Full research paper

THE ROLE OF SPATIAL ANXIETY IN THE RELATIONSHIP BETWEEN MATHEMATICS ANXIETY AND SPATIAL REASONING

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ABSTRACT

This study explored the connection between mathematics anxiety and spatial reasoning, examining potential mediating and moderating effects of spatial anxiety, as well as the roles of grade level and gender. A cross-sectional survey was conducted with 477 elementary school students in Jakarta, selected through convenience sampling. Participants included 185 from grade 4, 179 from grade 5, and 113 from grade 6, with a gender distribution of 51.4% male and 48.6% female. Mediation and moderation analyses were performed using the PROCESS macro in SPSS. The findings revealed that (1) mathematics anxiety has a significant negative direct effect on spatial reasoning; (2) spatial anxiety mediates the relationship between mathematics anxiety and spatial reasoning; and (3) the strength of this relationship varies according to levels of spatial anxiety. These results suggest that students with higher mathematics anxiety may experience greater difficulty with spatial reasoning tasks. Accordingly, interventions targeting both mathematics and spatial anxiety could enhance spatial reasoning among those with elevated mathematics anxiety. Beyond these implications, the findings underscore the importance of improving educational efficiency through targeted interventions and strengthening educators' responsibility for addressing affective barriers that limit the development of spatial reasoning skills.

KEYWORDS

Educational efficiency, mathematics anxiety, responsibility in education, spatial anxiety, spatial reasoning

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Highlights

- *Mathematics anxiety has a negative and significant direct effect on spatial reasoning.*
- *Spatial anxiety mediates the relationship between mathematics anxiety and spatial reasoning.*
- *The relationship between mathematics anxiety and spatial reasoning may vary depending on the levels of spatial anxiety.*

INTRODUCTION

Geometry and spatial reasoning in the development of mathematical knowledge are interrelated (Battista, 2007; Clements and Battista, 1992) and play a crucial role in interpreting and reflecting on the physical environment. Geometry and spatial reasoning are not only useful for the development of both but also provide support for general mathematics performance (Lowrie et al., 2016) and learning other mathematical disciplines, such as arithmetic (Zhang and Lin, 2017), as well as other fields of science, such as science, technology, and engineering (Gilligan et al., 2017; Uttal et al., 2013).

In contrast to the recognized importance of geometry and spatial reasoning, several studies have reported the need to emphasize spatial reasoning in mathematics learning due to outcomes that fall short of expectations (Clements and Sarama, 2011; Hasanah et al., 2024; Mulligan, 2015). Hallowell et al. (2015) focused on identifying the spatial reasoning of first-grade students in constructing and decomposing geometric figures. However, the identification results highlight the difficulties students encounter, particularly in connecting 2D diagram lines with 3D boundaries. It is likely that these problems occur because spatial reasoning does not have an explicit place in the mathematics curriculum (Wai et al., 2009). In fact, given the important role that spatial reasoning plays, it should make sense that geometry and spatial reasoning have an important place in the school mathematics curriculum. Hejnová et al. (2024) also emphasized in their findings that geometric abilities, especially spatial ones, are integral to the thinking skills required in problem-solving.

The basis of most geometric thinking is spatial reasoning, which involves the ability to perceive, analyze, and mentally manipulate objects, visualize their images, and understand their interrelationships (Battista, 2007). Another opinion provides a definition related to spatial reasoning, which is the process of perceiving, collecting, creating, and communicating objects in two or three-dimensional space to conclude from various information collected, which involves three objects with spatial components, including mental rotation, spatial visualization, and spatial orientation (Lowrie et al., 2016; Lowrie and Logan, 2018). Examples of spatial reasoning include locating, orienting, decomposing/rearranging, balancing, diagramming, symmetry, navigating, comparing, scaling, and visualizing (Mulligan et al., 2018).

The rationale highlights the importance of spatial reasoning in problem-solving, decision-making, and other cognitive processes that require an understanding of space and spatial relationships (Duffy et al., 2024; Munoz-Rubke et al., 2021). Therefore, educators should prioritize the development of spatial reasoning skills in their teaching practices to ensure that students are equipped with the necessary tools to navigate the complex world around them. As a first step, an analysis of spatial reasoning and its relationship to mathematics learning is necessary to inform decision-making during learning activities (Ishikawa and Newcombe, 2021).

Spatial reasoning is considered part of cognitive abilities and related to problem-solving (Altıner and Doğan, 2018). It turns out that, apart from being closely related to cognitive abilities, spatial reasoning is also closely related to emotional (affective), biological, and experiential factors (Ramirez et al., 2012). Furthermore, Ramirez et al. (2012) mention that affective factors in spatial reasoning are an interesting focus of study and are still rarely found in the literature.

LITERATURE REVIEW

Spatial Reasoning and Mathematics Achievement

The term "spatial reasoning" is often used interchangeably with other related terms, such as "spatial thinking," "spatial ability," "spatial sensitivity," "spatial intuition," "spatial perception," and "spatial intelligence." In this section, each overlapping term will be clearly defined and then used as a guideline for naming the terms. The consensus regarding the definition of spatial reasoning centers on a range of mental processing abilities that enable the analysis, manipulation, and generation of mental representations of visual, spatial, and graphic information (Clements and Battista, 1992; Diezmann and Lowrie, 2012; Uttal et al., 2013). Spatial thinking is another type of human cognition, similar to verbal and numerical cognition, involving spatial relationships (Bednarz and Lee, 2019; Bednarz and Lee, 2011). Furthermore, spatial ability is defined as a separate intellectual concept that encompasses spatial relationships and spatial visualization factors (Pellegrino et al., 1984). Spatial sensitivity refers to the ability to detect or respond to differences or patterns of change (Lilburne and Tarantola, 2009); this term is more commonly used in the field of geography. Lastly, spatial intuition, as illustrated by Raftopoulos (2002), refers to an individual's ability to visualize objects related to spatial concepts. Based on several definitions of the similarities between the terms used, this study employs the term "spatial reasoning" because it provides a clearer understanding of the aspects of each construct that are expected in this study.

Different approaches exist for classifying spatial reasoning dimensions. Clements and Battista (1992) differentiate between two dimensions: spatial visualization and orientation. Others suggest a three-dimensional approach, including spatial visualization, orientation, and mental rotation, to adapt primary and secondary school curricula (Lowrie and Logan, 2018; Ramful et al., 2017). Spatial rotation involves mentally manipulating and rotating objects or images in space, transforming their orientation. Spatial visualization involves creating and manipulating mental images, whereas spatial orientation involves understanding and determining spatial relationships in relation to one's body orientation.

The relationship between spatial reasoning and mathematical achievement has been extensively studied and acknowledged in the literature. Cognitive skills involved in spatial reasoning, such as mentally manipulating objects in two and three dimensions, are crucial for understanding and solving complex mathematical problems. Resnick et al. (2020) and Cheng and Mix (2014) found a consistent relationship between spatial reasoning and mathematical achievement. They found that individuals with stronger spatial reasoning skills perform better in mathematics. They emphasize the importance of incorporating spatial reasoning activities and interventions in mathematics education to enhance students' understanding and problem-solving abilities. This is also emphasized by Prokýšek and Rambousek (2013), who state that spatial reasoning is directly related to the ability to absorb information; in other words, students with good spatial reasoning will find it easier to learn.

Mathematics Anxiety and Spatial Anxiety

Mathematics anxiety and spatial anxiety are two distinct types of anxiety experienced by individuals in relation to mathematics and spatial tasks. Mathematics anxiety involves fear, tension, and apprehension when faced with mathematical tasks, leading to negative emotions and avoidance behaviors (Harari et al., 2013; Suci and Purnomo, 2016; Zhang and Wang, 2020). Factors influencing mathematics anxiety include previous negative experiences, fear of failure, societal pressure, and a lack of confidence in mathematical abilities.

Spatial anxiety, on the other hand, refers to the discomfort individuals may feel when engaging in spatial tasks or dealing with spatial information. Factors such as lack of spatial reasoning, limited exposure to spatial tasks, or negative experiences related to spatial activities can influence spatial anxiety (Ramirez et al., 2012; Şanli, 2024). Although they are distinct, there may be some overlap in their underlying factors and impact on performance. For example, individuals with high levels of mathematics anxiety may experience heightened spatial anxiety when engaging in tasks involving spatial reasoning, such as geometry problems (Ferguson et al., 2015).

Spatial Reasoning and Anxiety

Mathematics anxiety is a significant concern for researchers due to its correlation with students' achievement in learning mathematics. It is considered a psychological construct that can predict lower math performance (Lukowski et al., 2019) and negatively impact cognitive processes, including spatial reasoning. Students experiencing high math anxiety tend to exhibit increased brain activity in the regions associated with threat detection (Schenck, 2022), leading to earlier feelings of anxiety. Consequently, mathematics anxiety can deplete cognitive resources, hindering effective engagement in spatial reasoning tasks and resulting in decreased performance in solving spatial problems.

In an empirical study, Malanchini et al. (2017) discovered a negative relationship between spatial anxiety and spatial reasoning. This means that an increase in spatial anxiety is associated with a decrease in spatial reasoning. Similar findings were also reported in research by Alvarez-Vargas et al. (2020), indicating that anxiety can interfere with mental rotation performance —a crucial aspect of spatial reasoning. Lourenco and Liu (2023) explored the impact of anxiety and motivation on spatial reasoning, both of which can influence performance in spatial tasks. Likewise, Ramirez et al. (2012) found that spatial anxiety is negatively correlated with spatial reasoning, a relationship similar to that between mathematics anxiety and mathematical performance.

The research conducted by Ramirez et al. (2013) suggests that children, even at a young age, tend to experience feelings of nervousness when confronted with spatial activities. Moreover, the findings suggest that feelings of nervousness associated with spatial activities can impact mental rotation ability, particularly among girls with high working memory. Understanding these patterns can contribute to a deeper understanding of the factors influencing spatial cognition and the development of interventions to support children in overcoming spatial anxiety and enhancing their spatial reasoning. Additionally, according to Blair (2010), it is crucial to consider how gender variations affect the development of spatial reasoning and to employ strategies that are tailored to each gender's traits. For example, girls tend to prefer manipulative games that emphasize social aspects, whereas boys tend to favor games that focus on competition. It's interesting to note that only girls showed this connection between working memory and spatial anxiety. However, a study by Wong (2017) on 182 toddlers in Hong Kong found an indication that spatial anxiety moderated the space-math link, but the effect differed for boys and girls. The spatial reasoning of boys is not relevant for computing at high levels of anxiety; the role of girls' anxiety in spatial mathematical relationships is less clear. These findings provide basic evidence of the relationship between spatial mathematics, including extrinsic spatial reasoning (targeting accuracy), and have implications for intervention programs. The study is supported by strong longitudinal and cross-sectional evidence that spatial reasoning and mathematical abilities are associated with childhood (Atit et al., 2022; Gilligan et al., 2017).

There is little literature that examines spatial reasoning associated with anxiety factors, making both of them interesting to study in more detail. This is, as stated by Ramirez et al. (2012), that understanding anxiety and its relationship to spatial reasoning can provide new ways of thinking about individual differences in spatial reasoning, ultimately leading to interventions designed to reduce anxiety and increase levels of spatial reasoning and achievement in student performance in STEM disciplines. Moreover, there are still very few empirical studies on spatial reasoning and mathematics anxiety in the context of Indonesian students, including the appropriate measurement tools, descriptions of student tendencies in Indonesia, and their implications. No evidence of intervention refers to the research results of these two variables. Therefore, based on these problems, researchers try to examine more deeply how these two variables are described in the research results.

The relationship between mathematics anxiety and spatial reasoning has been extensively studied. Still, little research has explored the potential changes in magnitude, direction, and type when considering mediating or moderating variables. This study aimed to investigate whether spatial anxiety is mediated by mathematics anxiety or if the relationship differs depending on its level. To examine the mediation or moderation model, grade and gender covariates were used to statistically control for the effect. The questions in this research include:

1. How does mathematics anxiety affect spatial reasoning? (Hypothesis: the higher the mathematics anxiety, the lower the spatial reasoning)
2. In addition to the direct effects above, is there a significant indirect effect between mathematics anxiety and spatial reasoning, through spatial anxiety? (Mediation hypothesis: the higher the mathematics anxiety, the higher the spatial anxiety, and the lower the spatial reasoning)
3. How can the level of spatial anxiety condition the relationship between mathematics anxiety and spatial reasoning? (Moderation hypothesis: the higher the level of spatial anxiety, the higher the negative relationship between mathematics anxiety and spatial reasoning).

MATERIALS AND METHODS

Context and Participant

This cross-sectional survey study aimed to collect data from elementary school students in Jakarta using convenience sampling. The sample included 477 participants, with 185 in grade 4, 179 in grade 5, and 113 in grade 6. Of the total participants, there were 245 males and 232 females. The gender distribution was balanced, with 51.4% male and 48.6% female, ensuring representation from both genders.

This research was conducted with the official permission of the elementary school, as evidenced by a research permit letter. After completing the research activities, the researchers also received a certificate as proof that the research had been conducted at the school in accordance with the applicable procedures. We did not undergo the ethical assessment procedure by an ethics review board because social science research ethics boards are not yet established in Indonesia, and this procedure is not commonly practiced for social science research in the country. Nevertheless, Participants were given the freedom to choose whether to participate before completing the questionnaire, and no personal or school information was disclosed.

Measure

Spatial Reasoning

To assess this ability, we have adapted a spatial reasoning test instrument based on the work of Ramful and his colleagues

(Ramful et al., 2017). The test measures three key factors: mental rotation, spatial orientation, and visual orientation. Mental rotation refers to the ability to mentally manipulate objects in three-dimensional space. Spatial orientation involves understanding one's position in relation to other objects in space. Finally, visual orientation refers to the ability to mentally rotate two-dimensional images.

Ramful et al. (2017) employed factor analysis to identify the most effective items for measuring the spatial reasoning test, which initially contained 45 items and was subsequently reduced to 30 items, with each factor consisting of 10 items. Although three of these forming factors do not have a high level of reliability, the thirty items as a whole have a Cronbach's alpha value of 0.849. The discriminating power of the three factors that form spatial reasoning itself ranges from 0.27 to 0.48, indicating that the discriminating power of each factor is medium to high. Table 1 below shows the indicators of spatial reasoning ability tests.

Factor	Item characteristics	No.	Number of items
Mental Rotation	• Determines the result of the rotation of a 2D and 3D object. • Distinguish between reflection and rotation	3, 5, 7, 8, 14, 15, 18, 20, 24, 28	10
Spatial Orientation	• Figuring out where an object is in relation to the observer • Examining maps from various angles • The process of determining a point's cardinality when the north is not in the vertical upright direction • Recognizing an object's orthogonal views	1, 4, 9, 11, 12, 16, 22, 25, 27, 29	10
Visual Orientation	• Visualize the result of folding/unfolding a given configuration • Constructing a solid from a given net and vice versa • Matching pieces and parts, finding symmetry in an object • Reflecting an object.	2, 6, 10, 13, 17, 19, 21, 23, 26, 30	10
Total			30

Table 1: Framework and Indicator of Spatial Reasoning Ability Test

A multiple-choice test consisting of 30 items is used to assess this skill. The scoring system awards one point for each correct answer and zero for incorrect responses. The following is an example of an instrument that has been adapted into Indonesian by researchers.

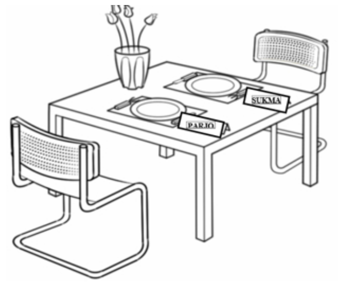
Original instruments	Adapted instruments
The seating positions of Kate and William are shown below.  In which position is the flower vase from Kate's view? a. To her right b. To her left	*Posisi tempat duduk Sukma dan Parjo ditampilkan di bawah ini* [Sukma and Parjo's seating positions are shown below].  *Dimana posisi vas bunga dari pandangan Sukma?* [Where is the flower vase from Sukma's point of view?] *a. Di kanan Sukma* [To Sukma's right] *b. Di kiri Sukma* [To Sukma's left]

Table 2: Example of Spatial Reasoning Instrument

Mathematics Anxiety

We adapted the scale developed by Harari et al. (2013) to measure mathematics anxiety. This scale has three factors: negative reactions, numerical confidence, and worries. There are 12 items on this scale with seven positive statements and five negative statements. In the study, children answered the questions using a 4-point emoji sliding scale, where each point was associated with a specific coding scheme for negative and positive items. The negative item was coded so that "yes" = 4, "kind of" = 3, "not really" = 2, and "no" = 1. The positive item was coded so that "yes" = 1, "kind of" = 2, "not really" = 3, and "no" = 4. The maximum score that students can achieve is 48, and the minimum score is 12. The mathematics anxiety questionnaire item factor is presented in Table 3.

Factor	Item	The number of items	Item Sample
Worries	2, 3, 6,	3	In math class, I am scared.
Negative Reactions	4, 8, 9, 12	4	My tummy hurts after doing math.
Numerical Confidences	1, 5, 7, 10, 11	5	I like being called on in math class.

Table 3: Indicator of Mathematics Anxiety Questionnaire

Spatial Anxiety

In the study, the researchers retained the original questionnaire instrument developed by Ramirez et al. (2012), which consisted of eight items. However, we modified the response scale by implementing a 4-point emoji sliding scale. The scale included four different emojis to represent the response options: normal (😀), confused (😵), nervous (😬), and afraid of being wrong (😨). The maximum score that students can achieve is 32, and the minimum score is 8.

Data Analysis Procedures

We use content validity and face validity, which were previously translated from the original instrument into Indonesian. These translations were reviewed by two experts to ensure accuracy and cultural appropriateness. Additionally, pilot testing was conducted to assess the clarity and comprehensibility of the translated instrument among 10 Indonesian elementary school students. Both of these validations indicate the feasibility of using the mathematics anxiety, spatial anxiety, and spatial reasoning instruments for data collection.

The researcher conducted a reliability test to determine the reliability of the instruments used in Indonesia. The Cronbach's Alpha value was used to assess the reliability of the spatial reasoning and anxiety instrument. A Cronbach's Alpha value greater than 0.60 is considered acceptable reliability, as agreed upon by Guilford and Spearman-Brown (Bahri and Zamzam, 2014). The reliability test results are presented in Table 4.

Instrument	Cronbach's Alpha	*N* of Items
Spatial reasoning abilities	0.622	30
Mathematics anxiety	0.642	12
Spatial anxiety	0.506	6

Table 4: Output Reliability Test of the Three Instruments

Table 4 displays Cronbach's alpha coefficients of 0.622 for spatial reasoning and 0.642 for mathematics anxiety, indicating acceptable internal consistency. However, the Spatial Anxiety Instrument did not perform as well. After removing problematic items, the revised instrument achieved a Cronbach's Alpha coefficient of 0.506. Although below the acceptable threshold, considering the time constraints, the exploratory and local nature of the research context, and the content validity that has undergone expert validation, the instrument was still used with certain limitations. The researcher suggests that this instrument be refined in future studies. The analysis was conducted using descriptive statistics to identify the trends in the data for the three variables and was also categorized by gender and grade level. Mediation and moderation analysis were employed to address the primary questions. All analyses are conducted using the SPSS software application.

RESULTS

Descriptive Data

Descriptive data and correlation analysis between variables and dimensions are presented in Table 5.

Table 5 presents the mean scores and standard deviations for each component of spatial reasoning abilities, along with the correlation coefficients between each component and spatial reasoning. Spatial orientation has the highest mean score of 6.338 (SD = 1.992), indicating participants performed well in tasks related to spatial orientation. The coefficient score of 0.796 indicates that spatial orientation has the strongest impact on overall spatial reasoning performance. Spatial visualization has the lowest mean score of 2.931 (SD = 1.517), suggesting participants performed less effectively in tasks related to spatial visualization. Spatial visualization has the least influence on spatial reasoning, with an influence coefficient of 0.668.

Table 5 shows that spatial reasoning and its components have a negative effect on mathematics anxiety and spatial anxiety. Spatial reasoning has a negative correlation with both anxiety and mathematics anxiety, with a coefficient of -0.092, and spatial anxiety, with a coefficient of -0.194. Higher levels of mathematics anxiety are associated with lower levels of mental rotation, but their influence on another component of spatial reasoning is not significant. Spatial anxiety has a more pronounced negative impact on spatial orientation than spatial visualization and mental rotation.

Based on Table 5, except for mental rotation, grade level appears to have a significant relationship with spatial reasoning and its components. Meanwhile, gender is found to have a significant relationship with spatial reasoning and its components, except for spatial visualization. Both grade level and gender are significantly correlated with mathematics anxiety. However, spatial anxiety does not show a significant relationship with these variables. Table 6 and Table 7 show, respectively, the analysis of the two variables, grade level and gender, on spatial reasoning, mathematics anxiety, and spatial anxiety.

Variable	Mean	SD	Min	Max	SR	SOR	SV	MR	MA	SA	Grade	Gender
SR	12.352	3.797	4	24	—							
SOR	6.338	1.922	1	10	0.796***	—						
SV	2.931	1.517	0	8	0.668***	0.300***	—					
MR	3.088	1.681	0	9	0.744***	0.384***	0.266***	—				
MA	23.000	5.605	12	40	-0.092*	-0.064	-0.020	-0.111*	—			
SA	10.774	3.153	6	24	-0.194***	-0.194***	-0.104*	-0.122**	0.220***	—		
Grade	—	—	—	—	0.232***	0.299***	0.120**	0.076	0.279***	-0.080	—	
Gender	—	—	—	—	0.145**	0.173***	-0.006	0.131**	-0.138**	-0.063	-0.119**	—

** p <.1, ** p <.05, *** p <.01*

Note: SR = Spatial Reasoning; SOR = Spatial Orientation; SV = Spatial Visualization; MR = Mental Rotation; MA = Mathematics Anxiety; SA = Spatial Anxiety

Table 5: Descriptive Data and Correlation Among Variables

	Gender	*N*	Mean	SD	Min	Max	*t*(475)	*p*	*d*
Spatial Reasoning	Female	232	11.789	3.499	4	23	-3.184	0.002	-0.292
	Male	245	12.886	3.993	4	24			
Mathematics Anxiety	Female	232	23.793	5.383	12	40	3.033	0.003	0.278
	Male	245	22.249	5.717	12	40			
Spatial Anxiety	Female	232	10.978	3.010	6	23	1.382	0.168	0.127
	Male	245	10.580	3.277	6	24			

Table 6: Analysis of Gender and Spatial Reasoning, Mathematics Anxiety, and Spatial Anxiety

Table 6 shows that male students have a higher mean spatial reasoning score than female students. The mean score for male students was 12.886, which was higher than the mean score for female students, which was 11.789. In terms of mathematics anxiety, female students have a higher mean score of 23.793 compared to males at 22.249. On average, female students report higher levels of mathematics anxiety. In terms of spatial anxiety, both male and female students have higher mean scores, with male students scoring 10.978 and females scoring 10.580.

	Spatial Reasoning			Mathematics Anxiety			Spatial Anxiety		
	4th-grade	5th-grade	6th-grade	4th-grade	5th-grade	6th-grade	4th-grade	5th-grade	6th-grade
N	185	179	113	185	179	113	185	179	113
M	11.362	12.575	13.619	21.470	22.933	25.611	11.011	10.804	10.336
SD	3.485	3.644	4.111	5.462	5.728	4.649	3.328	3.215	2.708
Min	4.000	5.000	5.000	12.000	12.000	14.000	10.000	10.000	10.000
Max	24.000	23.000	24.000	37.000	40.000	40.000	29.000	28.000	28.000
F	13.572, $p < .001$			20.750, $p < 0.001$			1.623, $p = 0.198$		

Table 7: Analysis of Grade Level and Spatial Reasoning, Mathematics Anxiety, and Spatial Anxiety

Table 7 presents the differences in mean values for mathematics anxiety, spatial anxiety, and spatial reasoning ability across various grade levels. Mathematics anxiety increases sequentially from grade 4 to grade 6, suggesting that higher grade levels tend to have higher mean scores. On the other hand, spatial anxiety has the highest mean score for grade 4 students, followed by grade 5, and the lowest mean score for grade 6. Grade 4 students generally exhibit higher levels of spatial anxiety compared to students in grades 5 and 6. Additionally, spatial reasoning ability has the highest mean score among grade 6 students, followed by grade 5, and the lowest among grade 4. This suggests that as students advance to higher grade levels, their spatial reasoning abilities tend to improve.

Mediation Analysis

We perform mediation analysis using the PROCESS feature in SPSS to evaluate the direct and indirect effects of mathematics anxiety on spatial reasoning, considering the mediating role of spatial anxiety. Additionally, it allows for examining the effects of grade level and gender on spatial anxiety and spatial reasoning. A summary of the analysis results is shown in Table 8.

Based on Table 8, the regression model describes a significant variance in both spatial anxiety ($R = 0.269$, $F(3, 473) = 12.251$, $p < 0.001$) and spatial reasoning ($R = 0.324$, $F(4, 472) = 18.521$, $p < 0.001$). This model examines the role of spatial anxiety as a mediator in the relationship between math anxiety and spatial reasoning. The measures and paths include:

1. Path from Math Anxiety to Spatial Anxiety
   As shown in the table above, math anxiety has a positive and significant effect on students' spatial anxiety with $b = 0.145$, $p < 0.001$.
2. Path from Spatial Anxiety to Spatial Reasoning
   Spatial anxiety (SA) has a direct negative and significant effect on spatial reasoning ($b = -0.165$, $p < 0.05$), indicating that higher levels of spatial anxiety are associated with lower spatial reasoning scores.

3. Path of Mathematical Anxiety and Spatial Reasoning
   In the direct effect, mathematical anxiety has a significant negative direct effect on spatial reasoning (b = -0.103, p < 0.001), indicating that higher levels of mathematical anxiety are associated with lower spatial reasoning scores.
4. Path of indirect effect
   As shown in Table 8, the evidence supports the hypothesis that spatial anxiety mediates the relationship between math anxiety and spatial reasoning. The indirect effect, which represents the mediating effect, is significant because the bootstrap confidence intervals do not include zero (Boot LLCI = -0.043, Boot ULCI = -0.007). This indicates that the relationship between math anxiety and spatial reasoning is partially mediated by spatial anxiety.

Table 8 also indicates the effects of covariates on spatial anxiety and spatial reasoning. Gender has a significant positive effect on spatial reasoning (b = 1.203, p < 0.05). However, there is no evidence that gender influences spatial anxiety levels. Grade level has a positive and significant effect on spatial reasoning (b = 1.436, p < 0.05). However, grade level has a negative effect on spatial anxiety (b = -0.639, p < 0.05).

	Coeff	SE	*t*	*p*			
Outcome: SA							
Constant	8.138	0.631	12.894	0.00			
MA	0.145	0.026	5.545	0.000			
Grade	-0.639	0.188	-3.400	0.001			
Gender	-0.293	0.283	-1.038	0.300			
Summary: SA	*R*	*R-sq*	*MSE*	*F*	*Df1*	*Df2*	*p*
	0.269	0.072	9.282	12.251	3.000	473.000	0.000
Outcome: SR							
Constant	14.221	0.860	16.532	0.000			
MA	-0.079	0.032	-2.500	0.013			
SA	-0.165	0.054	-3.058	0.002			
Grade	1.331	0.223	5.967	0.000			
Gender	1,155	0.332	3.480	0.001			
Summary: SR	*R*	*R-sq*	*MSE*	*F*	*Df1*	*Df2*	*p*
	0.350	0.123	12.984	16.473	4.000	472.000	0.000
Outcome: SR							
Constant	12.880	0.746	17.254	0.000			
MA	-0.103	0.031	-3.331	0.001			
Grade	1.436	0.222	6.461	0.000			
Gender	1.203	0.334	3.598	0.000			
Summary: SR	*R*	*R-sq*	*MSE*	*F*	*Df1*	*Df2*	*p*
	0.324	0.105	12.984	18.521	3.000	473.000	0.000

Note: SR =Spatial Reasoning; SOR = Spatial Orientation; SV = Spatial Visualization; MR = Mental Rotation; MA = Mathematics Anxiety; SA = Spatial Anxiety

Table 8: Summary of Mediation Analysis Results

Moderation Analysis

The role of moderator of spatial anxiety in the influence of mathematics anxiety on spatial reasoning is examined through a moderation analysis using the PROCESS feature in SPSS. The summary of the analysis is presented in Table 9.

Based on the information provided in Table 9, the results show that the effect of mathematics anxiety on spatial reasoning differs across different levels of spatial anxiety. In the low spatial anxiety group, the effect is statistically significant (b = -0.147; p < 0.001), suggesting that higher levels of mathematics anxiety are associated with lower spatial reasoning scores. In the medium spatial anxiety group, higher levels of mathematics anxiety are also associated with lower spatial reasoning scores, but to a lesser extent compared to the low anxiety group. In the high spatial anxiety group, the effect is not statistically significant (b = -0.012; p = 0.782), suggesting that there is no significant relationship between mathematics anxiety and spatial reasoning. These results indicate that the relationship between mathematics anxiety and spatial reasoning may vary depending on the levels of spatial anxiety. The impact of mathematics anxiety on spatial reasoning may be stronger when spatial anxiety is low or moderate, but becomes non-significant when it is high.

Group	SA	Effect	SE	*t*	*p*
Low	7.621	-0.147	0.042	-3.496	0.001
Medium	10.774	-0.079	0.031	-2.520	0.012
High	13.926	-0.012	0.042	-0.277	0.782

Table 9: Conditional effects of Mathematics Anxiety on Spatial Reasoning at Different Levels of Spatial Anxiety

DISCUSSION

This study aims to examine the relationship between mathematics anxiety, spatial anxiety, and spatial reasoning. We have formulated three hypotheses to explore these connections. Our first hypothesis suggests that math anxiety plays a significant role in determining spatial reasoning. Our second hypothesis proposes that spatial anxiety acts as a mediator between math anxiety and spatial reasoning. Finally, our third hypothesis suggests that the level of spatial anxiety conditions the relationship between math anxiety and spatial reasoning. Overall, our data support all three hypotheses.

First one, the results of the analysis indicate that the first hypothesis is not rejected, showing that mathematics anxiety significantly influences spatial reasoning with a direct negative effect. This means that the higher the mathematics anxiety, the lower the spatial reasoning ability. These findings align with a previous study by Ferguson et al. (2015), which reported that individuals experiencing mathematics anxiety also suffer negative consequences on their spatial reasoning. This phenomenon occurs because high mathematics anxiety can lead to difficulties in sensory control. Additionally, Wang (2020) corroborated these results, stating that mathematics anxiety negatively impacts spatial reasoning, which consequently affects the capacity to visualize and recall information during learning.

Second, the findings from our study support the second hypothesis, which suggests that spatial anxiety acts as a mediator in the relationship between mathematics anxiety and spatial reasoning. Our study indicated that higher levels of mathematics anxiety are associated with increased spatial anxiety, and in turn, elevated spatial anxiety is linked to lower spatial reasoning abilities. This implies that individuals with greater math anxiety are more likely to experience heightened levels of spatial anxiety, which, in turn, negatively affects their spatial reasoning skills. These results underscore the importance of addressing both mathematics and spatial anxiety to help individuals develop effective spatial reasoning abilities. A study by Ferguson et al. (2015) also reinforces these results, as it found that high math anxiety is associated with impaired sense of direction, spatial and general anxiety, and poorer performance on spatial reasoning tests. Furthermore, these findings remained consistent across tests conducted while considering gender and grade level variables, as well as when assessing the influence of the anxiety variable on spatial reasoning abilities.

Third, our findings reveal that the relationship between math anxiety and spatial reasoning may vary depending on the level of spatial anxiety. The influence of mathematics anxiety on spatial reasoning is more pronounced when spatial anxiety is low or moderate, but it becomes non-significant when spatial anxiety is high. In simpler terms, the effect of students' math anxiety on their proportional reasoning abilities is more significant when they belong to the lower spatial anxiety group. On the other hand, for students with higher spatial anxiety, the influence of mathematics anxiety on spatial reasoning is weaker. This is reasonable because spatial anxiety has a more substantial impact on spatial reasoning than mathematics anxiety. This conclusion is further supported by the correlation results, which indicate a stronger relationship between spatial anxiety and spatial reasoning than between mathematics anxiety and spatial reasoning, as shown in Table 5. These findings emphasize the crucial role of spatial anxiety in determining the relationship between mathematics anxiety and spatial reasoning. Therefore, addressing and reducing mathematics anxiety first could be a vital factor in mitigating the negative impact of spatial anxiety on proportional reasoning skills. Previous studies have also found that spatial anxiety is related to mathematics anxiety, and those with lower spatial reasoning have higher math anxiety (Douglas and LeFevre, 2018; Ferguson et al., 2015; Maloney and Beilock, 2012).

The descriptive statistics of this study also show that, in terms of gender, spatial reasoning ability is inversely proportional to the average math and spatial anxiety scores. Female students suffer more anxiety than male students in these two variables, implying that female students have a higher potential to experience mathematical anxiety and spatial anxiety. The level of math anxiety is affected by gender (Szczygieł, 2020), where female math anxiety dominated the proportion (Devine et al., 2012). Furthermore, this study explains math anxiety, and the anxiety test results show that females suffer more arithmetic anxiety than males (Devine et al., 2012). Santrock (2011) states that the concept that focuses on the differences between males and females is the corpus callosum, a collection of fibers that connects the two hemispheres of the brain. Females have a larger corpus callosum than males, which may explain why they are more conscious of their own and others' emotions. As a result, the level of mathematics anxiety among female students is higher than that of male students.

In contrast to math anxiety and spatial anxiety, according to some studies (Sorby, 1999, 2009), males tend to have better spatial reasoning, while females are considered better in areas such as language skills, motor skills, and reaction time. This suggests that gender roles impact students' spatial reasoning abilities. These findings have implications for education, particularly mathematics education. Since female students are more susceptible to anxiety, which impacts spatial reasoning, teachers can use this information to inform the implementation of learning activities. The findings of Furner and Marinas (2016) and Iossi (2007) suggest that engaging, technology-based learning can foster math understanding while reducing math anxiety. Best practices in mathematics learning can be implemented, such as the use of manipulatives (concrete math) and psychological techniques like anxiety management, desensitization, counseling, support groups, bibliotherapy, and discussions (Zemelman et al., 2015).

In terms of grade level, spatial reasoning abilities, as indicated by the descriptive statistical data in this study, can be attributed to the fact that grade 6 has the highest average and standard deviation levels of spatial reasoning abilities. In contrast, grade 4 has the lowest levels. This level of spatial reasoning ability is comparable to mathematics anxiety, where information is obtained that the higher the grade level, the higher the level of mathematics anxiety (Szczygieł, 2020). Previous research (Salthouse, 1987) relevant to the results of this analysis states that differences in age maturity affect spatial reasoning. This finding aligns with research by Wang et al. (2014), which suggests that age, in conjunction with grade level, significantly moderates spatial reasoning. Because the subjects of this study were elementary school students, it can be inferred that their spatial reasoning will develop more at each grade level. Low-grade 1, grade 2, and grade 3 will differ from high-grade 4, grade 5, and grade 6, which logically have experienced better cognitive development. Compared to grades 4 and 5, grade 6 is at the highest level of thinking. Piaget argues that spatial reasoning is an aspect of cognition that develops in line with cognitive development, namely, the concept of a child's spatial reasoning develops along with their growth (Šafhalter et al., 2016). Starting from the very simple, starting when the child is at a low level of thinking, namely sensory-motor, to the highest level, namely formal operations. Therefore, it is relevant to note that grade 6 achieves the highest level of spatial reasoning ability because, at that age, their cognitive thinking level is the highest between grades 4 and 5. Meanwhile, it is inversely proportional to mathematics anxiety that spatial anxiety shows a negative influence, where the higher the grade level, the lower the value of spatial anxiety.

Related to the existence of a negative influence between spatial reasoning components on students' anxiety, Diezmann's (2009) study offers solutions on how teachers can develop students' spatial reasoning and work towards spatial literacy for all students. First, ensure that the development of spatial skills and various spatial activities is embedded in the mathematics curriculum. Second, support students to develop their spatial vocabulary and provide opportunities for them to use this language. Third, cultivate the development of students' visual memory and spatial reasoning with special attention to the visualization of blurred views, the placement and orientation of shapes, and different points of view. Fourth, provide concrete examples of tasks before expecting students to visualize them and encourage them to relate the task to their previous experiences. Fifth, follow up on students' difficulties and mistakes, and provide practice assignments on each sub-component of the problem assignment. Finally, utilize 21st-century technology to provide opportunities for developing spatial literacy.

From the perspective of efficiency, reducing mathematics and spatial anxiety can streamline learning by minimizing wasted effort and improving the effectiveness of mathematics instruction. From the perspective of responsibility, educators and policymakers bear the obligation to recognize and address affective challenges to ensure equitable and accountable educational practices in mathematics learning. Furthermore, this research will not only enrich the academic literature but also make a tangible contribution to creating a more efficient, effective, and accountable educational ecosystem for all students. This research suggests that to establish an efficient and accountable education system, both emotional and cognitive factors must be addressed as an inseparable whole. The results of this study contribute to the focus of research fields in education and the sciences, as well as the application of operations research in evaluating education and science.

LIMITATIONS

Although this study provides valuable insights into the affective and cognitive relationship between mathematics anxiety, spatial anxiety, and spatial reasoning among Indonesian elementary students, several limitations must be acknowledged to contextualize the findings and guide future research. One limitation of this study lies in the relatively low internal consistency of the spatial anxiety instrument (Cronbach's α = 0.506). This may have been influenced by the limited number of items, the affective and context-dependent nature of anxiety, and possible differences in item interpretation among younger respondents. Further validation and refinement of items are recommended for future studies. While we adhered to local ethical norms, the absence of a formal ethics review board and the use of verbal consent may not fully align with international ethical standards. Future studies should formalize their ethical procedures and align with global research protocols that involve minors. Future research should aim to develop more culturally appropriate and psychometrically sound instruments to assess spatial anxiety in young learners. Experimental or intervention-based designs could also be conducted to examine whether reducing mathematics and spatial anxiety can enhance spatial reasoning performance. Additionally, exploring qualitative data (e.g., student interviews) may provide deeper insights into students' emotional experiences during mathematical and spatial tasks.

Besides that, the limitations of this study include its focus on fourth-, fifth-, and sixth-grade elementary school students. The findings may not be directly generalized to other age groups, such as middle school students, college students, or adults. The dynamics between anxiety and cognitive ability may change with cognitive development, educational experiences, and different social pressures at each age level. Despite its limitations, this study highlights important affective factors influencing spatial reasoning in early education. It provides a foundation for future research that aims to integrate cognitive and emotional perspectives in mathematics education.

CONCLUSION

This study aims to test and validate our three proposed hypotheses, and the data analyzed have supported all three hypotheses. Firstly, mathematics anxiety has a negative impact on spatial reasoning. Additionally, our study's data indicates that spatial anxiety acts as a mediator in the relationship between math anxiety and spatial reasoning. Higher levels of math anxiety lead to higher spatial anxiety, which, in turn, results in lower spatial reasoning abilities.

Furthermore, our findings empirically demonstrate that the relationship between math anxiety and spatial reasoning may vary depending on the level of spatial anxiety. Mathematics anxiety appears to have a stronger effect on spatial reasoning when spatial anxiety is low or moderate, but this effect becomes less significant when spatial anxiety is high. The descriptive statistical data in this study also showed that female students' spatial reasoning plays a greater role in determining math anxiety and spatial anxiety than that of male students. Meanwhile, in terms of grade level, the level of spatial reasoning ability is comparable to math anxiety, where information is obtained that the higher the grade level, the higher the level of math anxiety.

Considering the above findings, addressing both mathematics and spatial anxiety becomes crucial for intervention, with a focus on addressing mathematics anxiety as a priority. Interventions targeted at math anxiety should also consider individuals' levels of spatial anxiety, as it can influence how math anxiety affects spatial reasoning. By addressing both types of anxiety in interventions, we can effectively support individuals in enhancing their spatial reasoning. The results of this study can serve as a reference to highlight the importance of paying attention to students' math anxiety, as it is directly related to spatial reasoning. Especially, research on math anxiety and spatial reasoning was conducted in Indonesia, where spatial anxiety has a direct relationship to math anxiety and spatial reasoning. In broader terms, this research contributes to building a more efficient and accountable education system, where both cognitive and affective aspects are integrated into teaching practices, aligning with educators' responsibility to ensure fair and effective learning.

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