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K-MEANS CLUSTERING ANALYSIS OF THE RELATIONSHIP BETWEEN CRITICAL AND METAPHORICAL THINKING ABILITIES

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ABSTRACT
The low level of metaphorical thinking ability affects students' ability to solve complex mathematical problems. This study aims to examine the strength of the relationship between critical thinking ability and metaphorical thinking ability. Data were collected from the mid-semester assessment of the SPLDV (Simultaneous Linear Equations with Two Variables) topic. The population in this study consisted of 170 ninth-grade students from SMP Negeri 2 Pangkalan in the 2024/2025 academic year, with a sample of 63 students selected using a simple random sampling technique. The objectives of this study include categorizing students' abilities using the K-means clustering method and determining the relationship, direction, strength, and coefficient of determination between critical thinking ability and metaphorical thinking ability through Spearman's rank correlation analysis. The results show that 37 students fall into the high ability category, 20 into the moderate ability category, and 6 into the low ability category. The Spearman's rank correlation analysis yielded a correlation coefficient of 0.632 for the entire dataset and 0.482 for Cluster 1, indicating a significant positive (direct) relationship between critical thinking ability and metaphorical thinking ability, with a moderately strong correlation. The coefficient of determination shows that critical thinking and metaphorical thinking abilities influence 39.9% of the overall data and 23.2% of Cluster 1, while the remaining variance is influenced by other factors beyond these two cognitive abilities.
Keywords: correlation; critical thinking; metaphorical thinking.

ABSTRAK
Rendahnya kemampuan berpikir metafora berdampak pada kemampuan siswa dalam memecahkan masalah matematika yang kompleks. Penelitian ini bertujuan untuk melihat seberapa kuat hubungan variabel kemampuan berpikir kritis dan berpikir metafora. Data diambil dari penilaian tengah semester materi SPLDV. Populasi dalam penelitian adalah peserta didik kelas IX SMP Negeri 2 Pangkalan tahun ajaran 2024/2025 sebanyak 170 peserta didik. Teknik yang digunakan yaitu simple random sampling dengan besarnya sampel sebanyak 63 peserta didik. Tujuan penelitian yang diharapkan diantaranya 1) Untuk memperoleh kategori kemampuan peserta didik berdasarkan metode K-means clustering, 2) Untuk mengetahui hubungan, arah hubungan, tingkat hubungan, serta besarnya koefisien determinasi kemampuan berpikir kritis dan berpikir metafora melalui analisis korelasi Rank Spearman. Hasil penelitian menunjukkan sebanyak 37 peserta didik berada pada kategori kemampuan tinggi, 20 peserta didik kategori kemampuan sedang, dan 6 peserta didik masuk kategori kemampuan rendah. Hasil analisis korelasi rank Spearman diperoleh nilai koefisien korelasi pada seluruh data yaitu 0,632 dan data di cluster 1 yaitu 0,482 menunjukkan bahwa terdapat hubungan positif (searah) yang signifikan antara kemampuan berpikir kritis dan berpikir metafora, dengan tingkat hubungan cukup kuat. Adapun koefisien determinasi menunjukkan besarnya pengaruh kemampuan berpikir kritis dan berpikir metafora pada seluruh data yaitu 39,9% dan data di cluster 1 yaitu 23,2%, sedangkan sisanya dipengaruhi oleh faktor lain diluar kemampuan berpikir kritis dan berpikir metafora.
***Kata kunci**: berpikir kritis; berpikir metafor; korelasi.*

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Introduction

Mathematics is known as a discipline that often involves advancements in science and technology. The diverse branches of mathematical knowledge result in an increasing amount of information being received, necessitating the ability to select and filter relevant information according to the problem at hand. Solving complex problems requires critical thinking skills to determine appropriate and accurate solutions. In general, critical thinking is an optimal cognitive process for defining objectives in alignment with expected outcomes. According to Saputra (2020), critical thinking encompasses skills in recognizing relationships, identifying problems and causes, and drawing conclusions. Critical thinking can also be defined as a process of integrating previously acquired knowledge to generate new knowledge that is applicable to solving mathematical problems, including problem-solving, formulating conclusions, considering possibilities, and making decisions (Kusumawati et al., 2022). Additionally, Shavab & Gurdjita (2017) describe critical thinking as an activity of comprehensively understanding ideas or concepts obtained from various information sources to solve problems. According to Ennis (Apiati & Hermanto, 2020), there are four main indicators of critical thinking: (1) identifying problems, (2) developing models, (3) determining strategies, and (4) drawing conclusions. The process of problem identification in critical thinking involves focusing on the questions and elements within the given problem. Recent studies have also emphasized that critical thinking is central to mathematics education, not only as a problem-solving skill but also as a reflective and strategic process that enables students to evaluate reasoning and solutions effectively (Ariawan et al., 2024; Jablonka, 2018).

Field observations indicate that most students still have low critical thinking skills. According to Setiawan et al. (2023), one of the main causes of this issue is that many students rely on contextual methods or rote memorization when learning mathematics. As a result, they struggle with identifying problems, interpreting information, drawing conclusions, and evaluating the outcomes of given problems. This finding is further supported by research conducted by Marissa et al. (2024), which highlights students' difficulties in comprehending and interpreting word problems related to Simultaneous Linear Equations with Two Variables (SPLDV) into mathematical models. One contributing factor to this issue is the lack of development in students' metaphorical thinking ability, which is essential for interpreting abstract mathematical concepts into more concrete forms Lestari & Yudhanegara (2015). Consequently, this problem may arise because students' metaphorical thinking skills are not nurtured to assist them in solving abstract mathematical problems. Therefore, students are expected to connect each mathematical concept with the problems they encounter in order to enhance their understanding and problem-solving abilities. This is in line with findings of Susanti et al. (2023), who reported that the application of metaphorical thinking strategies significantly improved students' critical thinking skills. Similiary, Prahmana et al. (2022) emphasized that metaphorical-based approaches in mathematics education

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can foster both cognitive and reflective skills by enabling students to link abstract ideas with contextual expreriences.

The process of connecting abstract concepts with mathematical models can be achieved through metaphorical thinking. Metaphorical thinking is the ability to process and relate previously learned material to the problems at hand. According to Tama et al. (2019), systematic metaphorical thinking refers to an individual's ability to structure and formulate a model to solve problems based on their understanding of previously learned concepts. Lestari & Yudhanegara (2015) state in their book that there are three key aspects supporting metaphorical thinking: (1) identifying the initial concept design, where students are required to recognize mathematical concepts relevant to the given problem; (2) linking theoretical concepts with real-world concepts, where students are expected to connect new concepts with previously learned ones; and (3) representing mathematical ideas through metaphors, where students can explain each process and the final outcome based on their initial plan. Several studies on metaphorical thinking ability indicate that students' metaphorical thinking processes fall into the moderate category. This is primarily due to insufficient development of students' initial conceptual understanding, making it difficult for them to interpret or model problems into mathematical forms, leading to frequent misconceptions (Nurjasia et al., 2021). These findings are consistent with Zahro (2022), who found that metaphorical thinking plays a crucial role in supporting critical thinking, particularly in connecting abstract mathematical ideas to more concrete representations that facilitate systematic problem solving.

K-means is the simplest and most widely used non-hierarchical method for clustering large datasets within a relatively short processing time. The K-means clustering algorithm is highly effective in categorizing students' abilities. Previous studies have frequently employed the K-means clustering method to classify and evaluate students' academic performance using a data mining approach (Rifais & Laksana, 2024). Additionally, the K-means clustering method has been utilized to divide students into high, moderate, and low achievement groups based on attendance records and academic subject scores (Saputra & Nataliani, 2021). Alfarisi et al. (2020) successfully demonstrated the application of the K-means clustering method in measuring and categorizing students' cognitive and affective abilities related to volcanic disaster mitigation, with results showing 4 students classified as low, 14 as moderate, and 6 as high. Other studies also confirmed the effectiveness of K-means clustering in analyzing student learning profiles, such as in grouping computational thinking ability levels into high, medium, and low categories (Mulyani et al., 2025). Similarly, studies in mathematics education highlight the potential of clustering methods in categorizing reasoning patterns and understanding levels, thus providing more targeted instructional strategies (Rizky et al., 2023). Therefore, in this study, the K-means clustering algorithm will be used to support data analysis in categorizing students' abilities based on cognitive scores, specifically about critical thinking and metaphorical thinking abilities. Furthermore, the study conducted by Dwitasari & Noor (2024) also discusses the application of the K-means clustering method for categorizing students' abilities based on numerical data in the cognitive domain, effectively grouping students into high, moderate, and low ability categories.

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Relevant studies on the relationship between critical thinking and metaphorical thinking abilities include research by Abdillah et al. (2023), which revealed that students who applied a metaphorical thinking approach (transforming abstract concepts into concrete representations) demonstrated significant improvements in critical thinking skills when learning about three-dimensional geometric shapes in a school in Tasikmalaya. The study reported a mean score of 0.63 for the experimental class, compared to 0.54 for the control class. Additionally, research by Annizar & Zahro (2020) concluded that students in the low-achievement category, with report card scores below 70, failed to meet the indicators of metaphorical thinking, as they did not explain or record the necessary information. Consequently, these students were unable to identify problems required for solving higher-order thinking (HOTS) questions. Furthermore, a study conducted by Zahro (2022) analyzed the role of metaphorical thinking in solving HOTS questions, highlighting that students' cognitive styles influenced their metaphorical thinking ability. The research, conducted on tenth-grade science students at SMA Nuris Jember, found that metaphorical thinking plays a crucial role in critical thinking, particularly in linking abstract concepts to concrete experiences. This connection enables students to systematically apply metaphorical models to solve problems effectively. In line with these findings, instructional strategies integrating metaphorical and critical thinking dimensions—especially those considering individual differences such as learning styles and cognitive ability—have been shown to effectively enhance students' reasoning and metacognitive skills (Retta et al., 2025).

Although numerous studies have been conducted on critical thinking and metaphorical thinking abilities, the relationship between these two cognitive skills still requires further investigation. Analyzing this relationship serves as an effort to demonstrate that cognitive development should be interconnected, specifically by proving that students' critical thinking and metaphorical thinking abilities are linked. The novelty of this study lies in examining the relationship between critical thinking and metaphorical thinking abilities while employing the K-means clustering method for data classification. Based on these considerations, the researcher is interested in analyzing the relationship between critical thinking and metaphorical thinking abilities using the K-means clustering method.

Research Methods

The approach used in this study is quantitative with a correlational method. The correlational method is employed to examine the relationship between variables, focusing on the strength and significance of the established relationship (Lestari & Yudhanegara, 2015). Based on this approach, the study aims to determine the relationship between critical thinking ability and metaphorical thinking ability. The population in this study consists of ninth-grade students from SMP Negeri 2 Pangkalan, located in Karawang, with a total population of 170 students. The sampling technique used is simple random sampling, with the sample size determined using Slovin's formula as follows:

$$n = \frac{N}{1+N(e)^2}, \tag{1}$$

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where:

n = sample size

N = population size

e = *error level* (set as 10% or 0,1).

Thus, the sample size for this study is determined as follows:

$$n = \frac{N}{1+N(e)^2} = \frac{170}{1+170(0,1)^2} = 62{,}962 \approx 63 \text{ students.} \quad (2)$$

The data collection technique in this study utilized a test instrument consisting of seven mid-semester assessment questions on the topic of Systems of Linear Equations in Two Variables (SPLDV). The test comprised four questions assessing critical thinking skills and three questions assessing metaphorical thinking skills. The instrument was administered in two stages: first, participants were given the critical thinking test, followed by the metaphorical thinking test. Before distribution to the sample, the instrument underwent validity and reliability testing to ensure its feasibility. Based on these tests, the research instrument was confirmed to be suitable for use. This was evidenced by the results, which indicated that all test items were valid and reliable, as presented in Table 1.

Table 1. Results of validity and reliability testing of the test instrument

	No.	**R-count**	**R-table**	**Validity**	**Cronbach's alpha**	**Reliability Standard**	**Reliability**
CTA	1	0,390		Valid			Reliable
	2	0,848		Valid	0,806		
	3	0,748		Valid			
	4	0,745	0,248	Valid		0,600	
MTA	1	0,902		Valid			Reliable
	2	0,613		Valid	0,876		
	3	0,778		Valid			

Base on Table 1 present the result of the validity and reliability tests, which indicate that all items are both valid and reliable. In the subsequent stage, the data analysis technique was carried out through several stages. First, students' responses were scored based on a predetermined scoring rubric and then calculated using the following formula:

$$Score = \frac{Maximum\ score\ per\ question}{Total\ score} \times 100\% \quad (3)$$

Second, the scored responses were analyzed using the K-means clustering algorithm to categorize students' abilities into three clusters: high ability category

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(K1), moderate ability category (K2), and low ability category (K3). The formula for the K-means clustering algorithm, utilizing Euclidean distance, is derived from Yudhanegara et al. (2020) is

$$J(U,C) = \sum_{l=1}^{k} \sum_{i=1}^{n} \sum_{j=1}^{m} u_{i,l}\ d(x_{i,j}\ , c_{l,j})\ , \tag{4}$$

where:

J(U,C)	=	objective function to minimize distance
U	=	partition matrix indicating membership in a cluster
C	=	set of centroids in each cluster
$u_{i,l}$	=	variable indicating the placement of data i in cluster l (value 0 or 1)
k	=	number of clusters
n	=	number of objects/data
m	=	number of research variables
$d(x_{i,j}\ , c_{l,j})$	=	distance between feature j of object i and the centroid in cluster l.

The conditions used for these calculations are as follows:

$$\sum_{l=1}^{k} u_{i,j} = 1\ , \text{for } 1 \leq i \leq n\ . \tag{5}$$

This means that each data member i in a given cluster l must have a value of 1, indicating that the data belongs to that cluster. The detailed steps of the K-means algorithm used in this study are as follows:

1. Determine the number of clusters to be formed.
2. Randomly select the initial centroid points or values based on the research needs and objectives.
3. Calculate the distance of data point i to the selected centroid using the formula:
$$d^2\left(x_{i,j}\ , c_{l,j}\right) = \sum_{j=1}^{m} (x_{i,j} - c_{l,j})^2\ , \tag{6}$$
4. Determine cluster membership based on the shortest distance from each data point to the centroid.
5. Calculate the new centroid value based on the average of all objects within a cluster using the formula:
$$c_{l,j} = \frac{\sum_{i=1}^{n} u_{i,l}\, x_{i,j}}{\sum_{i=1}^{n} u_{i,l}}\ , \text{for } 1 \leq l \leq k, \text{and } 1 \leq j \leq m\ , \tag{7}$$
6. Evaluate the centroid values. If changes occur, repeat the iteration from steps 3 to 6 until the centroid values remain stable.

Third, the clustered data is then analyzed using Spearman's rank correlation to examine the relationship between critical thinking skills and metaphorical thinking skills across all data and within the largest cluster. The Spearman correlation coefficient formula, adapted from Lestari & Yudhanegara (2015), is:

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum {d_i}^2}{2\sqrt{\sum x^2 . \sum y^2}}\,, \tag{8}$$

where:

$$\sum x^2 = \frac{n^3 - n}{12} - \sum \mathrm{T}_x \tag{9}$$

$$\sum y^2 = \frac{n^3 - n}{12} - \sum \mathrm{T}_y \tag{10}$$

$$\sum \mathrm{T}_x = \sum \mathrm{T}_y = \frac{\mathrm{t}^3 - t}{12}. \tag{11}$$

The correlation coefficient formula was chosen because the test instrument results indicated the presence of tied ranks in the data. According to this formula, n represents the number of data points, and T denotes the number of tied observations within a ranking.

The correlation coefficient obtained through statistical calculations can be interpreted as the degree of relationship between critical thinking skills and metaphorical thinking skills using Guilford's criteria table (Lestari & Yudhanegara, 2015), as shown in Table 2 below:

Table 2. The strength of correllation based on Guilford's criteria

Correlation Interval *(r)*	**Relationship Strength**
$0{,}00 < r < 0{,}20$	Very weak
$0{,}20 \leq r < 0{,}40$	Weak
$0{,}40 \leq r < 0{,}70$	Moderate
$0{,}70 \leq r < 0{,}90$	Strong
$0{,}90 \leq r < 1{,}00$	Very strong

Base on Table 2 present the strength of the correlation based on Guilford's criteria, which will be used as a reference in this study. Next, the correlation coefficient is calculated to determine the direction of the relationship between critical thinking skills and metaphorical thinking skills, where the coefficient ranges from +1 to -1. If the correlation coefficient is positive, it indicates a direct relationship, meaning that an increase in critical thinking skills corresponds to an increase in metaphorical thinking skills, and vice versa. Conversely, if the correlation coefficient is negative, it signifies an inverse relationship, where an increase in critical thinking skills corresponds to a decrease in metaphorical thinking skills, and vice versa. If the correlation coefficient is zero (0), it means there is no relationship between the two variables.

The statistical test formula is adapted from McClenaghan (2024), which states that when the sample size exceeds 10, the correlation coefficient approximates a normal distribution. Therefore, the statistical test in this study follows the formula:

$$t_{count} = r_s\sqrt{n-1}\,, \tag{12}$$

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where:

r_s = correlation coefficient

n = number of data samples

The obtained test statistic value t_{count} is then compared with the critical value t_{table}. The research hypothesis proposed in this study states that there is a significant relationship between critical thinking ability and metaphorical thinking ability. This comparison is used to determine the acceptance or rejection of the hypothesis, following the decision criteria:

If $t_{count} \leq t_{table}$, then H_0 is not rejected.

If $t_{count} > t_{table}$, then H_0 is rejected.

Thus, the decision-making process for testing the Rank Spearman correlation hypothesis follows these criteria

H_0 : $\rho = 0$, there is no significant relationship between critical thinking ability and metaphorical thinking ability.

H_1 : $\rho \neq 0$, there is a significant relationship between critical thinking ability and metaphorical thinking ability.

Additionally, the researcher will calculate the coefficient of determination or the percentage of the influence of critical thinking ability on metaphorical thinking ability. The formula for the coefficient of determination to be used is:

$$\mathrm{D} = {r_s}^2 \times 100\% \,. \tag{13}$$

Results and Discussion

Results

The data was obtained through an essay-based mid-semester assessment test on the main topic of Systems of Linear Equations in Two Variables (SPLDV), consisting of seven questions. Four questions measuring critical thinking ability included Ennis' indicators: (1) identifying the problem, (2) identifying the model, (3) determining the strategy, and (4) drawing conclusions. Meanwhile, three questions measuring metaphorical thinking ability were based on the indicators outlined by (Lestari & Yudhanegara, 2015), namely: (1) identifying the initial conceptual framework, (2) connecting theoretical concepts with real-world applications, and (3) representing mathematical ideas through metaphors.

Based on the collected data, Attribute 1 represents Critical Thinking Ability (CTA), and Attribute 2 represents Metaphorical Thinking Ability (MTA), with a total sample of 63 students. The assessment results are presented in Table 3.

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Table 3. Mid-semester assessment results on SPLDV.

Data (*i*)	**Sample**	**CTA**	**MTA**
1	AK	57,14	57,14
2	AS	45,24	39,29
3	AL	83,33	89,29
...	...	...	...
61	SE	7,14	21,43
62	SW	66,67	67,86
63	SP	78,57	85,71

Base on Table 3 presents the mid-semester assessment results on SPLDV. The data include individual samples along with their scores on the CTA and MTA. The data was analyzed using the K-means clustering algorithm to classify students into high, medium, and low ability groups. The number of these categories corresponds to the number of clusters formed, where the high-ability category is defined as K1, the medium-ability category as K2, and the low-ability category as K3.

The initial centroid values were determined by selecting data points randomly. As a result, the initial centroids for CTA and MTA were chosen as follows: K1 from data point 21, K2 from data point 39, and K3 from data point 61. The selection of initial centroid values is represented in Table 4.

Table 4. Initial centroid determination for CTA and MTA data

Variable	***Centroid***		
	1	**2**	**3**
CTA	90,48	76,19	7,14
MTA	96,43	21,43	21,43

Table 4 present the initial centroid for teh CTA and MTA, in which the variables are classified into three centroid. After determining the initial centroids, the next step is to apply the Euclidean formula to calculate the distance of each data point from the assigned initial centroids. The manual calculation can be performed as follows:
Distance of the i-th data point to the first initial centroid

$$d\left(x_{1,j}\,, c_{1,j}\right) = \sqrt{(57{,}14 - 90{,}48)^2 + (57{,}14 - 96{,}43)^2} = 51{,}52 \quad (14)$$

$$d\left(x_{2,j}\,, c_{1,j}\right) = \sqrt{(45{,}24 - 96{,}43)^2 + (39{,}29 - 96{,}43)^2} = 72{,}88 \quad (15)$$

Distance of the i-th data point to the second initial centroid

$$d^2\left(x_{1,j}\,, c_{2,j}\right) = \sqrt{(57{,}14 - 76{,}19)^2 + (57{,}14 - 21{,}43)^2} = 40{,}48 \quad (16)$$

$$d^2\left(x_{2,j}\,, c_{2,j}\right) = \sqrt{(45{,}24 - 76{,}19)^2 + (39{,}29 - 21{,}43)^2} = 35{,}73 \quad (17)$$

Distance of the i-th data point to the third initial centroid

$$d^2\left(x_{1,j}\,, c_{3,j}\right) = \sqrt{(57{,}14 - 7{,}14)^2 + (57{,}14 - 21{,}43)^2} = 61{,}45 \quad (18)$$

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$$d^2(x_{2,j}\,, c_{3,j}) = \sqrt{(45{,}24 - 7{,}14)^2 + (39{,}29 - 21{,}43)^2} \;= 42{,}07 \tag{19}$$

Perform the Euclidean formula calculation for the entire sample data to determine which data points have the shortest distance from the cluster center, ensuring that they belong to the same cluster group. The manual calculation results are presented in Table 5.

Table 5. Calculation results of the shortest distance from the initial centroid

Data (*i*)	**d1**	**d2**	**d3**	**Shortest Distance**	***Cluster***
1	51,52	40,48	61,45	40,48	2
2	72,88	35,73	42,07	35,73	2
3	10,10	68,23	102,03	10,10	1
4	8,58	68,52	103,82	8,58	1
5	112,11	69,05	0,00	0,00	3
...	...	...	...	...	...
60	24,45	50,90	93,13	24,45	1
61	112,11	69,05	0,00	0,00	3
62	37,19	47,40	75,49	37,19	1
63	16,02	64,33	96,10	16,02	1

Base on Table 5 present the calculation results of the shortes distance from the initial centroid. For each data, the distance to centroids d1, d2, and d3 wew computed, and the shortest distance was then used to determine the corresponding cluster. The new centroid values can be calculated using the following formula:

$$c_{1,1}\ \text{CTA} = \frac{\sum_{i=1}^{63} u_{i,1}\, x_{i,1}}{\sum_{i=1}^{63} u_{i,1}} = \frac{(1\times 83{,}33)+(1\times 85{,}71)+\cdots+(1\times 78{,}57)}{38} = 71{,}12 \tag{20}$$

$$c_{1,2}\ \text{MTA} = \frac{\sum_{i=1}^{63} u_{i,1}\, x_{i,2}}{\sum_{i=1}^{n} u_{i,1}} = \frac{(1\times 89{,}29)+(1\times 75)+\cdots+(1\times 85{,}71)}{38} = 78{,}85\,. \tag{21}$$

Similarly, the new centroid values for CTA and MTA should be computed for the second and third centroids. After performing the iteration process, the cluster values stabilized at the fourth iteration. The final centroid values for each cluster are presented in Table 6.

Table 6. Final centroid formed

Variable	***Cluster***		
	1	**2**	**3**
CTA	71,30	59,52	24,21
MTA	79,25	49,82	23,22

Base on Table 6 presents the final centroids formed after the clustering process. The final cluster results can be interpreted as the average mid-semester assessment scores categorized based on ability levels: high ability (K1) with CTA 71.30 and MTA 79.25, moderate ability (K2) with CTA 59.52 and MTA 49.82, and

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low ability (K3) with CTA 24.21 and MTA 23.22.

Based on the results of the K-means clustering, the distribution of students' ability categories is as follows: 37 students in the high ability category (K1), 20 students in the moderate ability category (K2), and 6 students in the low ability category (K3). See Table 7.

Table 7. Final cluster distribution using K-means clustering

Cluster	**Data**
1	37
2	20
3	6

Base on Table 7 present the final cluster distribution obtained using the K-means clustering method. Next, the correlation analysis process is carried out to examine how the relationship between the variables studied, namely critical thinking skills and metaphorical thinking skills. The Spearman rank correlation analysis is a non-parametric technique that is conducted because there is no information regarding the population and the assumption that the data is not normally distributed, so it must be analyzed based on the order of the data or ranked first. The Spearman rank correlation analysis is performed on **all data** and the group of data with the highest data distribution, which is K1 or **Cluster 1**.

Based on the results of the mid-semester assessment, several identical scores were obtained; therefore, the Spearman rank correlation coefficient formula used is the one that accounts for tied data. The correlation coefficient calculation for all data resulted in a value of

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum {d_i}^2}{2\sqrt{\sum x^2 . \sum y^2}} = \frac{20696{,}5 + 20678 - 15229}{2\sqrt{20696{,}5 \times 20678}} \approx 0{,}632\,. \quad (22)$$

The calculation results of the Spearman Rank correlation coefficient show a positive (direct) correlation value of 0.632. According to Guilford's criteria, a correlation value of 0.632 falls into the moderately strong category. This indicates that critical thinking ability and metaphorical thinking ability in the entire dataset have a moderately strong positive or direct relationship, with a correlation coefficient of 0.632. Therefore, if there is an increase in critical thinking ability, metaphorical thinking ability will also increase, and vice versa.

Next, the statistical test calculation is conducted based on the previously formulated hypothesis to verify the significance of the relationship between critical thinking ability and metaphorical thinking ability in the entire dataset. The statistical test value for the analysis across all data is obtained as

$$t = r_s\sqrt{n-1} = 0{,}632\sqrt{63-1} = 4{,}976\,. \quad (23)$$

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The statistical test calculation results in a $t_{count} = 4{,}976$, which is compared to the $t_{table} = 1{,}999$ with α = 0.05 and df = 63 - 2 = 61. Since t_{count} > t_{tabel}, H_0 is rejected. Thus, it can be concluded that there is a significant positive or direct relationship between critical thinking ability and metaphorical thinking ability across the entire dataset, with a correlation value of 0.632, which falls within the moderately strong relationship category. Furthermore, the coefficient of determination for the relationship between critical thinking ability and metaphorical thinking ability is obtained as:

$$\mathrm{D} = {r_s}^2 \times 100\% = (0{,}632)^2 \times 100\% \approx 39{,}9\% \,. \tag{24}$$

The coefficient of determination indicates that 39.9% of the influence on critical thinking ability and metaphorical thinking ability is accounted for by the entire dataset, while the remaining 60.1% is influenced by factors outside of critical thinking ability and metaphorical thinking ability. Furthermore, the calculation of the Spearman rank correlation coefficient for the largest data group, namely K1 or cluster 1, which represents the high-ability category, yielded a value of:

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum {d_i}^2}{2\sqrt{\sum x^2 . \sum y^2}} = \frac{4185+4108-4299{,}5}{2\sqrt{4185 \times 4108}} \approx 0{,}482 \,. \tag{25}$$

The calculation of the Spearman rank correlation coefficient shows a positive (direct) correlation value of 0.482. According to Guilford's criteria, a correlation value of 0.482 falls into the moderately strong category. Thus, critical thinking ability and metaphorical thinking ability in the K1 data group or cluster 1, which represents the high-ability category, have a moderately strong positive or direct relationship with a correlation coefficient of 0.482. This implies that if critical thinking ability increases, metaphorical thinking ability will also increase, and vice versa.

Next, a statistical test calculation is performed based on the formulated hypothesis to verify the existence of a significant relationship between critical thinking ability and metaphorical thinking ability in the K1 data or cluster 1, which represents the high-ability category. The test statistic value for data analysis in K1 or cluster 1 is obtained as:

$$t = r_s\sqrt{n-1} = 0{,}482\sqrt{37-1} = 2{,}892 \,. \tag{26}$$

The statistical test calculation results in a $t_{count} = 2{,}892$, compared to a $t_{table} = 2{,}030$ with α = 0.05 and df = 63 - 2 = 61. Since t_{count} > t_{table}, H_0 is rejected. Therefore, it can be concluded that there is a significant positive or direct relationship between critical thinking ability and metaphorical thinking ability in the K1 data or cluster 1, which represents the high-ability category, with a correlation value of 0.482, classified as a moderately strong relationship. Furthermore, the coefficient of determination for the relationship between critical thinking ability and metaphorical thinking ability is obtained as:

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$$D = {r_s}^2 \times 100\% = (0{,}482)^2 \times 100\% \approx 23{,}2\% \,. \quad (27)$$

This coefficient of determination indicates that 23.2% of the variance in critical thinking ability and metaphorical thinking ability within the K1 data or cluster 1 (high-ability category) is explained by their relationship, while the remaining 76.8% is influenced by factors outside of critical thinking and metaphorical thinking abilities.

Discussion

Overall, the results of the statistical test calculations with t_{count} of 4.976 indicate a positive relationship between the variables of critical thinking ability and metaphorical thinking ability, with r_s of 0.632 demonstrating a moderately strong and direct correlation. Furthermore, the influence of both variables is reflected in the coefficient of determination value of 39.9%, while the remaining 60.1% is influenced by factors beyond critical thinking and metaphorical thinking abilities.

Further analysis based on the categorization of students' abilities using K-means clustering shows that the majority of students belong to K1 or the high-ability category, with a total of 37 students. The results of the statistical test calculations with t_{count} of 2.892 indicate a positive relationship between the variables of critical thinking ability and metaphorical thinking ability, with r_s of 0.482 demonstrating a moderately strong and direct correlation. Additionally, the influence of both variables is reflected in the coefficient of determination value of 23.2%, while the remaining 76.8% is influenced by factors beyond critical thinking and metaphorical thinking abilities.

The difference in relationships observed between the analysis of the entire dataset and the analysis of the largest student ability category group (K1) may be influenced by various factors. However, in general, the analysis results indicate a moderately strong and direct correlation between critical thinking ability and metaphorical thinking ability. This means that the higher the students' critical thinking ability, the better their ability to understand and connect abstract mathematical concepts through metaphorical thinking.

The difference in relationships between the analysis of the entire dataset and the analysis within the high-ability student category (K1) can be explained by referring to previous research by Abdillah et al. (2023), which found that students who applied metaphorical thinking approaches in understanding geometric concepts showed significant improvements in critical thinking, as evidenced by the higher average score in the experimental class (0.63) compared to the control class (0.54). This aligns with the findings of this study, which show that students with high critical thinking abilities tend to be better at using metaphors to comprehend abstract mathematical concepts. However, research by Annizar & Zahro (2020) indicates that students in the low-ability category (report scores < 70) struggle to meet the indicators of metaphorical thinking. They fail to identify problems effectively because they cannot write down the necessary information, which directly impacts their difficulties in critical thinking. These findings support the results of this study, where lower-ability groups face challenges in connecting abstract concepts and solving problems requiring higher-order thinking skills.

In the context of mathematics learning, the relationship between critical thinking and metaphorical thinking serves as a fundamental basis for problem-solving based on abstract concepts. Critical thinking enables students to analyze, evaluate, and develop problem-solving strategies effectively, while metaphorical thinking helps build more intuitive mental representations of complex mathematical concepts. Therefore, the findings of this study affirm that strengthening both abilities simultaneously can enhance the effectiveness of mathematics learning, particularly in solving higher-order thinking problems that require a deeper conceptual understanding.

This study provides new insights into the relationship between critical thinking and metaphorical thinking in mathematics learning. By utilizing the K-means clustering algorithm, it effectively categorizes students' ability levels, offering valuable insights for evaluating and determining appropriate interventions for specific student groups. However, this study has limitations, such as not considering other factors that might influence the relationship between critical thinking and metaphorical thinking. Therefore, future research is encouraged to conduct a more complex analysis of the relationship between critical thinking and metaphorical thinking by examining each indicator in greater detail.

Conclusion and Suggestion

Based on the results and discussion, this study demonstrates that the K-means clustering method is effective in categorizing students' abilities, resulting in three categories: high ability (37 students), medium ability (20 students), and low ability (6 students).

The Spearman rank correlation analysis on the entire dataset indicates a significant positive relationship, with $r_s = 0{,}632$, which falls into the moderately strong correlation category. Additionally, the coefficient of determination for the entire dataset shows that critical thinking skills contribute 39.9% to metaphorical thinking ability. Specifically, within the high-ability group, a significant relationship between the two abilities was found, with $r_s = 0{,}428$. Furthermore, the coefficient of determination for the high-ability category (K1) indicates that critical thinking skills contribute 23.2% to metaphorical thinking ability.

This study has limitations in analyzing the relationship based on the overall indicators of each variable without considering specific individual indicators. Therefore, future research is recommended to focus on analyzing each indicator separately to obtain a more detailed understanding.

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