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The Influence of Mathematical Representation Ability and Spatial Ability on Students' Mathematics Learning Outcomes in Terms of Gender

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ABSTRACT

This quantitative experimental study aims to examine the effect of mathematical representation ability and mathematical spatial ability on students' mathematics learning outcomes, with gender as a moderating factor. The population consisted of 74 third-semester Mathematics Education students at UIN Syekh Nurjati Cirebon during the 2024/2025 academic year. A sample of 30 students was selected using purposive sampling. Validated test instruments were used to measure mathematical representation ability, spatial ability, and learning outcomes. Data were analyzed using simple and multiple linear regression. The results show that for female students, both abilities significantly and positively influenced learning outcomes ($p < 0.05$). For male students, only mathematical spatial ability showed a significant effect ($p < 0.05$). These findings suggest that female students may be better at integrating representational and spatial skills in mathematical learning than their male counterparts.

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1. INTRODUCTION

A country's progress is heavily dependent on the quality of its human resources, which can be significantly influenced by education [1]. In the context of mathematics, one of the main factors that helps students overcome the challenges of understanding abstract and complex concepts is their mathematical abilities [2]. Two crucial skills in this regard are mathematical representation abilities and spatial abilities, which are essential in learning three-dimensional geometry [3]. These cognitive skills enable students to connect abstract mathematical concepts with real-world forms and visualize spatial relationships between objects.

Mathematical representation is a fundamental aspect of the mathematical process, recognized in global standards such as PISA [4]. This representation refers to the ability to transform and connect abstract concepts with symbols and representations that are logically structured [5], [6], [7], [8]. As a primary learning objective in the national curriculum, representation plays a key role in optimizing students' thinking abilities through abstraction and mathematical construction processes [9], [10]. The National Council of Teachers of Mathematics (NCTM) identifies three indicators of representation: using physical models to interpret problems, organizing and communicating mathematical ideas, and transforming symbols to solve mathematical problems [11]. Villegas [12] further classifies representation into verbal, graphic, and symbolic forms, all of which assist students in solving complex mathematical problems.

Spatial ability also plays an important role in understanding geometric shapes, particularly in three-dimensional geometry [13]. This ability includes aspects such as spatial perception, visualization, mental rotation, spatial relationships, and spatial orientation [14], [15]. These aspects help students visualize and manipulate objects in space, which is crucial in understanding geometric structures.

Both mathematical representation abilities and spatial abilities have been shown to enhance students' mathematics learning outcomes [16]. These learning outcomes are measured using Bloom's taxonomy, which encompasses a range of cognitive skills from remembering (C1) to problem-solving and creating solutions (C6) [17]. The integration of representation and spatial abilities has been linked to better achievement in geometry and mathematics in general.

Research also shows that gender can affect how students approach and perform mathematical tasks. Gender Cognitive Theory suggests that differences in thinking styles and cognitive skills between males and females can be influenced by biological, social, and cultural factors [18]. Some studies indicate that female students tend to excel in verbal and symbolic representation, while male students are often more skilled in spatial abilities and problem-solving involving manipulation of objects in space [19]. This aligns with the theory that gender can moderate how students utilize representation and spatial abilities in mathematics learning, leading to academic achievement differences between genders.

Therefore, this study aims to fill this gap by examining how mathematical representation abilities and spatial abilities affect students' mathematics learning outcomes, with gender as a moderating factor. The topic of spatial geometry is chosen due to its complexity, which requires the integration of both mathematical representation abilities [20] and spatial ability [21], which both play vital roles in understanding more advanced geometric concepts. The findings of this study are expected to contribute more deeply and integratively to understanding how mathematical representation, spatial abilities, gender, and learning outcomes are interrelated in the context of mathematics education.

2. METHOD

This study uses a quantitative approach with an experimental method to analyze the influence of mathematical representation ability and spatial ability on students' mathematics learning outcomes in terms of gender factors. The experimental method is defined as a research method that examines the effect of certain treatments on other variables under controlled conditions [22]. The design used is a one-group post-test only design, as this study does not include a control group.

The population in this study consists of all students of the Mathematics Education program at UIN Syekh Nurjati Cirebon for the 2024/2025 academic year, totaling 74 students. A sample of 30 third-semester students was selected based on specific criteria relevant to the research objectives. Gender in this study is operationalized based on enrollment data recorded in the academic system and confirmed by the participants' gender identity.

Figure 1. Data Collection Conducted by the Researcher in the Classroom

The research instruments include three types of tests: (1) a mathematical representation ability test consisting of 6 items based on three main indicators; (2) a spatial ability test with 10 items based on five key indicators; and (3) a mathematics learning outcomes test containing 12 items developed according to Bloom's taxonomy from levels C1 to C6. All instruments underwent a validation process, including validity, reliability, item difficulty, and discrimination index assessments. The reliability coefficient (Cronbach's Alpha) for the representation instrument is 0.65.

The collected data were analyzed using simple linear regression and multiple linear regression techniques to determine the impact of representation and spatial abilities on mathematics learning outcomes, with gender as a moderating variable. The analysis was conducted separately for male and female participants to identify differences in learning outcomes based on gender.

3. RESULTS AND DISCUSSION

3.1. Results

Before performing the simple and multiple linear regression analyses, prerequisite tests were conducted to verify that the data met the required statistical assumptions, ensuring the reliability of the analysis results. These tests checked whether the data follows

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a normal distribution and whether the variances across groups or variables are homogeneous. The normality test was carried out to confirm that the data adheres to a normal distribution, a key assumption in regression analysis. In addition, the homogeneity test was applied to check that the variances between the groups or variables being tested are consistent. Both tests are crucial for confirming the validity and accuracy of the regression analysis.

A normality test was performed to assess whether the data originates from a population with a normal distribution. The Shapiro-Wilk test was employed for this purpose, with a significance level (α) set at 0.05. The statistical hypotheses for this test are as follows:

H_0: The data is derived from a normally distributed population.
H_1: The data is not derived from a normally distributed population.

The decision rule is: H0 is accepted if the p-value is greater than or equal to 0.05, and H0 is rejected if the p-value is less than 0.05. The results of the normality test are shown in the table below.

Table 1. Normality Test

Group	Mathematical Representation Ability	Mathematical Spatial Ability	Mathematics Learning Outcomes
N	30	30	30
Shapiro-Wilk	0.000	0.135	0.077
Conclusion	Not Normal	Normal	Normal

The results of the normality test indicate that the data for mathematical representation ability has a significance value of 0.000, suggesting that it is not normally distributed. In contrast, the data for spatial ability and learning outcomes have significance values of 0.135 and 0.077, respectively, both of which are above the 0.05 threshold, implying that these datasets follow a normal distribution. Given that the dataset for representation ability is not normally distributed, a non-parametric test will be employed to analyze this specific data.

Once the data met the necessary assumptions, it was further analyzed using both simple and multiple linear regression to investigate the influence of mathematical representation ability and spatial ability on students' mathematics learning outcomes, with gender as a moderating variable. The analysis aimed to determine the degree to which each of these abilities contributes to mathematics learning outcomes. Additionally, the analysis was performed separately for male and female students to explore potential differences in the effects on each gender. This method is expected to provide a more comprehensive understanding of the varying impact of these two abilities on mathematics learning outcomes for male and female students. The results of this analysis are presented below to offer a more in-depth view of the influence of these factors.

3.1.1. The Influence of Mathematical Representation Ability on Female Students' Mathematics Learning Outcomes

Data on the mathematical representation ability of female students in the geometry course were collected through a test administered to 23 female students. This test was specifically designed to assess how well students can represent mathematical concepts using various forms, including verbal, visual, and symbolic representations. The ability to use these representations effectively is crucial for understanding and solving mathematical problems. The results from these tests were then analyzed using simple linear regression to explore the effect of mathematical representation ability on the mathematics learning outcomes of female students. By applying regression analysis, we aim to examine the strength and direction of the relationship between mathematical representation ability and learning outcomes in this group. The analysis results, including the linear regression output, ANOVA test, and regression coefficients, are presented in three tables below, illustrating the influence of mathematical representation ability on the learning outcomes of female students. These findings aim to provide a more comprehensive understanding of the various factors that influence students' learning outcomes, particularly in relation to their ability to represent mathematical concepts, which plays a significant role in enhancing students' problem-solving skills and overall success in mathematics.

Table 2. Model Summary of the Linear Regression Results for the Mathematical Representation Ability and Learning Outcomes of Female Students

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.948[a]	0.898	0.893	0.841

The correlation coefficient (R) between mathematical representation ability and learning outcomes is 0.948, indicating a very strong relationship. The R-squared value of 0.898 suggests that 89.8% of the variation in mathematical learning outcomes can be explained by mathematical representation ability. Factors outside of this model explain the remaining 10.2%.

Next, an ANOVA test was conducted to determine whether the regression model between mathematical representation ability and female students' learning outcomes was statistically significant.

Table 3. ANOVA Test Results of the Linear Regression of Representation Ability on Female Students' Mathematics Learning Outcomes

ANOVA[a]						
	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	130.973	1	130.973	185.174	0.000[b]
	Residual	14.853	21	0.707		
	Total	145.826	22			

With an F-value of 185.174 and a significance level of p = 0.000 (which is less than the threshold of 0.05), the regression model is found to be statistically significant. This indicates the presence of a linear relationship between mathematical representation ability and mathematics learning outcomes.

After confirming the statistical significance of the regression model through the ANOVA test, the next step is to examine the regression coefficients. This analysis provides insights into the extent to which mathematical representation ability influences the learning outcomes of female students.

Table 4. The Linear Regression Coefficient of Representation Ability on Female Students' Learning Outcomes

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.378	2.099		-0.656	0.519
	RA	1.978	0.145	0.948	13.608	0.000

Based on Table 4 above, the regression equation is obtained as follows:

$$Y = -1.378 + 1.978X \quad 1)$$

The constant value of -1.378 and the coefficient of the independent variable, mathematical representation ability, which is 1.978, suggest that mathematical representation ability has a positive and significant influence on the learning outcomes of female students. This indicates that as mathematical representation ability improves, the mathematics learning outcomes of female students also tend to increase, highlighting the importance of developing this ability in enhancing academic performance.

3.1.2. The Influence of Mathematical Spatial Ability on Female Students' Mathematics Learning Outcomes

After examining the influence of mathematical representation ability on students' mathematics learning outcomes, data on the mathematical spatial ability of 23 female students in the spatial geometry course were analyzed using linear regression to assess its impact on their mathematics learning outcomes. The analysis aimed to determine how mathematical spatial ability affects the overall academic performance of these students in the course. In addition, the regression model provided insight into the strength and direction of this relationship. Below are three tables that present the results of the linear regression analysis, the ANOVA test, and the regression coefficients, all of which provide a detailed overview of the influence of mathematical spatial ability on the learning outcomes of female students.

Table 5. Model Summary of the Linear Regression Results for the Mathematical Spatial Ability and Learning Outcomes of Female Students

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.937[a]	0.878	0.872	0.921

An R value of 0.937 reflects a very strong correlation, while the R-squared value of 0.878 indicates that 87.8% of the variation in mathematics learning outcomes can be accounted for by mathematical spatial ability. The remaining 12.2% of the variation is attributed to factors not included in this model.

Next, an ANOVA test was conducted to determine whether the regression model between mathematical spatial ability and female students' learning outcomes was statistically significant.

Table 6. ANOVA Test Results of the Linear Regression of Spatial Ability on Female Students' Mathematics Learning Outcomes

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	128.008	1	128.008	150.867	0.000[b]
	Residual	17.818	21	0.848		
	Total	145.826	22			

The F value of 150.867, with a significance level of p = 0.000 (which is below the threshold of 0.05), shows that the regression model is statistically significant. This indicates the existence of a linear relationship between mathematical spatial ability and the mathematics learning outcomes of female students.

After confirming the statistical significance of the regression model through the ANOVA test, the next step is to examine the regression coefficients. This analysis provides insights into the extent to which mathematical spatial ability influences the learning outcomes of female students.

Table 7. The Linear Regression Coefficient of Spatial Ability on Female Students' Learning Outcomes

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.889	2.060		0.917	0.370
	SA	1.008	0.082	0.937	1.283	0.000

Based on Table 7 above, the regression equation is obtained as follows:

$$Y = 1.889 + 1.008X \quad 2)$$

The constant value of 1.889 and the coefficient of the independent variable, spatial ability, which is 1.008, suggest that mathematical spatial ability positively and significantly influences the mathematics learning outcomes of female students. This indicates that as spatial ability increases, the mathematics learning outcomes of female students tend to improve accordingly.

3.1.3. The Influence of Mathematical Representation Ability and Mathematical Spatial Ability on Female Students' Mathematics Learning Outcomes

After evaluating the individual impacts of mathematical representation ability and mathematical spatial ability on the mathematics learning outcomes of female students, a multiple linear regression analysis was performed to investigate the combined effect of both variables. This analysis was designed to explore whether these two abilities, when considered together, have a significant contribution to students' mathematics learning outcomes. By conducting a multiple linear regression analysis, the study aims to gain a more comprehensive understanding of how the integration of mathematical representation and spatial abilities influences students' performance in mathematics. This approach is expected to offer valuable insights into the interaction of these two abilities and their collective impact on female students' learning outcomes in the subject. The findings of this analysis will clarify the simultaneous influence of these variables, providing a more nuanced understanding of their role in shaping the mathematics learning outcomes of female students.

To investigate the joint effects of mathematical representation ability and mathematical spatial ability on the mathematics learning outcomes of female students, a multiple linear regression analysis was performed. This method was chosen to provide a clearer understanding of how these abilities collectively contribute to the outcomes of the students. In addition to the regression analysis, an ANOVA test was conducted to assess the overall significance of the regression model and determine whether the model's findings are statistically robust. The following tables present the key findings from the regression analysis, including the ANOVA test results and the regression coefficients, to provide a comprehensive picture of how these two abilities impact female students' mathematics performance.

Table 8. ANOVA Test Results of the Multiple Linear Regression of Mathematical Representation Ability and Mathematical Spatial Ability on Female Students' Mathematics Learning Outcomes

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	137.995	2	68.997	176.213	0.000[b]
	Residual	7.831	20	0.392		
	Total	145.826	22			

The F value of 176.213 and the p-value of 0.000 indicate that the overall regression model is statistically significant. Therefore, both independent variables, Mathematical

Representation Ability and Mathematical Spatial Ability, jointly explain the variation in mathematics learning outcomes.

To further understand the contribution of each independent variable, the regression coefficients of mathematical representation ability and mathematical spatial ability on female students' mathematics learning outcomes were analyzed. The following table presents the regression coefficients and their interpretation, which highlights the influence of both variables on learning outcomes.

Table 9. The Multiple Linear Regression Coefficients of Mathematical Representation Ability and Mathematical Spatial Ability on Female Students' Mathematics Learning Outcomes

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.623	1.563		-1.038	0.311
	RA	1.139	0.226	0.546	5.050	0.000
	SA	0.492	0.116	0.458	4.235	0.000

Based on Table 9 above, the regression equation is obtained as follows:

$$Y = -1.623 + 1.139X_1 + 0.492X_2 \quad 3)$$

The constant value of -1.623, along with the coefficients for the independent variables' mathematical representation ability (1.139) and mathematical spatial ability (0.492), indicates that both mathematical representation ability and mathematical spatial ability have a positive and significant effect on the mathematics learning outcomes of female students.

3.1.4. The Influence of Mathematical Representation Ability on Male Students' Mathematics Learning Outcomes

In order to assess the impact of mathematical representation ability on the mathematics learning outcomes of male students, a similar analysis was performed to that conducted for female students. This analysis specifically focused on a sample of 7 male students, selected to explore the influence of mathematical representation ability on their academic performance in mathematics. By examining this relationship, the study aimed to identify how effectively mathematical representation ability contributes to the learning outcomes of male students. The results of this analysis are presented in the subsequent tables, which include the linear regression analysis, ANOVA test, and regression coefficients. These results offer valuable insights into the significant role that mathematical representation ability plays in shaping the mathematics learning achievements of male students. The findings highlight not only the overall influence but also any potential differences compared to female students.

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Table 10. Model Summary of the Linear Regression Results for the Mathematical Representation Ability and Learning Outcomes of Male Students

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.078[a]	0.006	-0.193	2.395

The R value of 0.078 suggests a very weak correlation between mathematical representation ability and mathematics learning outcomes. In addition, the R-squared value of 0.006 shows that only 0.6% of the variation in learning outcomes can be attributed to mathematical representation ability, with the remaining 99.4% influenced by other factors not included in this model.

Next, an ANOVA test was conducted to determine whether the regression model between mathematical representation ability and male students' learning outcomes was statistically significant.

Table 11. ANOVA Test Results of the Linear Regression of Representation Ability on Male Students' Mathematics Learning Outcomes

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.174	1	0.174	0.030	0.868[b]
	Residual	28.683	5	5.737		
	Total	28.857	6			

The F-value of 0.030, with a significance level of p = 0.868 (which is greater than 0.05), indicates that the regression model does not reach statistical significance. This suggests that there is insufficient evidence to support a linear relationship between mathematical representation ability and mathematics learning outcomes among male students.

Although the ANOVA test indicated that the regression model was statistically insignificant, an analysis of the regression coefficients was still performed. This follow-up analysis seeks to offer a deeper understanding of the connection between mathematical representation ability and the mathematics learning outcomes of male students, even though the model does not demonstrate statistical significance.

Table 12. The Linear Regression Coefficient of Representation Ability on Male Students' Learning Outcomes

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	30.634	10.237		2.992	0.030
	RA	-0.122	0.700	-0.078	-0.174	0.868

Based on Table 12 above, the regression equation is obtained as follows:

$$Y = 30.634 – 0.122X \quad 4)$$

The constant of 30.634 and the regression coefficient of –0.122 suggest that mathematical representation ability does not significantly contribute to predicting the mathematics learning outcomes of male students.

3.1.5. The Influence of Mathematical Spatial Ability on Male Students' Mathematics Learning Outcomes

After analyzing the impact of mathematical representation ability, data on male students' spatial mathematical ability were subjected to linear regression analysis to evaluate how this factor influences their mathematics learning outcomes, similar to the analysis conducted for female students. The findings from this linear regression analysis, including the ANOVA test and regression coefficients, will be discussed in detail to understand the degree of influence spatial geometry ability has on the mathematics learning outcomes of male students. These results will be presented in tables, highlighting the relationship between the two variables.

Table 13. Model Summary of the Linear Regression Results for the Mathematical Spatial Ability and Learning Outcomes of Male Students

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.814[a]	0.662	0.595	1.396

The R-value of 0.814 indicates a very strong correlation between mathematical spatial ability and mathematics learning outcomes. Furthermore, the R-squared value of 0.662 suggests that approximately 66.2% of the variation in students' mathematics learning outcomes can be attributed to mathematical spatial ability. This means that this ability explains a significant portion of the variation in learning outcomes, while the remaining 33.8% is influenced by other factors that are not captured in this model.

Next, an ANOVA test was conducted to determine whether the regression model between mathematical spatial ability and male students' learning outcomes was statistically significant.

Table 14. ANOVA Test Results of the Linear Regression of Spatial Ability on Male Students' Mathematics Learning Outcomes

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.110	1	19.110	9.802	0.026[b]
	Residual	9.748	5	1.950		
	Total	28.857	6			

The F value of 9.802 with a significance of p=0.0026 (p<0.05) indicates that the relationship between the variables is statistically significant. This means there is a linear relationship between mathematical spatial ability and the mathematics learning outcomes of male students.

After confirming the statistical significance of the regression model through the ANOVA test, the next step is to examine the regression coefficients. This analysis provides insights into the extent to which mathematical spatial ability influences the learning outcomes of male students.

Table 15. The Linear Regression Coefficient of Spatial Ability on Male Students' Learning Outcomes

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.330	6.896		1.063	0.336
	SA	0.806	0.257	0.814	3.131	0.026

Based on Table 15 above, the regression equation is obtained as follows:

$$Y = 7.330 + 0.806X \quad 5)$$

The constant value of 7.330 and the coefficient of 0.806 indicate that mathematical spatial ability has a positive and significant effect on the mathematics learning outcomes of male students.

3.1.6. The Influence of Mathematical Representation Ability and Mathematical Spatial Ability on Male Students' Mathematics Learning Outcomes

After evaluating the individual impacts of mathematical representation ability and mathematical spatial ability on the mathematics learning outcomes of male students, a multiple linear regression analysis was carried out to examine how these two variables, when considered together, affect the learning outcomes, this analysis aims to determine whether the combined influence of both abilities contributes significantly to male students' performance in mathematics.

To assess the overall contribution of both variables, an ANOVA test was conducted to determine if the multiple regression model is statistically significant. The results of this analysis are presented in the following table, which illustrates the relationship between the variables and their collective impact on mathematics learning outcomes for male students.

Table 16. Table 8. ANOVA Test Results of the Multiple Linear Regression of Mathematical Representation Ability and Mathematical Spatial Ability on Male Students' Mathematics Learning Outcomes

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.971	2	9.985	4.495	0.095[b]
	Residual	8.886	4	2.222		
	Total	28.857	6			

The F-value of 4.495 and a p-value of 0.095 suggest that the regression model does not achieve statistical significance. This indicates that the combined influence of the two independent variables, mathematical representation ability and spatial ability, does not significantly account for the variation in mathematics learning outcomes.

Although the ANOVA test showed that the regression model did not reach statistical significance, further analysis was conducted on the regression coefficients to evaluate the individual contributions of each independent variable. This examination is important as it allows for a deeper understanding of the role that mathematical representation ability and spatial ability play in influencing male students' mathematics learning outcomes, even if their combined effect does not reach statistical significance. The table below displays the regression coefficients, followed by an interpretation of each, highlighting their potential impact on the learning outcomes.

Table 17. The Multiple Linear Regression Coefficients of Mathematical Representation Ability and Mathematical Spatial Ability on Male Students' Mathematics Learning Outcomes

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10,777	9,210		1,170	0,307
	RA	-0,273	0,438	-0,174	-0,623	0,567
	SA	0,826	0,277	0,834	2,985	0,041

Based on Table 17 above, the regression equation is obtained as follows:

$$Y = 10.777 - 0.273X_1 + 0.826X_2 \qquad 6)$$

The constant of 10.777, combined with the coefficient of -0.273 for mathematical representation ability, suggests that this variable does not have a substantial effect on the mathematics learning outcomes of male students. In contrast, mathematical spatial ability, with a coefficient of 0.826, shows a significant positive impact on students' learning outcomes. This highlights the importance of spatial ability in influencing male students' performance in mathematics, while mathematical representation ability appears to have a lesser contribution.

3.2. Discussion

This study investigates how mathematical representation ability and spatial ability affect students' mathematics learning outcomes, with a focus on gender differences. The linear regression analysis produced two models that illustrate the relationship between the two independent variables and the mathematics learning outcomes of both female and male students. For female students, the regression model as in equation 3, namely:

$$Y = -1.623 + 1.139X_1 + 0.492X_2$$

The model indicates that the constant value of −1.623 represents the mathematics learning outcome of female students when both mathematical representation ability and

spatial ability are equal to zero. The coefficient for mathematical representation ability is 1.139, indicating that a one-unit increase in this ability is associated with an increase of 1.139 units in mathematics learning outcomes. Meanwhile, the coefficient for spatial ability is 0.492, suggesting that a one-unit increase in spatial ability leads to a 0.492-unit increase in mathematics learning outcomes. The positive coefficients for both variables indicate that mathematical representation ability and spatial ability have a positive and significant influence on the mathematics learning outcomes of female students.
For male students, the resulting regression model as in equation 6, i.e.:

$$Y = 10.777 - 0.273X_1 + 0.826X_2$$

This model shows that the constant value of 10.777 represents the mathematics learning outcome of male students when both mathematical representation ability and spatial ability are equal to zero. The coefficient for mathematical representation ability is −0.273, indicating that a one-unit increase in this ability is associated with a 0.273-unit decrease in mathematics learning outcomes; however, this relationship is not statistically significant. In contrast, the coefficient for spatial ability is 0.826, suggesting that a one-unit increase in spatial ability significantly increases mathematics learning outcomes by 0.826 units.

A comparison of the two regression models reveals a significant difference between female and male students. For female students, mathematical representation ability has a greater influence (B = 1.139) than spatial ability (B = 0.492), and both variables are statistically significant. In contrast, for male students, spatial ability (B = 0.826) significantly influences mathematics learning outcomes, while mathematical representation ability (B = −0.273) is not statistically significant.

The regression analysis indicates that female students have a stronger mathematical representation ability, which significantly influences their mathematics learning outcomes more than it does for male students. This finding contrasts with the research by Ina et al. [23], which suggests that male students outperform female students in mathematical representation ability. On the other hand, male students demonstrate superior mathematical spatial ability, which plays a significant role in their mathematics learning outcomes. This observation aligns with the findings of Ismi et al. [24] and Alimuddin et al. [25], who found that male students tend to have higher mathematical spatial ability than female students.

4. CONCLUSION

The findings from the linear regression analysis reveal that for female students, both mathematical representation and spatial abilities significantly and positively influence mathematics learning outcomes. In contrast, for male students, only spatial ability has a significant impact, while mathematical representation ability does not show a significant effect. This suggests that female students benefit from the synergy of both abilities, whereas male students predominantly depend on spatial ability to achieve better mathematics learning outcomes.

These results underscore the need to implement teaching strategies that acknowledge the cognitive strengths associated with gender differences. In practice, instructors can use differentiated teaching approaches, such as focusing on enhancing representation skills for male students or incorporating spatial activities into geometry lessons for all students.

This research has its limitations, especially the small sample size for male students (n = 7), which may influence the statistical power and the broader applicability of the results. As such, the findings should be interpreted cautiously.

For future studies, it would be beneficial to adopt longitudinal research designs, use larger and more balanced gender samples, and consider intervention-based approaches that focus on enhancing representation or spatial skills. This research is expected to contribute to developing more inclusive teaching strategies in mathematics that can better address cognitive differences across students.

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