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The relationship between formal reasoning ability and metacognitive awareness with differential calculus ability in mathematics education students

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Abstract

The purpose of this study was to determine the relationship between formal reasoning ability and metacognitive awareness with the differential calculus ability of mathematics education students. The population of this study were Mathematics Education students at Halu Oleo University. The sampling technique was purposive sampling, so the sample of this study was students of the S1-Mathematics Education Study Program who programmed the Differential Calculus course, consisting of new students' class of 2024 and old students' class of 2021. The instruments of this study were the Formal Reasoning Ability Test adapted from the Test of Logical Thinking (TOLT), a questionnaire adopted from the Metacognitive Awareness Inventory (MAI) and a test of understanding the concept of Differential calculus. The data analysis technique used descriptive statistical analysis and inferential statistical analysis. The results of the study concluded that there was a significant relationship between Formal Reasoning Ability and Calculus Ability of New Students of Mathematics Education, with a correlation coefficient of $r = 0.40$; while the relationship between metacognitive awareness and Calculus Ability of New Students was not significant, with correlation coefficient $r = -0.12$. The relationship between Formal Reasoning Ability and Calculus Ability of Old Students of Mathematics Education was not significant, with correlation coefficient $r = -0.11$; while the relationship between metacognitive awareness and Calculus Ability of Old Students was significant, with correlation coefficient $r = 0.43$.

Keywords: formal reasoning ability, metacognitive awareness, differential calculus ability

Calculus is a very important branch of mathematics and is widely applied by other branches of science, especially science and technology, medicine, and economics. In general, calculus can be grouped into two large branches, namely differential calculus and integral calculus. If you pay attention, the core of calculus lessons is the limit, derivative, and integral of a function, so studying these three concepts requires high thinking and reasoning skills. Therefore, many students have difficulty learning calculus because their high thinking and reasoning skills are still low (Ningsi et al., 2022; Susilo et al., 2022). This is in accordance with the results of the differential calculus learning of the UHO Mathematics Education Department for the 2023 Academic Year, which is still very low, namely an average score of 38.41 for new students and 52.83 for old students. This data shows that the differential calculus scores of old students are better than new students because they have programmed this course for the second time, but the scores are still low.

The low understanding of students towards calculus is caused by the low initial ability of students (Sebsibe et al., 2019). This is in accordance with the results of Ario's research (Ario, 2019) showing that the initial ability of students is very low with an average mastery of 19.55%. Several factors that influence students' initial ability include metacognitive awareness (Jang et al., 2020; McCabe, 2011), and formal

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reasoning ability (Handayani & Kusuma, 2024; Topçu et al., 2011). Thus, the low ability of students' calculus is caused by the low awareness of students' metacognition (Dibbs, 2019; Mariano Jr & Ancheta, 2021; Radmehr & Drake, 2017). In addition, the low ability of students' calculus is caused by the students' formal reasoning ability (Misu & Rosdiana, 2015; Zahroh, 2018).

This study aims to review the relationship between formal reasoning ability and metacognitive awareness towards the differential calculus ability of Mathematics Education students. To determine the differential calculus ability of students through solving problems related to differential calculus. Problem solving is one of the parts listed in the curriculum in high schools, especially the 2013 curriculum because it is considered important to teach. One of the goals of teaching problem solving is so that students can use the right heuristic steps in solving problems. According to Charles & Lester (Fan & Zhu, 2007), the use of heuristic steps is monitoring and evaluating the process and results of thinking (Fan & Zhu, 2007).

The concept of metacognition is a person's assumption of his/her thinking which includes metacognitive knowledge (a person's awareness of what he/she knows), metacognitive skills (a person's awareness of something he/she does) and metacognitive experience (a person's awareness of the cognitive abilities he/she has) (Flavell, 1979). Furthermore, Flavell (1979) divides metacognitive knowledge into three categories, namely declarative knowledge, procedural knowledge, and conditional knowledge. Declarative knowledge refers to knowledge of mathematical facts and concepts that students have or factors that influence their thinking and attention in learning. Procedural knowledge refers to a person's awareness of how to do something (using a strategy) in learning. Conditional knowledge refers to a person's awareness of the conditions that influence their learning, namely: when a strategy should be applied, why to apply the strategy, and when the strategy applied is appropriate in learning. Meanwhile, Ozturk (2017); Schraw (1998), metacognitive skills include planning, monitoring and regulation, and evaluation. Planning is related to goal setting that guides cognition in general and monitoring in particular. Monitoring activities involve assessing learning and performance in action while regulation is concerned with changing cognition and behavior to fit personal goals and task demands. Evaluation, finally, is concerned with "assessing the products and efficiency of one's learning" by reviewing one's goals and conclusions.

In addition to metacognitive awareness in solving problems, also in compiling problem-solving questions to adjust to the level of cognitive development of students. Piaget (Ormrod, 2012) stated that each individual experiences levels of intellectual development, namely: (a) Sensorimotor thinking level; estimated child age 0 - 2 years, (b) pre-operational thinking level; estimated child age 2 - 7 years, (c) Concrete operational thinking level; estimated child age 7 - 12 years, and (d) Formal operational thinking level; estimated child age 12 years and above. Then, Piaget and Inhelder (Irawati, 2016; Misu & Rosdiana, 2015), stated that formal operations are classified into five types from the lowest level to the highest level, namely: (a) Proportional Reasoning, (b) Variable Control, (c) Probabilistic Reasoning, (d) Correlational Reasoning, and (e) Combinatoric Reasoning. However, not all students are at a higher level of reasoning (combinatorics), and it is possible that most are still at a low level of reasoning (proportional). The low level of formal reasoning ability of students is caused by the lack of student exercises in solving problems.

Based on the description above, it can be seen that students' metacognitive awareness in understanding a concept and problem solving, namely seeing awareness of how to understand a concept, and how to solve a problem. Meanwhile, the level of formal reasoning ability is to see the level of students' reasoning ability based on the level of formal reasoning ability according to Piaget and Inhelder. Thus, the problems of this study are (1) what is the level of metacognitive awareness of UHO Mathematics

Education students? (2) what is the level of formal reasoning ability of UHO Mathematics Education students? and (3) is there a relationship between the level of metacognitive awareness and formal reasoning ability towards the understanding of calculus concepts of UHO Mathematics Education students?

METHODS

This type of research is ex post facto, which is research that shows that the treatment of the causal variable has occurred previously, so there is no need to provide treatment, just see the effect on the effect variable. The population of this study were students of Mathematics Education at Halu Oleo University. The sampling technique was purposive sampling, so the sample of this study were students of the S1-Mathematics Education Study Program who programmed the Differential Calculus course, consisting of new students' class of 2024 and old students' class of 2021. There are 3 research instruments, namely: (1) Formal Reasoning Ability Test adapted from the Test of Logical Thinking (TOLT) developed by Kenneth Tobin and Willian Capie (Amsad et al., 2021), (2) Metacognitive awareness was measured using a questionnaire adopted from the MAI (Metacognitive Awareness Inventory) which refers to Schraw & Dennison (Schraw & Dennison, 1994), and (3) Differential calculus concept understanding test. The Formal Reasoning Ability and Metacognitive Awareness Test grid can be seen in Table 1 and Table 2 below.

Table 1. Formal Reasoning Ability Test Grid

Indicator	Item Number
Proportional reasoning	1 & 2
Identification and control of variables	3 & 4
Probabilistic reasoning	5 & 6
Correlational reasoning	7 & 8
Combinatorial reasoning	9 & 10
Proportional reasoning	1 & 2
Identification and control of variables	3 & 4

Table 2. Metacognitive Awareness Questionnaire Grid

Variables	Aspects	Indicators	Item Number	
			Favorable	Non-Favorable
Metacognitive Knowledge	Declaration Knowledge	Factual knowledge that students need before being able to process a topic.	3, 4	1
		Be aware of one's own skills, intelligence and abilities in learning	6, 7	5
	Procedural Knowledge	Knowledge of how to do something in solving problems	9, 10	
	Conditional Knowledge	Knowledge of why/when to use procedures, skills/strategies	11, 12	
		Selecting important information that is used in problem solving	13	
Metacognitive Experience	Planning	Knowing what the purpose of the task given is	14	

Variables	Aspects	Indicators	Item Number	
			Favorable	Non-Favorable
or Regulation		Knowing what skills/resources to involve in problem solving	24	
		Determine the amount of time provided to solve a problem	16, 22	
		Designing/choosing the right strategy in problem solving	18, 20	
		Elaborating information from various sources	30	
	Reflection	Considering the accuracy of data collection results	21, 25	26
		Identifying sources of error from the data obtained	17, 23	
		Choosing the right repair strategy when the chosen strategy does not work	15	
		Monitor self-progress and provide feedback to oneself	27, 28, 29	
	Evaluation	Assessing goal achievement	19	8
		Assess the effectiveness of strategies that have been used in problem solving	2	

The variables in this study consist of independent variables, namely Formal Reasoning Ability and Metacognitive Awareness, while the dependent variable is Differential Calculus Understanding. The data analysis technique used descriptive statistical analysis and inferential statistical analysis. Descriptive analysis techniques are used to describe the characteristics of the research respondents' scores which include frequency distribution, mean, standard deviation, variance, maximum score, minimum score. In addition, the percentage of frequency will be described based on indicators, both formal reasoning ability indicators and metacognitive awareness indicators. Inferential statistical analysis is used to test the relationship between formal reasoning ability and metacognitive awareness on the understanding of Differential Calculus using the r-correlation test.

RESULTS AND DISCUSSION

The results of this study revealed 6 things, namely: (1) Formal Reasoning Ability of UHO Mathematics Education Students Based on Formal Reasoning Ability Indicators, (2) Metacognitive Awareness of UHO Mathematics Education students based on Metacognitive Awareness indicators, (3) Descriptive of formal reasoning ability, metacognitive awareness, and calculus understanding in new students of UHO Mathematics Education, (4) Descriptive of formal reasoning ability, metacognitive awareness, and calculus understanding in old students of UHO Mathematics Education, (5) Relationship between formal reasoning ability and metacognitive awareness towards the understanding of calculus of new students of UHO Mathematics Education, and (6) Relationship between formal reasoning ability and metacognitive awareness towards calculus understanding in old students of UHO Mathematics Education.

Description of Formal Reasoning Ability of UHO Mathematics Education Students

The percentage of the results of the analysis of the description of the formal reasoning abilities of new and old students of UHO Mathematics Education can be presented in a bar chart as in Figure 1 below.

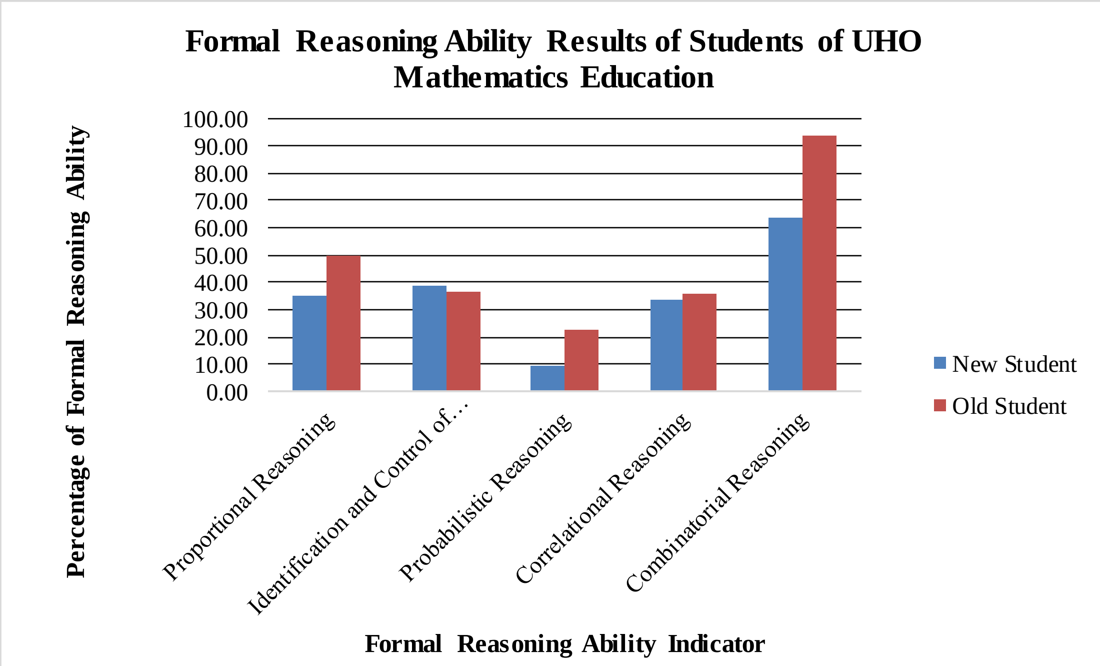

Figure 1. Bar Chart of Formal Reasoning Ability of UHO Mathematics Education Students

Based on Figure 1, it can be seen that the percentage of formal reasoning ability of the old batch of Mathematics Education students in each indicator is higher than that of the new batch, except for the variable control indicator. The highest percentage is in the combinatorial indicator (63.35% for the new batch and 93.47% for the old batch) and the lowest percentage is in the probabilistic indicator (9.3% for the new batch and 22.30% for the old batch). In general, the average percentage of formal reasoning ability of the new batch of Mathematics Education students is around 36.15% and the old batch is around 45.07%.

Description of the Results of Metacognitive Awareness of UHO Mathematics Education Students

The percentage of the results of the analysis of the description of metacognitive awareness of new and old students of UHO Mathematics Education can be presented in a bar chart as in Figure 2. Based on Figure 2, it can be seen that the percentage of Metacognitive Awareness of the new batch of Mathematics Education students in each indicator is higher compared to the old batch. The highest percentage is in the monitoring skills indicator (84.30% for the new batch) and the Declarative knowledge indicator (82% for the old batch). While the lowest percentage is in the Evaluation skills indicator (74% for the new batch and 71.33% for the old batch). In general, the average percentage of Metacognitive Awareness of the new batch of Mathematics Education students is around 82.17% and the old batch is around 77.94%.

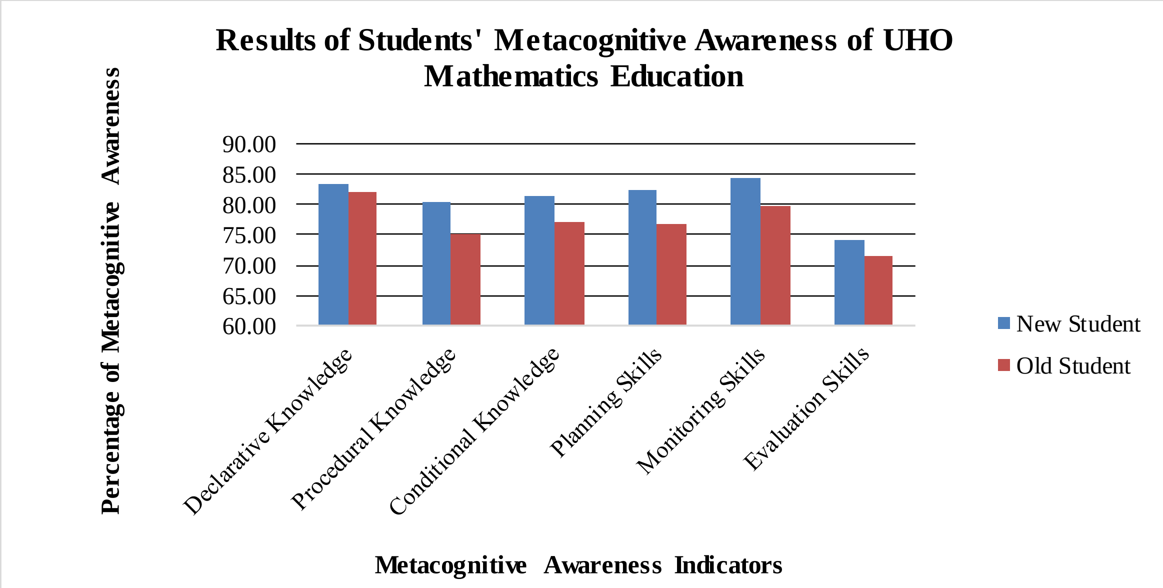

Figure 2. Bar Chart of UHO Mathematics Education Students' Metacognitive Awareness

Descriptive Analysis of Formal Reasoning Ability, Metacognitive Awareness, and Calculus Ability in New Students of UHO Mathematics Education

Descriptive analysis of formal reasoning ability, metacognitive awareness, and calculus understanding of new students of UHO Mathematics Education can be seen in Table 3 below.

Table 3. Descriptive of Formal Reasoning Ability, Metacognitive Awareness, and Calculus Understanding in New Students of UHO Mathematics Education

	TKPF	Metacognition	Calculus
Mean	3,61	98,78	62,11
Standard Error	0,21	0,92	1,02
Median	4,00	99,00	65,00
Mode	4,00	95,00	65,00
Standard Deviation	1,81	7,98	8,92
Sample Variance	3,28	63,64	79,51
Kurtosis	0,11	-0,18	0,40
Skewness	0,24	0,01	0,38
Range	9,00	38,00	40,00
Minimum	0,00	78,00	45,00
Maximum	9,00	116,00	85,00
Sum	274,00	7507,00	4720,00
Count	76,00	76,00	76,00

Based on Table 3, it can be seen that the average formal reasoning ability of new students of UHO Mathematics Education is very low (3.61 out of a total score of 10); the average metacognitive awareness of new students of UHO Mathematics Education is very high (98.78 out of a total score of 120); and the average understanding of Differential Calculus of new students of UHO Mathematics Education is moderate (62.11 out of a total score of 100).

Descriptive Analysis of Formal Reasoning Ability, Metacognitive Awareness, and Calculus Ability in Old Students of UHO Mathematics Education

Descriptive analysis of formal reasoning ability, metacognitive awareness, and calculus understanding of old students of UHO Mathematics Education can be seen in Table 4 below.

Table 4. Descriptive of Formal Reasoning Ability, Metacognitive Awareness, and Calculus Understanding in Old Students of UHO Mathematics Education

	TKPF	**Metacognition**	**Calculus**
Mean	5,19	91,19	63,57
Standard Error	0,53	1,43	1,43
Median	6,00	92,00	65,00
Mode	6,00	92,00	65,00
Standard Deviation	2,42	6,57	6,55
Sample Variance	5,86	43,16	42,86
Kurtosis	-1,08	0,94	-0,43
Skewness	-0,57	-0,04	0,14
Range	7,00	30,00	20,00
Minimum	1,00	77,00	55,00
Maximum	8,00	107,00	75,00
Sum	109,00	1915,00	1335,00
Count	21,00	21,00	21,00

Based on Table 4, it can be seen that the average formal reasoning ability of old students of UHO Mathematics Education is moderate (5.19 out of a total score of 10); the average metacognitive awareness of old students of UHO Mathematics Education is high (91.19 out of a total score of 120); and the average understanding of Differential Calculus of old students of UHO Mathematics Education is moderate (63.57 out of a total score of 100).

The Relationship between Formal Reasoning Ability and Metacognitive Awareness to the Understanding of Differential Calculus in New Students of UHO Mathematics Education

The relationship between formal reasoning ability and metacognitive awareness towards the understanding of calculus of new students of UHO Mathematics Education can be seen in Table 5 below.

Table 5. Relationship between Formal Reasoning Ability and Metacognitive Awareness towards the Understanding of Calculus of New Students of UHO Mathematics Education

	TKPF	**Metacognition**	**Calculus**
TKPF	1,00		
Metacognition	0,05	1,00	
Calculus	0,40	-0,12	1,00

Based on Table 5, it can be seen that the relationship between formal reasoning ability and understanding of differential calculus of new students of UHO Mathematics Education is significant (r = 0.40). While the relationship between metacognitive awareness and understanding of differential calculus of new students of UHO Mathematics Education is not significant (r = -0.12). This shows that new students are already at the formal operational stage so that by having formal reasoning ability they can understand the concept of differential calculus. Thus, new students in studying differential calculus do not utilize their metacognitive awareness, so they are more dominantly influenced by the variables of proportional, probabilistic, correlational, variable control, and combinatorial reasoning. New students in studying differential calculus have not utilized declarative knowledge, procedural knowledge, and conditional knowledge, as well as planning, monitoring, and evaluation skills.

The Relationship between Formal Reasoning Ability and Metacognitive Awareness to the Understanding of Differential Calculus in Old Students of UHO Mathematics Education

The relationship between formal reasoning ability and metacognitive awareness towards the calculus understanding of old UHO Mathematics Education students can be seen in Table 6 below.

Table 6. Relationship between Formal Reasoning Ability and Metacognitive Awareness towards Calculus Understanding in Old Students of UHO Mathematics Education

	TKPF	**Metacognition**	**Calculus**
TKPF	1,00		
Metacognition	-0,06	1,00	
Calculus	-0,11	0,43	1,00

Based on Table 6, it can be seen that the relationship between formal reasoning ability and differential calculus understanding of old students of UHO Mathematics Education is not significant (r = -0.11). While the relationship between metacognitive awareness and differential calculus understanding of old students of UHO Mathematics Education is significant (r = 0.43). This shows that for old students, they are already at the formal operational stage so that by having formal reasoning ability, they can understand the concept of differential calculus. However, old students in studying differential calculus are more dominant in utilizing their metacognitive awareness, so they are more influenced by the variables of declarative knowledge, procedural knowledge, and conditional knowledge, as well as planning, monitoring, and evaluation skills.

Based on the results of the descriptive analysis, it can be seen that the formal reasoning ability of new students is still very low, while old students are in the medium category. This means that new students are generally still at the concrete operational level, while some old students are already at the formal operational level. This is not in accordance with Piaget's cognitive development theory (Ormrod, 2012) that children aged 12 years and above are at the formal operational stage. The low reasoning ability of these students is caused by a lack of practice in solving difficult problems that require critical and creative thinking processes. This is in accordance with Brookhart's opinion (Brookhart, 2010) who categorizes high-level thinking skills into: transfer, critical thinking and problem solving. Because the aspects of critical thinking and problem solving are intended to help students reason effectively (Fisher et al., 2019).

The results of the inferential analysis show that in new students of mathematics education there is a significant relationship between formal reasoning ability and students' differential calculus ability, while the relationship between metacognitive awareness and students' differential calculus ability is not significant. This means that in new students of mathematics education, the understanding of learning in class in the early semester is still influenced by their formal reasoning ability. This is in accordance with the opinion of Ausebel (Rambega, 2016) who emphasized that the learning process will occur if students are ready in the form of the ability to connect the concepts to be learned with old concepts. This ability is closely related to formal reasoning ability. New students have not utilized metacognitive awareness in solving mathematical problems. This is the result of research by Bulu (2015); and Alfiyah (2014) that there are still many students who have difficulty in using metacognitive awareness when faced with problems. Not all students are able to use metacognitive awareness well and still experience metacognitive difficulties in solving problems. On the other hand, in old mathematics education students, there is a significant relationship between metacognitive awareness and students' differential calculus ability, while the relationship between formal reasoning ability and students' differential calculus ability is not significant. This means that old mathematics education students' understanding of learning in class already uses their metacognitive abilities. This is because old students already have experience solving mathematical problems. This is in accordance with the results of Muhali's research (2013) that the metacognitive awareness that is developed causes students to be trained to always design the best strategy in choosing, remembering, re-recognizing, organizing the information they face, and in solving problems. Likewise, Anggo (2011) stated that students who have good metacognitive abilities tend to be able to solve the problems they face well through the spread of awareness and regulation of their thinking.

CONCLUSION

The percentage of formal reasoning ability of new students is on average 36.15%. The highest percentage is in the combinatorial indicator (63.35%) and the lowest percentage is in the probabilistic indicator (9.3%). And the percentage of formal reasoning ability of old students is an average of 45.07%. The highest percentage is in the combinatorial indicator (93.47%) and the lowest percentage is in the probabilistic indicator (22.3%).

The percentage of metacognitive awareness of new students is an average of 82.17%. The highest percentage is in the Declarative Knowledge indicator (83.5%) and the lowest percentage is in the Evaluation Skills indicator (74%). And the percentage of metacognitive awareness of old students is on average 77.94%. The highest percentage is in the Declarative Knowledge indicator (82%) and the lowest percentage is in the Evaluation Skills indicator (77.94%).

The relationship between Formal Reasoning Ability and Calculus Ability of New Students of Mathematics Education is $r = 0.40$, while the relationship between metacognitive awareness and Calculus Ability of New Students is $r = -0.12$. And the Relationship between Formal Reasoning Ability and Calculus Ability of Old Students of Mathematics Education is $r = -0.11$, while the relationship between metacognitive awareness and Calculus Ability of Old Students is $r = 0.43$.

Based on the results of this study, it is recommended that teachers who teach in the early semester need to consider students' formal reasoning abilities as their learning approach. Meanwhile, teachers who teach in the final semester need to consider their metacognitive awareness as their learning approach.

Declarations

Author Contribution	:	Author 1: Conceptualization, Writing - Original Draft, Editing and Visualization; Author 2: Writing - Review & Editing, Formal Analysis, and Methodology; Author 3: Writing - Review & Editing, Formal Analysis; Author 4: Validation and Supervision
Conflict of Interest	:	The authors declare no conflict of interest.
Additional Information	:	No additional information is provided.

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