Spatial reasoning ability of mathematics college students

T Septia¹,², I Yuwono¹, I N Parta¹ and H Susanto¹

¹Universitas Negeri Malang, Jl. Semarang No. 5, Malang, Indonesia
²STKIP PGRI Sumbar, Jl. Gunung Pangilun, Padang 25173, Indonesia

E-mail: septia.1703119@students.um.ac.id

Abstract. Calculus is one of the courses related to Science, Technology, Engineering, and mathematics (STEM). To be able to understand this material, the competence that students must possess is spatial reasoning ability. Spatial reasoning is ability related to representation, use of objects and their relationships in the 2D and 3D worlds. Spatial reasoning ability is essential for a college student. The study was carried out to analyze and measure the spatial reasoning ability of mathematics college students. Descriptive used in this qualitative study. The subject involved 97 college students, consists of 21 male and 76 female. The measurement used a spatial reasoning test based on three aspects which are spatial visualization, mental rotation and spatial orientation. The average of the three aspects which are spatial visualization, mental rotation and spatial orientation were as follows 9.47; 11.22; 8.25. It indicated that more than half college students had the average ability. The construct of mental rotation was the aspects that had the highest value compared to the other elements. The findings show that there was no difference in ability between male and female. It can be concluded that the spatial reasoning ability in college students still low and need some scaffolding to improve the spatial reasoning ability.

1. Introduction
Science, Technology, Engineering, and mathematics (STEM) is a learning approach in four specific disciplines, namely, science, technology, engineering, and mathematics into a holistic whole [1]. The purpose of STEM in education is in line with the demands of 21st-century education, namely that students have scientific and technological literacy from reading, writing, observing, and doing science, and can develop the competencies they have to apply in dealing with problems in daily life. Days related to STEM science. One of the courses related to STEM is Calculus [2]. A better understanding of Calculus is needed to improve student success in calculus and STEM [2].

Calculus is one of the core subjects that is necessary for the understanding of many other subjects (e.g., physics, chemistry, engineering, etc.) that are especially important for those planning to proceed in STEM-related fields [3,4]. One of the material in Calculus is the area of the plane region and the volume of solids of objects. To be able to understand this material, the competence that students must possess is spatial reasoning ability [5]. Spatial ability is an important skill that the student needs to have. Considering this aspect, the development of students’ spatial ability can no longer be ignored. This ability does not appear but needs to be trained continuously and sharpened.

Spatial reasoning is a crucial component of mental ability [5] in the process of mathematical thinking. Spatial reasoning refers to the ability to generate, retain, retrieve, and alter visual images, so they are well structured[6]. This capability involves the rotation, retention, and transformation of visual information in a spatial context. Spatial reasoning ability can be trained to improve student learning.
outcomes [7–10]. It makes the ability of spatial reasoning be taught at all levels of Education especially now when the development of spatial reasoning capabilities expressed as one of the objectives of mathematics education from the level Kindergarten to university [7]. Preparing excellence in various fields, students must be trained to develop and foster spatial reasoning abilities [11–13]. The college is an appropriate and strategic place to improve that ability; the development process can be integrated into every learning activity. So, it’s important to The Analysis of Spatial Reasoning Ability of Mathematics College Students because this analysis can measure the first ability of students. The first ability of students can be used to improve the quality of education, cause it can be realized if the learning process organised effectively, it means that the learning process can run smoothly, directed and for learning.

2. Method
The subject involved 97 college students, consists of 21 male and 76 female. The research subjects were the first-semester college students. First semester students chose because these students had not yet learned calculus so that they could see the first abilities of students' spatial reasoning. The measurement used a spatial reasoning test based on three aspects which are spatial visualization, mental rotation and spatial orientation. The test sees the spatial reasoning ability of college students. The indicator of spatial reasoning seen in Table 1.

| Table 1. Indicators to Measure Spatial Reasoning |
|--------------------------------------------------|
| **Construct** | **Spatial reasoning aspects** | **Item Characteristics** |
| Mental rotation | Rotates 2D and 3D objects clockwise and counterclockwise | Determines results after 2D and 3D objects played. Distinguish between reflection and rotation |
| Spatial Orientation | Imagine yourself in a room Reading the map | Determining the position of an object relative to the observer |
| Spatial Visualization | Symmetry, patterns, 2D and 3D forms and their relationship, reflection | Visualizing the outcome of folding/unfolding a particular configuration |
| | | Constructing a solid from a given net and vice versa. Matching pieces and parts |
| | | Finding the symmetry in an object |
| | | Reflecting an object |

This framework from Table 1 developed into 45 questions, consists of 15 questions spatial visualization; 15 questions mental rotation; 15 questions spatial orientation. Test construct in multiple choice. The sample of the question can be seen in Figure 1.
Figure 1 is an example of a problem used to measure a student's spatial reasoning ability. Figure 1 is an example of spatial visualization. The indicator of Figure 1 was visualizing the outcome of folding/unfolding a particular configuration, constructing a solid from a given net and vice versa. Students do this test within 60 minutes. The score of each item is one point for the correct answer and zero points for an incorrect answer. If any item not answered by the respondent, the score is zero point. The total maximum score of this test is 45 points. The result of the test categorised as following 31-45: high ability 16-30: the average ability 0-15: low ability The categorized used to know the spatial reasoning of college students. If college students get a score of 31-45, we can conclude that they have good spatial reasoning abilities.

3. Result and discussion
The result of spatial reasoning tests conducted based on three aspects of spatial reasoning presented in Table 2.
Table 2. Score and Classification of Spatial Reasoning Test

| Classification        | Interval Score | Number of Students |
|-----------------------|----------------|--------------------|
| High Ability          | 31-45          | 16                 |
| Average Ability       | 16-30          | 70                 |
| Low Ability           | 1-15           | 11                 |

Table 2 indicated that more than half college students had the average ability. Only 16% of college students have good spatial reasoning ability. When viewed from aspects of spatial reasoning, the test results indicate that students tend to have the highest value on certain aspects. It can be seen in Figure 2.

![Mean Value of Spatial Reasoning Test](image)

**Figure 2. Mean Value of Spatial Reasoning Test**

Mean value spatial reasoning test presented in Figure 2. The construct of mental rotation was the aspects that had the highest value compared to the other elements. We then analyzed performance differences by the three spatial constructs. Most college students were good in mental rotation aspects, but not for spatial visualization and spatial orientation aspects [15]. It may be causing that students need different aspects of training to establish proficiency and sophistication level [16]. Aspect with the lowest value is spatial orientation. The indicator of spatial orientation is determining the position of an object relative to the observer, so it is important to challenge students solving such tasks with less reliance on manipulative, consequently encouraging the more excellent use of imagery [16,17]. Some scaffolding can improve spatial reasoning ability faster.

When viewed regarding gender, the findings show that there was no difference in ability between male and female [18,19]. It can be seen in Figure 3.
From figure 3, we concluded that female tend to have a good score in mental rotation and spatial orientation, and men tend to a good score in spatial visualization. Although there is a tendency for differences between male and female abilities, this is not too obvious[19]. Although from Figure 3 there is a difference between male and female spatial reasoning ability, overall the difference is not very significant.

4. Conclusion
Spatial reasoning is very potential to improve students' mathematical performance [7,9,11]. Based on this situation, we can conclude that the spatial reasoning ability in college students still low and need some scaffolding to improve the spatial reasoning ability. If spatial reasoning can be routinely used by a lecturer in learning then the potential that the learning is done can make college students’ math performance better. Besides the mathematical performance, the spatial reasoning ability will also develop. If the spatial reasoning ability of college students were good, then they have the potential to succeed in both mathematics and STEM [11,12,20,21].

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References
[1] Roberts A 2012 A justification for STEM education Technology and Engineering Teachere 1
[2] Seymour E and Hewitt N M 1997 Talking about leaving: Why undergraduate leave the sciences (Boulder: Westview Press)
[3] Education O M of 2014 Paying Attention to Spatial Reasoning, K-12 Support Document for Paying Attention to Mathematics Education (Ontario: Queen’s Printer for Ontario)
[4] National Research Council (US) Committee Successful Schools or Programs for K -12 STEM Education 2011 Successful K-12 STEM education: Identifying effective approaches in science technology, engineering, and mathematics (Washington DC: National Academies Press)
[5] Vu K and Mitsunobu F 2004 Spa Therapy for Bronchial Asthma Studies at the Misasa Medical Center 10 144-150
[6] Linn, M. and Petersen A 1985 Emergence and Characterization of Sex Differences in Spatial Ability: A Meta Analysis. Child Dev. 56 1479
[7] Cheng Y L and Mix K S 2014 Spatial Training Improves Children’s Mathematics Ability J. Cogn.
[8] David L T 2012 Training effects on mental rotation, spatial orientation and spatial visualisation depending on the initial level of spatial abilities *Procedia - Soc. Behav. Sci.* 33 328
[9] Lowrie T, Logan T and Ramful A 2017 Visuospatial training improves elementary students’ mathematics performance *Br. J. Educ. Psychol.* 87 170
[10] Ramful A, Lowrie T and Logan T 2017 Measurement of Spatial Ability: Construction and Validation of the Spatial Reasoning Instrument for Middle School Students *J. Psychoeduc. Assess.* 35 709
[11] Newcombe N S 2013 Seeing Relationships. Using Spatial Thinking to Teach Science, Mathematics, and Social Studies *American Educator* 26
[12] Moore-Russo D, Viglietti J M, Chiu M M and Bateman S M 2013 Teachers’ spatial literacy as visualization, reasoning, and communication *Teach. Teach. Educ.* 29 97
[13] Gilligan K A, Flouri E and Farran E K 2017 The contribution of spatial ability to mathematics achievement in middle childhood *J. Exp. Child Psychol.* 163 107
[14] Mayer R E and Massa L J 2003 Three Facets of Visual and Verbal Learners: Cognitive Ability, Cognitive Style, and Learning Preference *J. Educ. Psychol.* 95 833
[15] Yurt E and Tünkler V 2016 A study on the spatial abilities of prospective social studies teachers: A mixed method research *Kuram ve Uygulamada Egit. Bilim.* 16 965
[16] Maeda Y and Yoon S Y 2013 A Meta-Analysis on Gender Differences in Mental Rotation Ability Measured by the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R) *Educ. Psychol. Rev.* 25 69
[17] Moore-russo D 2013 Teachers’ spatial literacy as visualization, reasoning, and communication *Teach. Teach. Educ.* 29 97
[18] Terlecki M S, Newcombe N S and Little M 2008 Durable and Generalized Effects of Spatial Experience on Mental Rotation: Gender Differences in Growth Patterns 1013 996
[19] Baenninger M and Newcombe N 1989 The Role of Experience in Spatial Test Performance: A Meta-Analysis 1 20 327
[20] Hawes Z, Moss J, Caswell B and Poliszczuk D 2015 Effects of mental rotation training on children’s spatial and mathematics performance: A randomized controlled study *Trends Neurosci. Educ.* 4 60
[21] Gilligan K A, Flouri E and Farran E K 2017 The contribution of spatial ability to mathematics achievement in middle childhood *J. Exp. Child Psychol.* 163 107