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THE RELATIONSHIP BETWEEN MATHEMATICAL EXPLORATION ABILITY AND STUDENTS MATHEMATICAL PROBLEM SOLVING ABILITY USING K-MEANS CLUSTERING

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ABSTRACT

Given the significance of mathematical exploration and problem-solving skills in students' learning, this research aims to examine the relationship between these two abilities and their mutual influence. By utilizing the K-Means clustering method, this study provides a systematic analysis of students' competencies while offering valuable insights for educators to design more effective and tailored learning experiences based on individual student needs. This study seeks to categorize students' abilities into different levels based on various characteristics. The research population consists of grade IX students from SMP Negeri 1 Klari Karawang during the 2024/2025 academic year, totaling 440 students across 11 classes. A simple random sampling technique was applied, selecting 25% of the total population, resulting in a research sample of 110 students. This quantitative study employs the K-Means clustering method, analyzed through manual calculations. The research instrument consists of descriptive test questions designed to measure both mathematical exploration and problem-solving abilities based on relevant indicators. The sampled students are classified into three clusters using K-Means clustering: cluster 1 represents high-ability students, cluster 2 indicates medium-ability students, and cluster 3 corresponds to low-ability students. The clustering results reveal that cluster 1 includes 45 students, cluster 2 comprises 49 students and cluster 3 consists of 16 students. These findings suggest that the majority of students at SMP Negeri 1 Klari Karawang fall into the medium ability category for both mathematical exploration and problem-solving skills.

Keywords: exploration ability; k-means clustering; problem solving.

ABSTRAK

Mengingat pentingnya kemampuan eksplorasi matematis dan pemecahan masalah matematis bagi siswa, penelitian ini berkontribusi untuk memahami bagaimana kedua kemampuan tersebut saling terkait dan mempengaruhi satu sama lain. Dengan menerapkan metode K-Means clustering, penelitian ini tidak hanya menawarkan analisis yang sistematis mengenai kemampuan siswa, tetapi juga memberikan wawasan yang berharga bagi pendidik dalam menciptakan pembelajaran yang lebih efektif dan terarah sesuai dengan kebutuhan individu siswa. Penelitian ini bermaksud mengkategorikan tingkat kemampuan yang berbeda berdasarkan sejumlah karakteristik yang berbeda. Siswa SMP Negeri 1 Klari Karawang pada tahun ajaran 2024/2025 yang terdaftar di kelas IX termasuk dalam populasi penelitian ini, dengan total 440 siswa dari 11 kelas. Sampel penelitian dipilih menggunakan teknik simple random sampling, yaitu 25% dari total populasi, sehingga diperoleh sebanyak 110 siswa. Penelitian ini bersifat kuantitatif dengan metode K-Means clustering, yang dianalisis dengan perhitungan manual. Instrumen penelitian berupa tes soal uraian yang telah dirancang guna mengukur kemampuan eksplorasi matematis dengan kemampuan pemecahan masalah matematis, berdasarkan indikator-indikator terkait. Sampel penelitian ini dikelompokkan menjadi tiga klaster menggunakan metode K-Means clustering, yaitu klaster 1 untuk kotegori kemampuan tinggi, klaster 2 untuk kategori kemampuan sedang, dan klaster 3 untuk kategori kemampuan rendah. Hasil klasterisasi menunjukkan bahwa klaster 1 terdiri dari 45 siswa, klaster 2

berisi 49 siswa, dan klaster 3 mencakup 16 siswa. Temuan ini menunjukkan bahwa tingkat kemampuan kedua variabel pada siswa di SMP Negeri 1 Klari Karawang sebagian besar berada pada kategori sedang.
Kata kunci*: eksplorasi matematis; k-means clustering; pemecahan masalah. (10pt)*

Introduction

Mathematics is a comprehensive science that provides the foundation for the development of modern technology, plays important contributions in various fields, and enhances human thinking abilities (Purba, et al. 2024). The advances in information & communication technology that were highly advanced during this period were supported by advances in various branches of mathematics, such as algebra, number theory, discrete mathematics, and probability theory (Romadhoni & Hasanudin 2023). That is why a deep understanding of mathematics from an early age is essential for future technological development. Mathematics is a learning that must be introduced to students from elementary school, especially because it helps children develop their ability to think logically, analytically, methodically, critically, and creatively, and build cooperative skills (Nabilah et al., 2024). Therefore, a deep understanding of mathematics from an early age is crucial for students. In solving mathematical problems that mostly involve numbers, the ability to count becomes very important. Therefore, numerical ability is indispensable in mathematics learning, especially in solving problems (Zaini & Sutirna 2021).

An important aspect of learning mathematics is mathematical exploration ability, it is an ability where students can explore mathematical concepts and ideas in depth (Nurbaya & Warmi 2021). Exploration in learning is an activity where students can gain new knowledge and experience in every condition they face. The direction of this exploration activity is to involve students deeply in the problem solving process (Susilawati, et al., 2017). In this activity, students play a leading actor in finding knowledge, while teachers serve as facilitators during the learning process. One of the many thinking abilities students need to master to support their development in the field of mathematics is mathematical exploration capabilities (Wahyuni & Alfiana 2022). Students' ability to explore during mathematical learning is known as mathematical exploration ability. Therefore, students need to master this ability to achieve critical thinking ability in mathematics (Rahman & Lestari 2024).

Students' mathematical exploration abilities appear when they solve mathematical problems. According to (Lestari & Yudhanegara 2017) mathematical exploration ability is the ability to deepen various things, including concepts that have been studied by students, so that they can be developed after a problem. In the exploration process, students are faced with rules that must be controlled, and can then be further developed as they face more complex problems that are related to the previous rules. Thus, mathematical exploration capabilities can be formed if students are consistently encouraged to explore many concepts or rules, solve problems, think creatively, and communicate their findings.

According to Susanto, problem solving can be interpreted as a process in which students apply prior knowledge in new situations (Setiawan, 2021). It is mentioned

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by (Rohaeti et al., 2017) that the Capacity to solve math problems is an important skill that means a lot to students studying math. They noted that these skills not only support mathematical learning but also have relevance to other subjects and their application in daily life. Soedjadi also stressed that students need to have skills in developing and using mathematics to solve problems (Agusta, 2020). As these quotations have stated, the relationship between mathematical exploration ability and mathematical problem solving is important. When students have good exploration skills, they are better able to recognize different approaches to solving math problems, as well as being more creative in finding solutions, by improving exploration skills, students can also improve their problem-solving skills. Which is not only useful in mathematics studies but also relevant in other subjects and everyday life (Azhar et al., 2021).

However, students' mathematical exploration skills are still relatively low because based on the results of observations made by researchers, it often occurs in the field that many students have difficulty solving mathematical problems. This is often due to a lack of mathematical exploration skills that are not good enough to be used are presented in Figure 2.

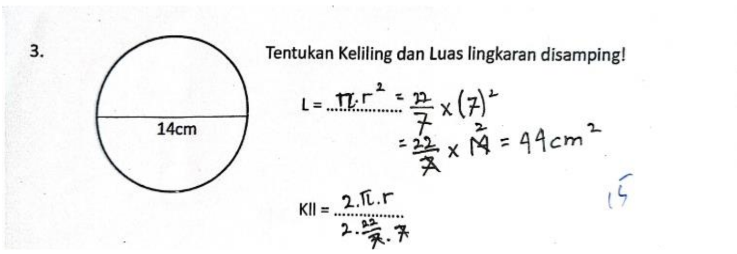

Figure 1. The Results of Student Observation

Based on Figure 3, it seems that the student did not understand the rank number which is one of the indicators of mathematical exploration ability, namely affirming the steps on problem resolution, thus impacting problem solving on flat building materials. Thus, it can be concluded that poor exploration capabilities will have an impact on the lack of mathematical problem-solving capabilities.

To analyze students' mathematical exploration capabilities, the approach to clustering methods, especially K-Means, is an interesting choice. This method allows the grouping of students by their level of exploration and problem-solving skills, thus facilitating the identification of appropriate learning strategies (Dwitasari and Yudhanegara 2024). Using K-Means clustering, educators can get a clearer picture of how students interact with mathematical concepts, as well as determine appropriate interventions based on the characteristics of different student groups (Sarwani and Sani 2018).

Aditya et al, explained that clustering is a way of grouping data into data groups that have a high degree of similarity, thus ensuring that the data in the collection have the highest and lowest degree of similarity (Aditya, Jovian, and Sari 2020). In addition, clustering can also be defined as data segmentation methods used in a variety of industries, including marketing, modeling analysis, and other fields. K-Means is one of the many clustering methods used in data mining. Grouping

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by this method is based on the proximity of data to the cluster's central point (centroid). The main goal is to improve data similarity in one cluster while reducing data similarity between different clusters (Sarwani and Sani 2018). K-means is an algorithm that maps data into different groups (Saputra and Nataliani 2021).

Therefore, this study aims to analyze students' mathematical exploration capabilities through a clustering approach using the K-Means algorithm, to find out the variability of students' abilities and their implications for mathematical learning.

Research Methods

In line with Arikunto's view (2010) when the number of research subjects is below 100, the recommended approach is to collect as many samples as possible. Conversely, for a larger number of subjects, it is generally agreed that a sample of 10-15%, which is equivalent to 20-25% of the total population, is appropriate. More than a hundred individuals accounted for an adequate proportion of samples (2010 Arikunto). All 440 students in the 9th grade of SMP Negeri 1 Klari, divided into 11 classes, became the population in this study. The direct random selection technique is used to select a research sample, a form of random sampling that does not pay attention to the stratification of the population, so that each individual in the population has an equal chance of being selected as a sample (Firmansyah 2022). Through this method, 25% of the population was selected as samples, resulting in a total of 110 students. This study used a quantitative approach and a method of K-means clustering.

The test instrument consists of several problems of the description that have been adjusted to each indicator in each capability, and the resulting data undergoes a quantitative analysis. Quantitative data facilitate the grouping and checking of correlations between the two variables in question. To measure mathematical exploration capabilities, some of the indicators used include: 1) can understand problems, 2) identify patterns, 3) conduct non-formal exploration, 4) affirm problem-solving steps, and 5) using symbolization (Nurbaya and Warmi 2021). Meanwhile, mathematical problem solving ability assessments include indicators such as 1) problem identification, 2) formulating strategies, 3) implementing strategies, and 4) solution verification (Chabibah, Siswanah, and Tsani 2019). It is in line with (Ningrum, Maulindar, and Farida 2023) that the exploration and problem solving test results will be scored first according to the criteria created, then the score data will be input for the K-Means grouping.

The K-means clustering method is used in the data analysis stage to categorize participants into three levels based on their low, medium, and high capabilities (Elda et al. and Elda et al.) 2021). This analysis is facilitated by using Microsoft excel and with the help of SPSS Software. The stages of the K-means clustering analysis in this study can be sorted as follows (Yudhanegara et al. 2022)

$$J\,(U,C) = \sum_{t=1}^{k}\sum_{i=1}^{n}\sum_{j=1}^{m} u_{i,l}\; d\big(x_{i,j}\,, c_{l.j}\big), \qquad (1)$$

with Description:

- $J(U,C)$ is the destination function that wants to be minimized,
- U is a partition matrix that represents the membership of each datastore within a cluster.

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- $u_{i,l}$ is a variable indicating whether the data points *i* belong to the *l* cluster
- C is the centroid for each cluster
- k is the number of clusters
- n is the number of data points
- m is the variable used
- $d(x_{i,j}, c_{l,j})$ is the distance between the data points *i* in the *j* characteristic and the cluster centroid in the same characteristic.

By rule:

$$\sum_{l=1}^{k} u_{i,l} = 1, untuk\ 1 \leq i \leq n, \quad (2)$$

The equation states that for each data point, the number of memberships to all clusters l must equal 1. This means that each data point can only be a member of 1 cluster. Here are further steps:

1. Specify cluster to create the first
2. Randomly selects the centroid in each cluster as the starting point
3. Measure the gap between points in the dataset and each centroid using the formula:
$$d^2(x_{i,j}, c_{l,j}) = \sum_{j=1}^{m} (x_{i,j} - c_{l,j})^2, \quad (3)$$
4. Set the cluster for each data point by assigning each data point to the nearest centroid.
5. Continue updating the centroid in each cluster by measuring the average of all data points in each cluster with the following formula:
$$c_{i,j} = \frac{\sum_{j=1}^{m} u_{i,l}\, x_{i,l}}{\sum_{i=1}^{n} u_{i,l}}, untuk\ 1 \leq l \leq k\ dan\ 1 \leq j \leq m, \quad (4)$$
6. Repeat Steps 1-5 onwards until the number of members of each cluster remains unchanged.

If there are 3 clusters (low, medium, high), then the scores of student test results will be grouped according to the proximity of scores to the centroid of each cluster. After clustering using the K-means clustering method, it will then be tested with the Spearman rank correlation test formula and the t-test on the data of all samples and data in clusters 1,2 and 3. For the Spearman rank correlation test formula used if the same scores are obtained are:

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum di^2}{2\sqrt{\sum x^2 \sum y^2}}, \quad (5)$$

with:

$$\sum x^2 = \frac{N^3 - N}{12} - \sum Tx,$$

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$$\sum y^2 = \frac{N^3 - N}{12} - \sum Ty,$$

$$\sum Tx = \sum Ty = \frac{t^3 - t}{12}.$$

Description:
N = amount of data
t = much of the same data

The strength of the relationship between the two variables examined can be analyzed through the guidelines of the table of interpretation of the correlation coefficients described by (Sugiyono 2022) in Table 1.

Table 1. Interpretation of the correlation coefficient

Interpretation of Coefficients	
Interval	**Relationship Strength**
0,00-0,19	Very weak
0,20-0,39	Weak
0,40-0,59	Moderate
0,60-0,79	Strong
0,80-1,000	Very strong

Table 1 illustrates that if we assume a positive or one-way correlation between the two variables in question, then the improvement in mathematical exploration ability is compatible with the improvement in mathematical problem solving ability, and vice versa. Conversely, if the relationship is negative, the improvement of mathematical exploration ability corresponds to the decrease in mathematical problem-solving ability, and vice versa.

Once a correlation coefficient value is obtained, the next step is to calculate the t_{count} value used to determine the intercluster capability relationship, which will then be compared to the t_{table} value to obtain a decision on the hypothesis. The statistical formula of the test according to (McClenaghan 2024) the 95% confidence level is

$$t = r_s\sqrt{n - 1}, \quad (6)$$

with:
t = t_{count}
r_s = correlation coefficient
n = number of sample

For the test criteria is If $t_{hitung} > t_{tabel}$ then H_0 rejected, and if $t_{hitung} \leq t_{tabel}$ then H_0 not rejected. The conclusion of the hypothesis used for the Rank Spearman correlation test is

H_0 : $\rho = 0$, there is no significant relationship between mathematical exploration ability and mathematical problem-solving ability.

H_1 : $\rho \neq 0$, there is a significant relationship between mathematical exploration ability and mathematical problem-solving ability.

Thereafter, a search for the coefficient of determination will be conducted to see how strongly mathematical exploration ability affects mathematical problem solving ability, calculated by the formula.

$$D = r_s^2 \times 100\%, \quad (7)$$

Results and Discussion

Following the steps of K-Means established in the research methodology, researchers randomly selected the initial centroid, the following are the selected initial centroid are presented in Table 2.

Table 2. Initial cluster

	Cluster		
	1	**2**	**3**
KEM	97	55	45
KPM	98	92	50

Description:
KEM = Mathematical Exploration Ability
KPM = Mathematical Problem Solving Ability

Table 2 presents preliminary centroid data taken randomly on variables of mathematical exploration and mathematical problem solving capabilities, which will be used in the initial clustering process before iteration. This data center serves as the basis for the formation of 3 clusters. The results of the table analysis show that Cluster 1 represents a high level of capability, Cluster 2 represents a moderate level of capability, and Cluster 3 represents a low level of capability. After calculating the distance between points in the data and each centroid, determine the cluster for each data point by assigning each point in the data to the nearest centroid, then update the centroid in each cluster by calculating the average of all points, continuously until the number of cluster members does not change, a total of 10 iterations were recorded. In the initial 9 iterations, the centers appeared insignificant. As a result, all clusters are successfully formed, ending iterations at the tenth stage with the final centroid result as follows Table 3.

Table 4. Final centroid

	Cluster		
	1	**2**	**3**
KEM	92	75	56
KPM	90	84	72

Description:
KEM = Mathematical Exploration Ability
KPM = Mathematical Troubleshooting Capabilities

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The results from Table 3 show that Cluster 1 reflects a high level of ability, consisting of 45 students. Cluster 2 with a moderate level of ability, includes 49 students, while Cluster 3 with a low level of ability, consists of 16 students.

Spearman rank test results throughout the sample

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum di^2}{2\sqrt{\sum x^2 \sum y^2}} = \frac{109611+108589,5-101358,6}{2\sqrt{(109611)(108589,5)}} = 0,535 \quad (8)$$

Using the calculation of Spearman rank correlation test formula used if there are similar scores, 0.535. The result of calculating the coefficient of determination explains that there is an effect of mathematical exploration ability on the mathematical problem-solving ability of 28.62% and vice versa. Meanwhile, the remaining 71.38% are affected by other factors outside of these two abilities. Referring to the table of interpretations of correlation coefficients by (Sugiyono 2022), the correlation between mathematical exploration ability and mathematical problem solving ability exists at intervals of values 0,40–0,59. That is, the strength of the relationship between the two abilities is moderate.

Cluster 1 Spearman Rank Test Results

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum di^2}{2\sqrt{\sum x^2 \sum y^2}} = \frac{7040,5+7338-14326,5}{2\sqrt{(7040,5)(7338)}} = 0,003 \quad (9)$$

By using the calculation of the Spearman rank correlation test formula used if there are similar scores in the sample in cluster 1, 0.003 is obtained. Refers to the table of interpretations of correlation coefficients by (Sugiyono 2022). The correlation between mathematical exploration ability and mathematical problem solving ability is at intervals of values 0,00–0,19. That is, the correlation strength between the two capabilities in cluster 1 is very low.

Cluster 2 Spearman Rank Test Results

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum di^2}{2\sqrt{\sum x^2 \sum y^2}} = \frac{9109+9420-19515}{2\sqrt{(9109)(9420)}} = -0,053 \quad (10)$$

Using the calculation of the Spearman rank correlation test formula is used if there are similar scores in the sample in cluster 2, a value of -0,053. Referring to the table of interpretations of correlation coefficients by (Sugiyono 2022). The correlation between mathematical exploration capabilities and mathematical problem solving capabilities is not at the table's susceptibility. That is, the strength of the correlation between the two capabilities in cluster 2 is that there is no correlation.

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Cluster 3 Spearman Rank Test Results

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum di^2}{2\sqrt{\sum x^2 \sum y^2}} = \frac{317{,}5 + 324{,}5 - 551}{2\sqrt{(317{,}5)(324{,}5)}} = 0{,}141 \qquad (11)$$

Using the calculation of the Spearman rank correlation test formula used if there are similar scores in the sample in cluster 3, a value of 0,141. Referring to the table of interpretations of correlation coefficients by (Sugiyono 2022), the correlation between mathematical exploration ability and mathematical problem solving ability is at a susceptibility of 0,00–0,19. That is, the correlation strength between the two capabilities in cluster 3 is very low.

Once a correlation coefficient value is obtained, the next step is to calculate the t_{count} value which will then be compared to the t_{table} value to obtain a decision on the hypothesis. Test T calculations were performed for all samples and clusters 1, 2 and 3.

T-test results throughout the sample

A correlation coefficient value of 0,535 was found based on the calculation of the correlation analysis between mathematical exploration ability and mathematical problem-solving ability in the entire sample. Next the count value is obtained

$$t = r_s\sqrt{n-1} = 0{,}535\sqrt{110-1} = 5{,}5855. \qquad (12)$$

Because the t_{count} value is 5.5855 > t_{table} 1,982173, so based on the test criteria, H_0 is rejected. It can be concluded that there is a significant relationship between mathematical exploration ability and mathematical problem-solving ability.

Cluster 1

A correlation coefficient value of 0,003 was found based on the calculation of the correlation analysis between mathematical exploration ability and mathematical problem solving ability in cluster 1. Next the count value is obtained

$$t = r_s\sqrt{n-1} = 0{,}003\sqrt{45-1} = 0{,}01989. \qquad (13)$$

Because the t_{count} value is 0,089 < t_{table} 2,016692, so based on the test criteria, H_0 is not rejected. It can be concluded that there is no significant relationship between mathematical exploration ability and mathematical problem-solving ability.

Cluster 2

A correlation coefficient value of -0.053 was found based on the calculation results of the relationship between mathematical exploration ability and mathematical problem solving ability in cluster 2. Next the count value is obtained

$$t = r_s\sqrt{n-1} = -0{,}053\sqrt{49-1} = -0{,}3671. \qquad (14)$$

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Due to the count value of -0.3671 < t_{table} 2.011741, so based on the test criteria, H_0 was not rejected. It can be concluded that there is no significant relationship between mathematical exploration ability and mathematical problem-solving ability.

Cluster 3

A correlation coefficient value of 0.141 was found based on the calculation of the correlation analysis between mathematical exploration ability and mathematical problem solving ability in cluster 3. Next the count value is obtained

$$t = r_s\sqrt{n-1} = 0{,}141\,\sqrt{16-1} = 0{,}5460. \tag{15}$$

Because of the count value 0.5460 < t_{table} 2.144787, H_0 is not rejected based on the test criteria. It can be concluded that there is no significant relationship between mathematical exploration ability and mathematical problem-solving ability.

Although the relationship between the two capabilities is significant overall, the significance of the relationship between mathematical exploration capabilities and mathematical problem-solving capabilities, when analyzed by clusters, can be due to several factors. First, the variations in the level of ability of students in each high, medium, and low cluster cause differences in how they relate the two abilities. In addition, smaller sample sizes in the cluster can make the analysis results unstable. Different learning contexts also play a role, such as the teaching methods applied or the support students receive. Finally, other factors that affect the two, such as student motivation, can function differently in each cluster, thus blurring relationships. Further research is needed to understand these dynamics and identify the factors that impact the difference between the overall and cluster analysis.

This study is in line with a study conducted by Rahman & Lestari (2024) that also emphasizes the importance of mathematical exploration ability in achieving critical problem solving in mathematics. This finding is consistent with Lestari & Yudhanegara's 2015 study, which suggests that mathematical exploration contributes to a deeper understanding of concepts. However, unlike previous studies that emphasized significant relationships among all population members, this study found different results among clusters, suggesting that there needs to be a more specific and segmented approach to teaching.

The results of this study contributed significantly to the development of mathematical teaching strategies in high schools. With the understanding that the relationship between exploration and problem-solving skills varies by ability level, teaching can be focused on meeting students' needs more individually. Therefore, the implications of this study are the need for the development of personalized teaching methods, which take into account students' exploration abilities and

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approaches, to improve their learning outcomes in the field of mathematics. It can also pave the way for further research to explore the factors that influence the relationship between the two capabilities.

Conclusion and Suggestion

Based on the research and discussion results, it is clear that the grouping results highlight a significant level of relationship across the sample between talent for mathematical problem solving and mathematical exploration. Meanwhile, cluster 1 (high-skilled student group), cluster 2 (medium-skilled student group), and cluster 3 (low-skilled student group) obtained insignificant relationship results. The results of the data analysis prove that the mathematical exploration ability and mathematical problem solving ability of students in SMP Negeri 1 Klari are generally at a moderate level. Spearman rank correlation analysis across sample populations illustrates a moderate interpretation of mathematical exploration capabilities and mathematical problem-solving capabilities with coefficient values worth 0.535. The result of calculating the coefficient of determination explains that there is an effect of mathematical exploration ability on the mathematical problem-solving ability of 28.62% and vice versa. Meanwhile, the remaining 71.38% are affected by other factors outside of these two abilities. The limitations of this study are analysis of relationships not based on each indicator of mathematical exploration ability and mathematical problem-solving ability.

Based on the findings of this study, there are several suggestions for subsequent studies. First, a qualitative approach can be taken to dig deeper into students' understanding, thinking processes, and strategies when solving math problems, through interviews or group discussions. Furthermore, research may explore other factors that may affect the relationship between exploration and problem solving abilities, such as student motivation and support from teachers and parents. The development of broader indicators to assess exploration and problem solving capabilities is also important so that student's skills can be accurately assessed. In addition, research focusing on innovative learning interventions, such as the use of educational technology or collaborative learning methods, can improve these two capabilities simultaneously.

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