonesia (Widayanti et al., 2019). STEM learning emerged due to increasing students' interest and skills in Science, Technology, Engineering, and Mathematics (STEM) (Brown, 2012; Gonzalez & Kuenzi, 2012; Permanasari et al., 2021; Quigley et al., 2017). The STEM approach relates to learning geography through the application of geographic tools (Nurković, 2020) such as Google Earth and GPS Essential, which are typically taught in cartography courses (Selway, 2021). It aligns with the objectives of this study, which are to analyze spatial abilities in cartography learning using the science, technology, engineering, and mathematics (STEM) approach.

STEM learning is mainly used in fields such as Mathematics (Lee et al., 2019; Nitzan-Tamar & Kohen, 2022), Physical (Lin et al., 2019; Martyniuk et al., 2021; Roccapriore et al., 2022) and Chemistry (Çalış, 2020; Chonkaew et al., 2019; Robinson et al., 2019). Numerous studies have examined STEM within the domains of problem-solving, creative and collaborative thinking, and the construction of geographic knowledge (Mahat et al., 2021). Evidence also shows that the STEM approach positively correlates with enhanced spatial thinking abilities (ESRI, 2012; Selway, 2021).

Spatial ability is usually measured with IQ test parameters and psychological tests (Jant et al., 2020). This study posits that the STEM approach can represent a better achievement of spatial thinking ability. STEM provides direction for project-based learning across various fields of science, technology, engineering, and mathematics (Zubaidah, 2019). It serves as a pedagogy that strengthens students' interest in these areas (Perignat & Katz-Buonincontro, 2019). One way to improve the quality of education is to apply STEM (Science, Technology, Engineering, and Mathematics), as it encourages students to integrate subjects and relate them to everyday life.

STEM education is essential in developing reasoning and spatial skills in geography learning. Geography relates to STEM disciplines by applying geographic tools to solve problems. The STEM approach is suitable for learning physical and engineering geography, including cartography, Geographic Information Systems (GIS), remote sensing, natural resources, environmental science, and atmospheric science. Geography strongly connects STEM disciplines (Science, Technology, Engineering, and Mathematics) with the application of geographic technologies/tools, providing a better understanding of cross-disciplinary phenomena to address critical issues (Al Mamun et al., 2015; English & King, 2015; Kulturel-Konak, 2020; Oyana et al., 2015). STEM learning in geography can develop a spatial mindset by applying spatial ability to solve complex science and spatial problems in daily life. This study examines the practice of spatial ability in the STEM approach for geography themes such as cartography. In addition, the researchers used spatial approach measurement parameters, typically assessed by psychological tests and IQ tests, modified with spatial ability indicators integrated with the STEM approach. Cartography learning plays an essential role in the repertoire of geography in building spatial skills. Spatial intelligence is inherent in geography. Geography learning has basic concepts, principles, and approaches related to spatial/space. Students should be able to develop intelligence and spatial behavior. STEM learning from a geographical perspective examines (1) place-based factors, (2) spatial behavior and inquiry-based learning, and (3) environmental education and community engagement. Spatial thinking and behavior are currently used to develop the skills needed to advance STEM fields. Spatial thinking behaviors and abilities drive engagement in STEM fields (Golledge & Stimson, 1997). Spatial thinking ability is an individual's capacity to accurately perceive the world both visually and spatially (i.e., thinking in two and three dimensions). Therefore, individuals with spatial thinking ability demonstrate the ability to research spatial reasoning, concepts, and representations (Hoffman et al., 2011; Kinniburgh, 2010). Learning STEM through real-world problems and experiences can also be considered "Informal Science Education" (Fadigan & Hammrich, 2004).

Cartographic learning plays a significant role in solving problems in urban and spatial planning (Selway, 2021). Education in Indonesia has used cartography to develop spatial thinking skills. Cartography learning products such as maps created with the help of GPS essential and Google Earth applications have the potential to visualize data and enable users to become spatially proficient. While relevant research examines STEM learning for GIS (Geographic Information system) (Jant et al., 2020) and PJ (Remote Sensing) learning (ESRI, 2012; Mahat et al., 2021), few practitioners have researched cartography to develop spatial abilities. Previous research has demonstrated the effectiveness of cartography learning. In some countries, such as Bosnia and Herzegovina, the Ministry of National Security categorizes Geographic Information Systems (GIS) and Cartography under STEM disciplines (Nurković, 2020). The effects of integrating cartography into the curriculum include utilizing maps in various scientific fields to solve environmental problems. Furthermore, cartographic learning also plays a role in improving learning outcomes

(Mre & Soko, 2015) and map reading skills (Ooms et al., 2016).

The focus of this research is the development of spatial abilities through the STEM approach in cartography learning. This study examines the STEM approach's impact on spatial thinking skills in cartography learning. At the beginning of learning using the STEM approach, students are taught to create maps manually. As their skills develop, students are directed to undertake planning projects and solve problems in everyday life. Each student creates a project plan to expand the area around the campus based on the patterns observed in the field during the survey. This research will examine the spatial ability of students in studying cartography, measuring their expertise in analyzing spatial interaction, scale, application, analysis, representation, and comprehension.

RESEARCH METHODS

This research employed a quasi-experimental design. It aims to test the theory of spatial thinking ability in the STEM approach to cartography learning. It used a One-Group Pretest-Posttest Design. One Group means this research was conducted for one experimental class without a control class. The pretest-posttest design measured changes in spatial thinking ability before and after implementing the STEM approach to Cartography learning. The scheme in the One-Group Pretest-Posttest Design research design is as follows.

Tabel 1 One Group Pretest-Posttest Design research design

Pretest	Treatment	Posttest
T1	X	T2

Source: (Sugiyono, 2014)

Description:

T1 : Pretest, to measure spatial thinking ability before treatment

X : The treatment given, using the STEM approach

T2 : Posttest, to measure spatial thinking ability after treatment.

This research was conducted over one semester. To obtain results relevant to the research objectives, learning was performed for 16 meetings. At the beginning of the meeting, students were given a test to measure their spatial abilities before learning using the STEM approach. In the next lesson, students received learning materials about map making and its application in everyday life. During the learning process, students searched for project themes and completed four Student Activity Sheets designed using the STEM approach the researcher provided. At the final meeting, students took a post-test to evaluate their progress in spatial thinking skills.

This research was conducted at Universitas Islam Negeri Maulana Malik Ibrahim Malang. The research subjects were students majoring in social science education. Subjects were selected through random sampling by drawing lots from classes A, B, C, and D, resulting in class B being chosen as a research subject. In the fifth semester, the student is taking a cartography course. The cartography course was selected because it has characteristics related to the STEM approach and spatial thinking skills. The students totaled 27, consisting of 17 women and ten men.

The instrument of this study used STEM-based Student Activity Sheets in cartography learning. The first Student Activity Sheets project involved creating waypoints with GPS Essential. The second project consists of creating a travel route with Essential GPS. The third project was a planning project with Essential GPS. The fourth project is creating a map from the data exported using GPS Essential to Google Earth. The ability to measure spatial thinking can be measured using a spatial thinking ability test. The Student Activity Sheets research instrument was validated first by expert validators in the field of STEM learning before being used in the classroom. Student Activity Sheets are student worksheets designed by STEM learning principles. The spatial thinking ability test instrument was used for pre and post-tests. After experts validated the instrument, a Focus Discussion Group (FGD) was conducted to refine the research instruments—the test consisted of 18 items covering six indicators of spatial thinking ability. Details of the mapping of spatial thinking items are as follows.

Table 2 Mapping Indicators of Spatial Thinking Items

No	Indicator	Question Number
1	Spatial interaction	1, 2, 3
2	Scale	4, 5, 6
3	Application	7, 8, 9
4	Analysis	10, 11, 12
5	Representation	13, 14, 15
6	Comprehensive	16, 17, 18

Source: Indicators of Spatial Thinking (Huynh & Sharpe, 2013)

The material expert validated the instrument before the trial to determine its validity level. The validity test used SPSS, using the Product Moment Correlation formula.

A reliability test was conducted using SPSS to determine the consistency of the research instrument using the Cronbach Alpha formula. The level of difficulty was calculated using Excel to determine easy and difficult questions. Discriminating power was also calculated using Excel to distinguish between groups of students who scored high and answered correctly from those with low scores who answered correctly on a given question. Differentiation power will also be measured using Excel.

Data analysis used SPSS 21 with a significance level of 95%. Data analysis techniques used prerequisite tests as follows. Normality test using SPSS with Shapiro-Wilk test. The homogeneity test used SPSS with the Levene test. The decision-making process was based on the significance value. This study used a paired sample T-Test. to analyze the following hypothesis;

H_a: There is an effect of using the STEM approach on spatial thinking ability.

H_0: The STEM approach has no effect on spatial thinking ability.

The decision-making process used the significance value. If the sig value of $t < 0.05$, H_0 is rejected, and the significance value of $t > 0.05$, then H_0 is accepted.

RESULTS AND DISCUSSION

Instrument Test Results

The instrument trial results include the difficulty level of the questions, which ranged from easy to complex. The trial showed two questions with easy criteria, 15 with moderate criteria, and 1 with complex criteria. The discriminating power was calculated to distinguish between students who scored high and answered correctly and those with low scores who also answered correctly. Because the number of respondents was fewer than 30 students, the upper and lower groups took as much as 50%. The odd number of students resulted in 1 middle student not being included in the discriminating power analysis. The t-test value shows 1 question with sufficient criteria, 12 with reasonable criteria, and 5 with excellent criteria. Validation Test of the 18 questions resulted in 3 invalid questions, including questions 1, 10, and 18, so the question will not be used. Therefore, the questions used in learning will consist of 15 questions. The reliability test shows Cronbach's Alpha 0.951, indicating very high reliability.

Data Description

Data on the results of spatial thinking ability come from multiple-choice tests by the indicators of spatial thinking ability. The results of spatial thinking ability were obtained from posttest and pretest scores. This score illustrates improving spatial thinking ability before and after being treated using STEM learning. The material covered two competencies; first, students can analyze map concepts, components, map scales and calculations, and contour lines. Second, students can design regional mapping and calculate distance and elevation using Google Earth.

The test comprised 15 items. The scoring technique awards 7 points for each correct answer and 0 points for incorrect answers. The correct answers are multiplied by 7 and -5 to achieve a maximum score of 100. Students can achieve a maximum score of 40 and a minimum of 0.

All questions used to measure spatial thinking ability were pre-tested with 7th-semester class C students taking cartography courses. Instrument testing includes validation, reliability, difficulty level, and discriminating power tests. The type of question tested was 18 multiple-choice items. The type of question tested was 18 multiple-choice items, with 27 students participating in the instrument trial. Based on the trial results, 15 questions were deemed suitable for use. From the SPSS results, the spatial thinking ability of students has increased on average, as in the table below.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	53.33	27	10.088	1.941
	Postest	82.11	27	12.482	2.402

Figure 1. Paired Sample T-Test (Source: Processed research results)

The data above shows an average pretest score of 53.33 and an average posttest score of 82.11. Students experienced an increase in average spatial thinking ability of 28.78. This shows that spatial thinking skills increased because of the STEAM approach.

Students completed the Student Activity Sheets 4 times during 1 semester. The results of the Student Activity Sheets were assessed based on the criteria of each STEM item, including science (S), technology (T), engineering (E), and mathematics (M). Each criterion is scored out of 100, so the total score for each Student Activity Sheet can reach 400. Then the value of the Student Activity Sheets is averaged on each item. The results of the average of each item are as follows: science (S) at 76%, technology (T) at 90%, engineering (E) at 74%, and math at (M) at 70%.

Data Analysis

The data on spatial thinking ability were analyzed using a t-test. Further data analysis was used to test the hypothesis formulated, which was that using the STEM approach did not affect spatial thinking ability. The results of the t-test data are as follows.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest - Postest	-28.778	11.376	2.189	-33.278	-24.278	-13.145	26	.000

Figure 2. Uji hypothesis (Source: Processed research results)

The t-test results using paired samples show that the significance value (2-tailed) is 0.000, which is smaller than the significance level of 0.05. Therefore, it can be interpreted that using the STEM approach affects spatial thinking ability.

Hypothesis Test

This study was conducted to test whether using the STEM approach has an effect on spatial thinking skills, using the following hypothesis.

H_0= there is no effect of using the STEM approach on spatial thinking ability.
H_a= there is an effect of using the STEM approach on spatial thinking ability.

The decision is made based on the significance of the value. If the probability value (p) >0.05, then H_0 is accepted, and H_a is rejected. The result shows that using the STEM approach does not affect spatial thinking ability. If the probability value (p) <0.05, then H0 is rejected and H_a is accepted. The results show that using the STEM approach affects spatial thinking ability.

The results of data analysis using the t-test show that the STEM approach affects spatial thinking skills. There is an effect of using the STEM approach on spatial thinking skills. This can be seen from the two-tailed significance level value of 0.000 so that $p<0.05$. Based on the above analysis results, the decision H_0 is rejected, and H_a is accepted as the study result. This shows that using the STEM approach affects spatial thinking ability.

The results of this study indicate that the STEM approach has a significant effect on spatial thinking ability. The average spatial thinking ability has increased after being treated using the STEM approach. From the results of data analysis, it can be concluded that the STEAM approach that combines science, technology, and engineering mathematics in cartography learning effectively improves spatial thinking ability similarly, as stated in the research of (Jant et al., 2020) learning using STEM technology based-on geographic information systems (GIS) and GPS proves that there is an exploration of the strong role of spatial abilities in the STEM approach. Other similar research was also conducted by (Oyana et al., 2015) claiming that geography has a role in STEM learning, which can develop spatial intelligence.

The STEM approach affects spatial ability because it has the characteristics of (1) integration with other disciplines, (2) student-centered approach, (3) relevance to daily life, (4) active student involvement in lessons, (5) collaborative learning environment, and (6) inquiry-based learning (Wijokongko, 2009). STEM integrates science, technology, engineering, and math. It is supported by research by (Mahat et al., 2021) which shows that using STEM in geography education improves proficiency in science, technology, engineering, and mathematics.

In cartography learning, it is very essential to sharpen spatial thinking ability. In addition, STEM is a student-centered approach. Cartography learning requires student-centered learning. Students in cartography learning need to be able to use tools for practical activities requiring active student participation in practical exercises. Cartography can integrate everyday life into practical activities, such as creating travel routes using GPS Essential and mapping them with Google Earth. Research conducted by Nurković (2020) supports the statement that geography education using geographic tools/technology in STEM learning can assist students in solving geographical problems.

The table below shows the effect of cartography learning using the STEM approach on improving spatial ability.

Table 3. Effect of Cartography Learning Using the STEM

No	STEM	Cartographic material	Spatial Ability
1.	Science	Organize materials, information from various sources to stimulate students' ability to think spatially.	Spatial interaction
2.	Technology	Using tools in learning such as internet, camera, GPS Essential software and Google Eart.	Scale Application

3.	Engineering	Students create a track project using the GPS Essential application based on the theme of the development of their respective regions, then export it to the Google Earth application.	Analytical Representational Comprehensive
4.	Mathematics	Data that has been exported to GoogleEarth will show representations in the form of regional scale, travel time, pattern shape, area, speed and location coordinates.	Scale Application

(Source: Processed Research Results, 2024)

In STEM learning, stage S stands for science, which involves the study of teaching materials that emphasize a wide range of learning sources such as books, articles, and journals. In general, science is an organized approach to studying the world. In this phase, students can learn theories from various references to foster the development of spatial thinking ability in the category of spatial interaction. Spatial interaction is an indicator that shows the ability to analyze the relationship between geospheric phenomena that aims to determine the cause and effect of a geospheric event. Spatial ability, specifically through spatial interaction analysis, helps understand the relationships between geospheric phenomena.

The results of the student's Student Activity Sheets show that the ability to master Science related to understanding the material is 76%, demonstrating proficiency in comprehending concepts. This is supported by research by (Arif & Maryani, 2023) which shows that learning geography can foster scientific literacy. The Science stage emphasizes learning through understanding material from various sources, enabling geography education to assess student literacy skills (Junaidin et al., 2023). Students with good abilities in science can find references through Harzing Publishers, Science Direct, and Google Scholar. However, the other 24% percent need to improve their skills. This finding aligns with the analysis from the Policy Research Center, which indicates that based on PISA (2018) data, Indonesia scores 37 points below the average for ASEAN students (Nur'aini et al., 2021). The analysis reveals that students lacked in the field of science due to the lack of interest in reading the material. Furthermore, the Student Activity Sheets revealed that students often relied on blogs and Wikipedia for cartographic information. Despite the emphasis on using books and articles from scientific journals as reference sources in the Student Activity Sheets, students still face challenges in accessing journal articles and electronic books. This can be seen when students worked on the Student Activity Sheets and only used Google to find references.

The T in STEM stands for technology, which involves the use and mastery of technology in learning to meet human needs and solve problems. Students use the internet, cameras, GPS Essential software, and Google Earth in this cartography learning. Students can use the application and determine the scale and distance traveled. They apply these skills directly through activities such as surveys, observations, and interpretations using software or hardware tools. Engineering technology in geospatial science combines geo-computer, geographic information science, geographic information technology, and geographic information system applications. Technologies in geography include earth satellite devices, geographic information systems, and global positioning systems, and various kinds of automated environmental monitoring. Based on the research results of (Berutu & Hanana, 2023), learning using a platform based on digital technology can help improve the quality of the learning process and learning outcomes.

Students' mastery of technology is highly proficient, reaching 90%, making this stage the most prominent in their abilities. During practical sessions, students demonstrate strong proficiency in using Android devices with the GPS Essential application. They also exhibited skills in operating a laptop that used Google Earth. This is supported by existing studies that show that Generation Z is notably engaged with technology and values innovation (Dunas & Vartanov, 2020; Hinduan et al., 2020; Hoque, 2018). The research results of Delita, et al (2022) show that learning using technology can increase digital literacy,

The E in STEM represents Engineering, which involves applying technology in everyday life to create something. Learning activities involve students creating track projects using the GPS Essential application based on the theme of the development of each region, which is then exported to the Google Earth application. This practicum can foster Analysis, Representation, and Comprehensive skills. The analysis involves investigating geospheric phenomena by analyzing spatial components to understand the causes and effects of these phenomena. Representation entails interpreting symbols on maps and images to understand geospheric phenomena observed in the field. Students apply their skills at this level by interpreting real-life maps and images. Comprehensive is the ability to conclude information on relationships, patterns, and interactions of geospheric phenomena so that students can decide on a policy to solve problems in the field.

Engineering activities are design-based learning in STEAM learning (Thibaut, 2018). Engineering activities in cartography can be likened to regional planning activities. The ability of students at this stage is 74%. The remaining 26% of students need to enhance their understanding of regional planning, particularly since there is no specific course on regional development in the social studies curriculum. Instead, this content is typically integrated into regional and social geography courses. The Student Activity Sheets completed by students reveal challenges in applying their knowledge to practical scenarios, such as planning areas based on the maps they create. For instance, a task requiring students to map food stalls around campus and then analyze potential locations for new stalls proves difficult for many. When asked where they would place a new food stall and what menu they would offer, most students struggle to provide a clear response, often leaving these questions unanswered.

The initial M in STEM stands for mathematics, which in learning is a language of shapes, numbers, and quantities. Data from previous practicums, which have been exported to Google Earth, will demonstrate achievements such as regional scale, travel time, pattern shapes, area, speed, and location coordinate points, enabling their application in formulas to calculate scale. Scale is the spatial ability to compare geospheric phenomena depicted on maps through symbols with phenomena that actually occur. When students compare images and real life, they can distinguish and find patterns, shapes, and sizes on the same object or different objects. Thus, students can apply spatial abilities to find, compare, and assess patterns in space by observing geospheric phenomena on maps by applying them to real-life situations.

Students who successfully calculate using geographic tools gain increased confidence in mathematics with each meeting. This aligns with the research of (Junaidin et al., 2023) which emphasizes that geography learning is important in increasing numeracy literacy. However, mathematics activities, including scale calculations, contour intervals, and slopes, were rated the lowest at 70% among other STEM elements. Numerous errors were observed in these application problems, primarily due to students' lack of accuracy during calculations. Another contributing factor is the student's background in social studies majors, where they often lack foundational math courses during lectures. This situation is also reflected in the PISA

(2018) assessment results, which indicate that Indonesia's mathematics skills lag behind the ASEAN average by 52 points (Nur'aini et al., 2021). Overall, based on research by (Wirda et al., 2018) learning using a project-based Students Activity Sheet can improve geography learning outcomes.

CONCLUSION

Based on the results of data analysis and discussion, it can be concluded that the average pretest and post-test scores increase after learning using the STEM approach. This shows that STEM learning significantly affects spatial thinking ability in Cartography learning.

Each stage in the STEM approach affects students' spatial abilities. The S stage (Science) facilitates the development of spatial skills by engaging students in spatial interactions. The T stage (Technology) enhances students' proficiency in technology and application skills.

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