Journal of Mathematics and Science Education
Available online at www.radenfatah.ac.id
Vol. 1 No. 1, May 2024, pages: 39-53
E-ISSN: 3063-6175
https://doi.org/10.19109/MathSciEdu.v1i1.20637

Research Article

OPEN ACCESS

Analysis of Students' Metacognitive Ability and Meta-skills in Solving Mathematical Problems with Higher-Order Thinking Skills

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Received: April 10, 2024	Revised: April 28, 2024	Accepted: May 05, 2024	Online: May 28, 2024

Abstract

This study aimed to identify students' metacognitive abilities and meta-skills when solving HOTS in mathematics learning. The method employed was quantitative. Data on metacognitive ability were collected by administering a 10-question test that comprised three thinking skills: problem-solving, critical thinking, and creative thinking. The data on meta-skills was collected by employing a questionnaire with Gustavo Razzetti's meta-skills indicators, which include creative problem-solving, resilience, and self-awareness. This study involved 86 mathematics education students in the seventh semester. The findings revealed that students' metacognitive abilities were low in solving HOTS problems when computer applications were used to assist them. However, students' meta-skills were in a high category, as evidenced by student responses to the indicators of creative problem-solving, resilience, and self-awareness, with more than half responded strongly agree or agree. Further research should be conducted to increase metacognitive abilities and meta-skills.

Keywords:
Metacognitive ability; Meta-skills; HOTS; Computer applications.

INTRODUCTION

The balance and complexity of human abilities in confronting global issues must be carefully planned, including the ability to think critically and creatively, innovative entrepreneurship, problem-solving, and adaptability to difficulties [1]. The Organization for Economic Cooperation and Development (OECD) Learning Compass 2030 distinguishes three types of skills required in this era: cognitive and metacognitive abilities, social and emotional skills, and practical and physical skills [2], [3]. Academics and educational practitioners have paid close attention to metacognition as a critical component of the learning process [4], [5]. Intelligence is not primarily determined by factual information but also by students' ability to understand and control their cognitive processes [6].

Previous research has identified these fundamental features of metacognition, providing a conceptual foundation for future research [7], [8], [9], [10]. This literature is built around empirical studies that show metacognition has a favorable impact on learning outcomes [11], [12]. Previous research has indicated a significant association between metacognitive ability and academic achievement [13], [14], [15], [16]. In this context, it has been demonstrated that implementing learning strategies that promote the development of metacognition, such as goal setting, self-monitoring, and self-assessment, improves learning efficacy [17], [18]. Its broad implications for education highlight the importance of developing metacognitive abilities in educational environments. This study builds on earlier research into students' metacognitive abilities in mathematical problem-solving.

Students' performance in learning generally corresponds to their ability to solve mathematics problems using higher-order thinking skills (HOTS). Experts define meta-skills as unique basic skills that exist within a person and serve to generate solutions to any difficulties that emerge [19]. Meta-skills are a collection of high-level skills or abilities that enable people to acquire, apply, and modify various other skills [20], [21]. These abilities are frequently viewed as encompassing qualities that facilitate learning, problem-solving, and personal development across different areas. Meta-skills extend beyond technical or domain-specific knowledge and are essential for success in various areas of life. They are basic because they improve an individual's ability to meet challenges in various settings, encouraging ongoing learning and personal growth. They are frequently considered transferable and applicable abilities in various contexts, making them beneficial in both professional and personal settings.

The key objective of this study is to create a new understanding of technological breakthroughs that impact all professions and integrate new concepts of metacognitive abilities and meta-skills into mathematics instruction [22]. Theoretical and empirical research has revealed that using cognitive abilities and meta-skills as conceptual and practical tools is critical for learning more complex mathematics [23]. However, lately, metacognitive abilities and meta-skills have received little attention in mathematics learning. According to Bushe and Marshak (2015), interactional approaches appear to be especially beneficial when breaking away from existing and ineffective approaches to dilemmatic and complicated problems [24]. Metacognitive and meta-skills, as a growing research subject, serve as an important foundation for improving the education system. Therefore, this study attempts to assess students' metacognitive abilities and meta-skills in solving HOTS in mathematics learning.

Theoretical Background

Metacognitive Abilities

Metacognitive ability reflects a vital component of learning and problem-solving [25], [26], [27]. This term refers to awareness and comprehension of thoughts and cognitive strategies. According to vast literature and research, metacognitive abilities are not merely an additional component in education but a critical key to obtaining deep comprehension, intelligent decision-making, and academic success. Metacognitive abilities refer to the knowledge, comprehension, and self-regulation of one's thinking and learning processes. They encompass not just declarative knowledge (what we know) and procedural knowledge (how we learn) but also regulative knowledge (the ability to monitor and regulate learning strategies).

Metacognitive abilities necessitate intense self-awareness. A person with this skill can tell whether they grasp or fail to comprehend an idea. This awareness enables people to recognize problems, assess their understanding, and successfully overcome learning hurdles. At the self-regulatory level, metacognitive abilities enable people to manage and regulate their learning processes. They involve the ability to develop, track, and evaluate learning processes. Students with strong metacognitive abilities can tailor their learning strategy to task demands and improve the learning process. Metacognitive abilities are more than a theoretical concept; they provide the foundation for effective and long-term learning. Individuals who understand and develop these abilities can become more self-sufficient learners, cope better with learning problems, and perform better academically. As a result, integrating the concept of metacognition in an educational atmosphere may result in students having the knowledge and the ability to keep learning and progressing.

Meta-skills

Meta-skills are exceptional basic abilities that exist within a person and serve to solve any challenge that emerges. Meta-skills involve problem-solving knowledge and skills that can be used for hard and soft skills [28]. They include recognizing and addressing possible dangers, fostering innovative learning outcomes, and developing new techniques. Meta-skills are a sort of ability that helps students acquire and develop new skills more quickly [29], [30]. They also enable students to hone and acquire additional abilities. Students can critically evaluate their comprehension and performance. Meta-skills also include being open and accepting changes with a positive attitude in enhancing students' skills [31], [32]. They become more aware of their abilities and flaws, allowing ongoing improvement. Meta-skills, in contrast, are intrinsic components of ourselves that facilitate achieving desired goals [31]. According to Holyoake (2021), while learning a language is a skill, the abilities we develop to learn a language, which allows us to learn numerous languages, are classified as meta-skills [28].

Meta-skills can assist students have a deeper understanding of how they learn and absorb information [33]. As a result, people may identify their strengths and flaws, allowing them to focus more on areas for progress. Students who build their meta-skills become more effective learners and develop skills and attitudes that will serve them well throughout their lives. These benefits include enhanced independence, improved efficiency, and the ability to successfully handle problems in the learning environment and beyond the classroom.

METHODS

Type of Research

The research employed a quantitative method to measure the metacognitive abilities and meta-skills in solving metacognitive tasks using computer programs.

Participants

The research included 97 seventh-semester mathematics education students from several State Islamic Universities in Indonesia.

Instrument

This study's instruments were a HOTS metacognitive test on mathematics problems and a meta-skill questionnaire. The metacognitive test instrument had ten questions that span three types of thinking skills: problem-solving, critical thinking, and creative thinking [34], [35], [36]. The meta-skill questionnaire assessed meta-skill aspects, such as creative problem-solving, resilience, and self-awareness [23], [37].

Procedure and Data Analysis

The analyzed data were metacognitive ability test results assisted by computer applications and meta-analysis questionnaires.

RESULTS AND DISCUSSIONS

Results

1. Mathematical Analysis Skills

This study utilized metacognitive questions level C4 (analysis) and C5 (synthesis). The metacognitive problems had been validated by colleagues and had been improved. Metacognitive problems as shown in Table 1.

Table 1. Metacognitive Problems

No	Problem	Thinking Skill
1.	Find the area of the shaded area in the figure.	Critical thinking
2.	Determine the value of $x + y + z + t$ if: $3\begin{bmatrix} x & y \\ z & t \end{bmatrix} = \begin{bmatrix} x & 6 \\ -1 & 2t \end{bmatrix} + \begin{bmatrix} 4 & x+y \\ z+t & 3 \end{bmatrix}$	Problem-solving
3.	The algebraic equation $\begin{cases} (x-1)(y-2) = 12 \\ (y-2)(z-3) = 20 \\ (z-3)(x-1) = 15 \end{cases}$, with $x, y, z < 0$. Find the solution for $2x - 3y + 4z^2$.	Critical thinking
4.	If $= \frac{\sqrt{7}+\sqrt{3}}{\sqrt{7}-\sqrt{3}}, y = \frac{\sqrt{7}-\sqrt{3}}{\sqrt{7}+\sqrt{3}}$. Determine the value of $x^4 + y^4 + (x+y)^4$.	Problem-solving
5.	Find the solution. $\sqrt{2\sqrt{2\sqrt{2\sqrt{2}\ldots}}} - \sqrt{2+\sqrt{2+\sqrt{2+\sqrt{2}\ldots}}}$?	Critical thinking
6.	The man of the following data is 8 $x_1, x_2, x_3 \ldots x_n$. Determine the mean of the following data $x_1 + 5, x_2 + 5, x_3 + 5 \ldots x_n + 5$?	Problem-solving

Table 1 contains six metacognitive problems out of ten available questions. The remaining four are multiple choice standard questions, while the six problems mentioned in the table are not standard. The ten questions provided are derived from numerous questions evaluated for topic validity, either from Olympic questions mid or end-of-semester exams.

The results of students' answers to Question No. 3 using Math Solver and answers to Question No. 4 using Wolfram Alpha are as shown in Figure 1.

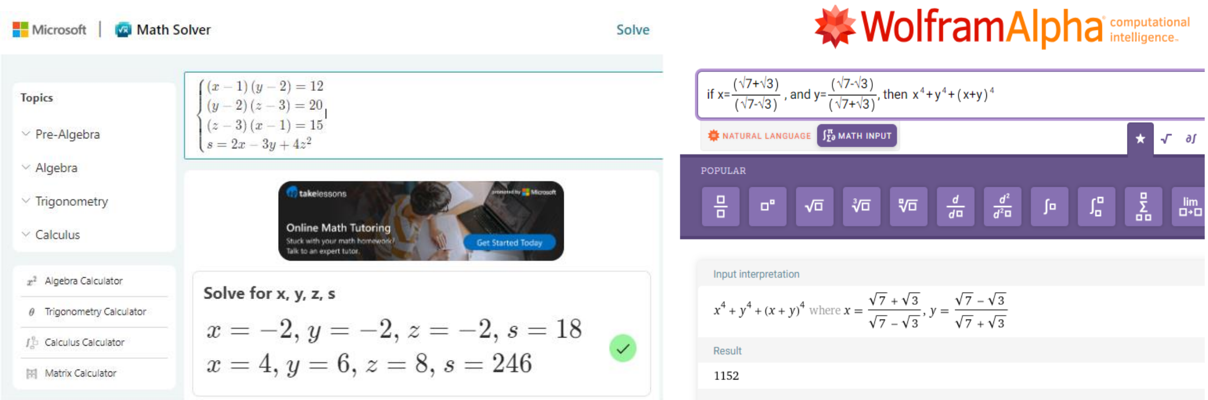

Figure 1. The Answer to Problem No. 3 Using Math Solver and the answer to Problem No. 4 Using Wolfram Alpha

The students were required to answer the third question about the system of three-variable linear equations with creative thinking skills and the fourth question about the fourth-degree equation with problem-solving skills. Students were allowed to address these cognitive metacognitive problems using mathematical computer applications. The ability to use mathematical computer applications necessitates understanding what steps and programs are acceptable for problem-solving. Therefore, two competencies are required: understanding the context of metacognitive problems and the ability (meta-skills) to use mathematical computer applications correctly and swiftly.

Students will find it easier to solve math issues if they can immediately understand and skillfully solve them using applications. The solution to the problem is 18 as x, y, and $z < 0$. Thus, the ten test problems presented can be solved using mathematical computer programs, and students, as the object of inquiry, should be able to locate the appropriate application to solve them. Furthermore, meta-skill questionnaires assessed students' reactions to mathematical applications in solving metacognitive problems. Meta-skills are high-level skills that improve an individual's ability to quickly learn and apply new knowledge [38], [39]. Some examples of meta-skills include abilities, such as learning a new language, plug-and-play skill transfer between industries, or the ability to solve complex problems. According to the study, three crucial meta-skills are self-awareness, creativity, and resilience [40], As these have the greatest impact on the modern workplace.

The outcomes of interviews with four students: A1, A2, A3, and A4. Q1 means question, and A is answer.

Q1 : *"What do students think are the benefits of using mathematical computer applications?"*

A1 : Answering questions using mathematical applications makes it easier for us to find answers quickly and precisely. However, manual steps make us think logically and mathematically;

A2 : If you use the app, it is easier and faster. However, if you calculate manually, it takes longer, and the answer is not necessarily correct;

A3 : There are advantages and disadvantages to addressing questions with mathematical computer applications vs manually. One advantage of using computer programs is that we will receive replies immediately. The disadvantage of using mathematical computer programs is that we will rely more frequently on the program, which encourages us not to think critically to solve problems with our efforts.

A4 : Computer applications can also be a learning solution for students who do not understand the teacher's explanation at school or university.

Q2 : *"Do you use mathematical computer applications in solving mathematics problems?*

A1 : Only a few and cannot use them;

A2 : Rarely, only easy questions for practice;

A3 : I would like to use a mathematical computer application and try it out.

A4 : Mathematical computer applications encourage me to try and practice them.

According to the student's responses, utilizing mathematical computer applications is more effective and faster in finding answers and detecting errors. Students rarely use mathematical computer applications to solve problems. However, students want to practice using it. Dependence on the application should be avoided so that when we encounter mathematical problems, we do not become preoccupied with accessing the application immediately. The principle is to master the steps of effective problem-solving. Table 2 shows the mathematical analysis test results of 86 students who worked on the test questions.

Table 2. Average Answers of Students Who Answered Correctly

Type	Average	Standard Deviation
Analytical Skills	26.92	17,39

Description: The Maximum Score is 100

Table 2 displays a score or value of 26.92 for 86 students' analysis skills, with a maximum score of 100, indicating that their ability to solve analysis problems remains low due to the high level of complexity. The processing time for 10 questions that must be answered was 60 minutes. Questions and answers were submitted to the Schoology app. Table 3 shows the percentage of students who answered the questions correctly.

Table 3. The Percentage of Students Answering Questions Correctly

Question No.	Percentage (%) of Students Answering Questions Correctly	Category
1	12.30	Low
2	19.85	Low
3	20.05	Low
4	21.00	Low
5	20.60	Low
6	29.85	Low
7	35.15	Low
8	42.10	Low
9	37.55	Low
10	30.75	Low

Table 3 indicates the percentage of students answering ten metacognitive questions correctly. Their percentages were in the low category. The lowest percentage was found in the first problem in determining the number of series of a number; only 12.30% of students answered correctly. In the second problem about the series of a number, 19.85% of students answered correctly. The third problem, which involved solving equations with three variables, was answered correctly by 20.05% of students. Problem number 4, which involved solving equations with three variables, was answered correctly by 21.00% of students. Problem 5, about variable algebra problems, was correctly answered by 20.60% of students. Only 29.85% of students correctly answered problem 6 (solving algebraic problems of the difference of variable root forms). Problem 7 addressed the algebraic problem of the area between two curves, which was correctly answered by 35.15% of students. Problem 8, the area between two presented in the form of a picture, was correctly answered by 42.10% of students. In problem number 9, 37.55% of students successfully answered the question about determining the average of a data set, and 30.75% properly answered the question about the magnitude of the angle in a triangle.

2. Meta-skills

Meta-skills are the ability to learn and apply new knowledge quickly. They are an overarching collection of abilities people require to learn new skills faster or to drive functional mastery in other skills [41]. Furthermore, students' meta-skills were measured utilizing creative problem-solving, resilience, and self-awareness indicators, as shown in Table 4.

Table 4. Meta-skills Questionnaire Results in Creative Problem-Solving Indicators

No.	Statements	Answer (%)			
		Strongly Agree	Agree	Disagree	Strongly Disagree
1	If the problem cannot be solved the usual way, I try to find another way.	26.80	68.04	5.15	0.00
2	When working on exercise problems, I do not rush to open the answer key before I finish it myself.	13.40	65.98	19.59	1.03
3	I used a mathematics application after I had solved it manually.	15.46	68.04	15.46	0.00
4	I use mathematical applications to check the correctness of my answers.	30.93	65.98	3.09	0.00
5	I do not immediately believe in the answers provided by the mathematical applications.	11.34	57.73	28.87	1.03
6	I strive to solve high-level problems.	11.34	74.23	14.43	0.00
7	Mathematical applications are very helpful in solving high-level problems.	40.21	57.73	2.06	0.00

According to the meta-skills questionnaire results of the creative problem-solving indicator, more than half or more than 50% of students answered that if the problem cannot be solved in the usual way, they tried to find other ways to solve it. They did not rush to open the answer key before solving the problems. They used mathematical applications after they solved it manually, and mathematical computer applications were used to check the correctness of the answer. Furthermore, the students did not immediately believe in the outcomes of mathematical application answers. They attempted to solve high-level problems and declared that mathematical applications were quite useful in addressing high-level mathematics problems. The answers demonstrated that their creative problem-solving was excellent, as evidenced by the students not relying on mathematical computer applications. Instead, they used the application to check the correctness of the answer and made it easier to complete the answer. Not rushing to open the answer key is one sign that the students solved the problems with their skills. They used the answer key as an answer comparison.

Table 5. Meta-skills Questionnaire Results in Resilience Indicators

No.	Statement	Answer (%)			
		Strongly Agree	Agree	Strongly Agree	Strongly Disagree
1	I actively seek ways to overcome the challenges of mathematics problems.	13.40	81.44	5.15	0.00
2	I see challenges as opportunities to learn.	24.74	71.13	3.09	0.00
3	I am not easily discouraged when I fail.	22.68	64.95	11.34	1.03
4	I tend to be more enthusiastic about tackling high-level problems than avoiding them.	6.19	62.89	29.90	1.03
5	I am interested in facing and solving problems.	18.56	73.20	7.22	0.00
6	I tend to bounce back quickly from stressful events.	24.74	59.79	15.46	0.00

Table 5 shows that more than half of respondents responded positively, indicating that students actively seek ways to overcome the challenges of learning difficulties in mathematics, see challenges as opportunities to learn, are not easily discouraged when failure occurs, are more enthusiastic about confronting high-level problems rather than avoiding them, are interested in confronting and solving problems, and recover quickly from stressful events. This demonstrates that student resilience belongs in an excellent category.

Table 6. Meta-skills Questionnaire Results in Resilience Indicators

No.	Statement	Answer (%)			
		Strongly Agree	Agree	Strongly Agree	Strongly Disagree
1	I try to solve my problems before asking my friends for help.	31.96	64.95	3.09	0.00
2	I try using a mathematical application if I have difficulty solving a mathematics problem.	37.11	59.79	3.09	0.00
3	Checking answers with mathematical computer applications increases my confidence.	23.71	73.20	3.09	0.00
4	I can learn mathematics by solving problems with mathematical applications.	15.46	78.35	6.19	0.00
5	I avoid difficult mathematics problems.	5.15	39.18	52.58	2.06
6	When I have a problem, I will try to be calm.	28.87	68.04	3.09	0.00
7	I will choose a job that does not use mathematics.	2.06	12.37	65.98	19.59

8	I have difficulty focusing my mind when I have a problem.	20.62	56.70	19.59	3.09
9	I like doing mathematics problems in English.	4.12	26.80	57.73	10.31
10	I try to solve my problems before asking my friends for help.	31.96	64.95	3.09	0.00

Table 6 shows meta-skill and self-awareness indicators. More than half of those questioned agreed or strongly agreed that students tried to solve problems independently before seeking peer assistance, that mathematical applications are employed to address challenging problems, and that the applications are used to check answers. Using mathematical computer applications boosts students' confidence; they can learn mathematics by solving problems with mathematical applications. Furthermore, 52.58% and 85.57% of students strongly agreed that they choose careers that require mathematics, indicating that students majoring in mathematics education will apply their knowledge in the future. 20.62% of students strongly agreed, while 56.67% agreed that they found concentrating difficult when faced with problems. 68.04%, or more than half of the students, answered negatively when asked to solve mathematics questions in English, implying that they find it difficult when mathematical problems are presented in English

Discussion

Metacognitive activities are necessary for an effective problem-solving process because problem-solving usually involves metacognitive awareness, metacognitive regulation, and metacognitive evaluation, all of which help students solve problems. This statement demonstrates that metacognitive skills play a crucial role in problem-solving [42], [43], [44], [45]. Persons with high metacognitive awareness may understand what have learned; they can solve problems properly. Metacognitive activities are associated with general knowledge and pre-existing assumptions about how people learn and absorb information. While metacognitive regulation refers to people' ability to monitor and intentionally reflect on their cognitive functions when solving problems [46], [47]. Furthermore, metacognitive evaluation seeks to enable students to reflect on their problems through self-evaluation [48], [49].

In problem identification stage, most students can identify the problem's known and uncertain details. This competence is defined by students writing what they know and asking reasonable question [50], [51], [52]. However, some students are unable to comprehend the problems assigned. One of the reasons they were unable to understand the problem was a lack of mathematical understanding and a failure to engage in self-questioning in metacognitive activities [53], [54], [55]. In metacognitive awareness, one must consider the position of his knowledge in the problem-solving process [56], [57], which strategies are essential and appropriate, and the relationship between the knowledge possessed and the strategies that can be utilized [58].

Students cannot engage in metacognitive awareness because they are unable to effectively explain the information presented. They do not participate in group discussions and present or analyze information that is expressly stated in the question text [59], [60], [61], [62].

During the planning stage, all students can choose the best strategic solution. According to prior study, students are required to first understand the problem and the defined concept [63], [64]. Students engage in metacognitive regulation activities throughout the planning stage, such as thinking about strategic problem-solving plans. They can use metacognitive regulation to prepare carefully and solve challenges. In metacognitive regulation, students consider and reflect on problem-solving strategies [65], [66]. Another viewpoint is that metacognitive regulation will help students gain awareness and self-control over their thought processes [67], [68]. This activity includes understanding how people process information, what they know and do not know, and how to properly structure problem-solving and decision-making processes.

While using metacognitive regulation, certain students may not understand the problems presented. It might occur when students are unable to understand the problem and devise a strategic plan for solving it using the appropriate mathematics. This idea is consistent with the notion that while selecting a plan for solving mathematical problems, students struggle to understand the problem and apply principles [54]. During the plan implementation stage, some students employ metacognitive regulation to apply the correct plan. The plan is implemented by working directly from the predefined solution strategy plan. Most students use metacognitive activities to obtain answers during the metacognitive evaluation stage. However, not all of them understand how to review their replies. This stems from a lack of metacognitive awareness. Some students may not be fully aware of their mental processes when addressing mathematics problems. They may not have received instruction on spotting or correcting errors, so they are unsure what to look for while assessing answers. In the metacognitive evaluation process, students should provide conclusions, check the answers by reading the questions and then examining the responses, and think that the processes taken are correct, as stated in prior studies.

CONCLUSIONS

Mathematical analytical skills in solving metacognitive problems belong to the poor category, caused by a lack of practice in solving HOTS metacognitive problems. In this study, mathematical computer applications can help solve the question. However, because these applications were not yet seamless, the students were unsure which mathematical applications were appropriate for handling certain problems. Students' meta-skills, including creative problem-solving, resilience, and self-awareness indicators, were excellent. Future studies should focus on enhancing mathematical and analytical skills using mathematical computer applications targeting a certain ability.

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Conflicts of Interest

The authors declare no conflict of interest.

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