JTK: Jurnal Tadris Kimiya 10, 1 (June 2025): 92-102
Website: http://journal.uinsgd.ac.id/index.php/tadris-kimiya/index
ISSN 2527-9637 **(online) ISSN** 2527-6816 **(print)**

Identifying Students' Metacognitive Characteristics in Solving Problems on the Hydrocarbons Topic

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Received: March 2025; Accepted: June 2025; Published: June 2025

Abstract

Metacognitive abilities play a critical role in students' learning processes by enabling them to regulate their thinking and select effective learning strategies. Understanding one's own metacognition allows students to optimize their learning outcomes by adapting approaches that align with their cognitive strengths. This study aimed to identify the metacognitive characteristics and levels of Grade XI students in learning hydrocarbons during the 2023/2024 academic year at MAN 4 Kampar. A quantitative descriptive research design was employed, involving 13 purposively selected students. Data were collected using an essay-based test instrument designed to assess three metacognitive indicators: declarative, procedural, and conditional knowledge. The results revealed that students demonstrated a high level of declarative knowledge (92.40%, categorized as very good), but performed poorly on procedural (60.26%) and conditional (59.62%) indicators, both falling into the low category. These findings suggest that while students possess strong factual knowledge, they struggle with applying and adapting that knowledge in problem-solving contexts. The study highlights the need for instructional strategies that explicitly develop procedural and conditional metacognitive skills to support deeper and more autonomous learning in chemistry education.

Keywords: conditional knowledge, declarative knowledge, hydrocarbons, metacognitive characteristics, procedural knowledge

DOI: https://doi.org/10.15575/jtk.v10i1.40868

1. Introduction

Efforts to cultivate 21st-century skills have become a central focus within educational systems. At the school level, education plays a crucial role in shaping environments, conditions, and learning situations that support students in developing these essential competencies. Twenty-first-century education emphasizes the development of higher-order thinking skills (HOTS), including critical thinking, creativity, problem-solving, and decision-making. These skills are essential to help students face global challenges, adapt to technological advancements, and think analytically and reflectively in diverse situations (Abarro & Asuncion, 2021; Astiningsih & Partana, 2020).

Among the areas of study related to higher-order thinking, metacognitive skills hold particular importance. In the context of chemistry education, metacognition helps students become aware of, monitor, and evaluate their own thinking processes—skills that are critical for understanding abstract concepts, designing experiments, and solving problems effectively. Students need strong metacognitive abilities to succeed in tackling complex problems. Research suggests that metacognitive thinking plays a vital role in successful learning, as it enables students to apply cognitive strategies through self-regulation and reflective control (Kodri & Anisah, 2020; Yıldız & Akdağ, 2017).

Metacognition refers to higher-level thinking where the object of reflection is one's own thought processes. It involves conscious awareness of what one knows and how one comes to know it (Sudirman & Yusnaeni, 2020; Toraman et al., 2020). The three core components of metacognition—declarative knowledge, procedural knowledge, and conditional knowledge—enable students to understand and regulate their learning. Students with strong metacognitive awareness can effectively manage their knowledge and apply it to problem-solving tasks (Özçakmak, 2021). Furthermore, understanding metacognitive strategies allows students to manage their cognitive capacities more effectively, thereby improving learning performance (Sumila et al., 2023). As Parlan et al. (2019) noted, the stronger a student's metacognitive ability, the better their learning outcomes tend to be. This demonstrates how students are able to organize and utilize their memory in meaningful ways.

The role of the teacher in fostering metacognitive awareness is crucial. Metacognitive learning strategies have been shown to enhance academic achievement (Smith et al., 2020). Students who are aware of their metacognitive abilities tend to study more strategically, understand how their thinking processes work, and identify areas for improvement (Özçakmak, 2021). This self-awareness supports more targeted learning efforts and promotes continuous academic growth.

Metacognitive awareness functions as a guide for students to learn more effectively. It enables them to identify their cognitive strengths, understand their preferred learning modalities, and apply appropriate strategies to enhance their learning outcomes (Zakiah, 2020). It also helps students assess their own problem-solving approaches, contributing to deeper comprehension and more effective decision-making (Muhid et al., 2020). However, when students are not supported in developing this awareness, they often experience confusion in learning—especially when instructional practices focus solely on mastering cognitive content through traditional written tests (Studianah, 2019). Such methods may encourage rote memorization rather than conceptual understanding, ultimately hindering students' ability to solve real-world problems.

The current chemistry curriculum positions the subject as essential for honing students' thinking skills, conceptual understanding, and ability to communicate scientific ideas. However, students' abilities in solving chemistry problems vary significantly (Lavi et al., 2019). According to Mudau and Tawanda (2024), problem-solving is one of the most critical competencies in chemistry learning. One of the major challenges is that chemistry deals with abstract subject matter (Agustin & Sunarto, 2018; Astiningsih & Partana, 2020), which often complicates students' comprehension. Unfortunately, many teachers have yet to fully understand the types of metacognitive characteristics their students possess, resulting in instructional approaches that are still not sufficiently effective in facilitating deep understanding.

Field data from class XI at MAN 4 Kampar revealed that most students tend to memorize concepts without being able to apply them effectively when confronted with problem-solving tasks. In several assessments, students struggled to adjust known concepts to the context of the problems presented. Many also had difficulty identifying the steps or instructions necessary to initiate problem-solving. MAN 4 Kampar is an Islamic-based senior high school under the Ministry of Religious Affairs of the Republic of Indonesia. While equivalent to general senior high schools, it places greater emphasis on Islamic religious education. Subjects like chemistry are often perceived as difficult in such contexts. Metacognitive skills are therefore crucial—not only for improving learning outcomes but also for promoting values such as critical thinking, honesty, and responsibility, which align with the principles of Islamic education (Sudirman & Yusnaeni, 2020).

Some students demonstrated fundamental misunderstandings regarding the actual problems presented, which led to the misuse of concepts and incorrect answers. Furthermore, many students reported that chemistry was an unenjoyable subject (Abarro & Asuncion, 2021). According to Syaiful (2024), such learning difficulties can be attributed to students' limited comprehension and lack of ability to manage their own thought processes. This highlights the need for students to develop an awareness of how best to learn according to their own capabilities—especially when dealing with abstract material like hydrocarbons, which requires both conceptual understanding and real-life application.

Hydrocarbons, in particular, present a significant challenge in chemistry learning. There are seven key topics students must master, each involving abstract concepts that frequently lead to confusion and misconceptions (Oktasari et al., 2020). Qodriyah et al. (2020) state that hydrocarbons are among the most disliked and difficult topics for students. The difficulty arises from the large number of terms, many of which are unfamiliar names of compounds not encountered in daily life. Mastery of hydrocarbons also demands a high level of conceptual understanding due to the material's broad scope. Their research found student difficulties in several areas: hydrocarbon compounds (22.1%), carbon atom specificity (23.6%), types of carbon atoms (22.9%), structure and nomenclature (24.8%), physical and chemical properties (38.7%), isomers (45.1%), and hydrocarbon reactions (31.4%).

To achieve success in learning such complex topics, students need to engage in metacognitive learning processes. Metacognition becomes especially important when students learn independently (Kallio et al., 2018). Nasution et al. (2021) emphasize that students who are unaware of their metacognitive abilities often fail to evaluate their own understanding and progress, which negatively impacts their learning outcomes. These findings support the need to explore and understand students' metacognitive profiles, as they significantly influence cognitive performance and academic achievement.

Based on the discussion above, it is clear that understanding students' metacognitive abilities is crucial for improving their problem-solving capacity, particularly in abstract chemistry topics like hydrocarbons. Therefore, the aim of this study is to identify the metacognitive characteristics of students at MAN 4 Kampar in solving problems related to hydrocarbon materials. This information is expected to guide future instructional practices and support targeted interventions that foster meaningful learning through improved metacognitive awareness.

2. Research Method

This research uses a quantitative descriptive design aimed at identifying students' metacognitive characteristics in solving problems on hydrocarbon topic. This research was conducted at MAN 4 Kampar which is located on Jl. Raya Pekanbaru–Bangkinang, Km. 35, District of Kampar, Riau, Indonesia. This research will be carried out in the odd semester of the 2023/2024 academic year in August. The subjects of this study were 13 students from class XI MIA 2 at MAN 4 Kampar, selected using purposive sampling.

Data are obtained by applying procedural steps: a) develop data collection instruments in the form of essay test questions containing hydrocarbon materials. Essay test questions have been adapted based on Rompayom (2010) instrument with modifications according to research needs. The instrument is used to see how students manage their metacognitive abilities in solving given problems. Each question contains the metacognitive indicator that is to be displayed; b) consulting data collection instruments with the supervisor and validating the instruments with the validator. The instruments were reviewed by two experts in chemistry education to ensure content validity and suitability for high school students; c) testing students' metacognitive abilities in solving problems on hydrocarbon material by providing test questions containing hydrocarbon material that has been taught when the hydrocarbon material chapter meeting ends. Reliability testing was conducted using the Cronbach's Alpha method. The test reliability was obtained at 0.856 so that it was included in the classification of very high reliability; d) the final stage is to collect the data that has been obtained and process it into research results. Scoring on essay questions was adapted from Rompayom (2010).

Quantitative analysis was carried out in the form of basic statistical calculations to reduce and group data, determine relationships, and identify differences between data groups on metacognitive ability instruments. Furthermore, the data obtained were used to describe the metacognitive level and characteristics of students based on the range of stage scores in students' answers. The data collected from each instrument was analyzed separately. As presented in Table 1, the students' answer data was assessed according to scoring indicators. Each student's score was then converted based on the weighted value of each indicator, and the overall score was accumulated in the form of an average percentage for each indicator. This percentage was calculated using the formula:

$$(\%) = \frac{number\ of\ part}{Total\ Amaount} \times 100\%$$

This formula was applied to normalize student scores and facilitate comparisons across different indicators.

Table 1. **Essay Test Scoring Criteria**

Criteria	Score
Correct Answer	2
Partially Correct Answer	1
Wrong Answer	0

Essay scores in percentage form are then categorized based on a range of metacognitive characteristic categories. The following is the range of students' metacognitive categories, as shown in Table 2.

Table 2. Range of Categorization of Metacognition Characteristics

Value Range (%)	Categorization
50-59%	Very Less
60-69%	Less
70-79%	Sufficient
80-89%	Good
90-99%	Very good

(Najah et al., 2020)

3. Result and Discussion

3.1. Characteristics of Metacognitive Knowledge

3.1.1. Declarative Knowledge

Procedural knowledge is considered important because it is the implementation or application in one's implementation of declarative knowledge (Sumila et al., 2023). Data on students' declarative knowledge on hydrocarbon material was obtained from the results of students' metacognitive knowledge tests on the declarative knowledge indicator. The percentage of student scores for each score can be seen in the following table.

Table 3. **Percentage of Student Scores in the Declarative Knowledge Category**

Question Number	Score				
	0	1		2	
	Σ%	*Σ*	%	*Σ*	%
2a		4	30.77 %	9	69.23 %
3a		1	7.69 %	12	92.31 %
Average		**2.5**	**19.23 %**	**10.5**	**80.77 %**

Declarative knowledge is knowledge that includes knowledge about oneself as a student and about what factors influence student performance (Moshman, 2018). Table 3 shows that almost all students got a score of 2 with an average percentage of 80.77% and an average percentage of 19.23% of students got a score of 1. Students with a percentage of less than 20% received a score of 1 on question number 2a, only mentioning the two types of concepts required. The following is an example of a student's answer who got a score of 1 for the concept identification question on the problem of determining the position of carbon atoms.

Table 4. Examples of Student Responses on Declarative Category

Score	Description of Response	Example Response
Score of 1 to question number 2a	Students with a percentage of less than 20% received a score of 1 on question number 2a, only mentioning the two types of concepts required.	The following is an example of a student's answer who got a score of 1 for the concept identification question on the problem of determining the position of carbon atoms.
Score of 2 to question number 2a	Students with a score of 2 clearly write what concepts are needed to solve the problems presented.	The concepts needed to answer the problem of determining the structure of carbon atoms and determining the number of isomers that will be formed by a hydrocarbon compound. Examples of student answers regarding the concepts needed to answer the problem of determining the structure of carbon atoms and determining the number of isomers that will be formed by a hydrocarbon compound.

Based on Table 4, it can be concluded that the majority of students (80.77%) have declarative knowledge at a high level. In other words, students are able to mention concepts and knowledge related to the questions given, although a small number are not able to mention them specifically.

According to Parlan et al. (2019), every student has initial knowledge, which can either support or hinder their individual learning process. If students possess strong prior knowledge, they are more likely to understand new material effectively. When initial knowledge is well mastered, it positively influences the development of declarative knowledge. Students with strong declarative knowledge are aware of both its advantages and limitations and understand how to address these shortcomings (Hwang et al., 2019). Similarly, Wardana et al. (2021) emphasize that students with well-developed declarative knowledge are better able to recognize their strengths and weaknesses in learning.

3.1.2. Procedural Knowledge

Data on students' procedural knowledge on hydrocarbon material was obtained from the results of metacognitive knowledge tests on procedural knowledge indicators. The percentage of student scores for each procedural indicator can be seen in the following table.

Table 5. Percentage of Student Scores in the Procedural Knowledge Category

Question Number	Score					
	0		1		2	
	Σ	%	Σ	%	Σ	%
1a	3	23.08	4	31	6	46.15
2b			12	92.31	1	7.69
3b	1	7.69	5	38.5	7	54
Average	**1**	**10.25**	**7**	**53.84**	**5**	**35.89**

Based on Table 5, the average percentage of students' results shows that 10.25% of students got a score of 0, 53.84% of students got a score of 1, and 35.89% of students got a score of 2. This means that students were able to understand the purpose of the assignment, but most students wrote concepts or stages that were less specific, somewhat unclear, or unrelated to the questions asked in the problem given.

The student received a score of 0 on question number 1a, indicating that the student actually understood the purpose of the assignment, but the student gave an answer or idea that was not specific and included reasons that were not related to the information provided. For example, students give answers to alkene compounds such as ethene, students do not explain further why ethene compounds can combine with bromine water. An example of a student's answer with a score of 0 (answering with a strategy that does not match the information provided) is presented as follows.

Table 6. Examples of Student Responses on Procedural Knowledge Category

Score	Description of Respons	Example response
Score of 0 on question number 1a	In fact, the answer given by the student already leads to the correct answer, but the reasons included by the student do not lead to the information or question asked.	The following is an example of a student's answer who got a score of 1 for the concept identification question on the problem of determining the position of carbon atoms.
Score of 1 on question number 2a	Students with a percentage of less than 20% received a score of 1 on question number 2a, only mentioning the two types of concepts required.	All students gave appropriate ideas or answers, but Students did not provide the structure of the compound requested and determine the position of the C atom in the structure. So it appears that students actually understand the meaning of the assignment, but the information provided is not specific enough to confirm the answers given by students. This gives the impression that students memorize concepts but are still hesitant in describing the concepts they understand.
Score of 1 on question number 2b	All students got a score of 1 on question number 2b regarding the question of determining the position of atoms when looking at their structure.	The concepts needed to answer the problem of determining the structure of carbon atoms and determining the number of isomers that will be formed by a hydrocarbon compound. Examples of student answers regarding the concepts needed to answer the problem of determining the structure of carbon atoms and determining the number of isomers that will be formed by a hydrocarbon compound.
Score of 2 on question number 3b	Students with a score of 2 clearly write what concepts are needed to solve the problems presented.	Most students got a score of 2 on question number 3b. In general, some students have a good understanding of the concept of the structure and naming of isomers of a hydrocarbon compound. Even though most students are able to describe and write the names of isomeric compounds well, most students still experience errors in answering problems regarding the nomenclature and structure of isomers of hydrocarbon compounds. This error is dominated by students who are still unable to describe the isomeric structure of a hydrocarbon compound. An example of a student who got a score of 2 on a problem related to the nomenclature and structure of isomers of a carbon compound is presented as follows.

Based on the explanation in Table 6, students' procedural knowledge is classified as moderate. Students generally understand the meaning of the problem, but many provide answers or steps that are less specific or not aligned with the given information. Students have not fully grasped the questions, making their strategies less targeted. Some students are still unable to solve problems in line with what is asked, possibly due to limited understanding of basic concepts.

Procedural knowledge refers to students' awareness of how to complete tasks—in other words, their self-perception regarding how to do something and apply it appropriately in context (Rompayom et al., 2010). Based on the results, 10.25% of students got a score of 0, 53.84% got a score of 1, and 35.89% got a score of 2. This suggests that although students generally understood the task, most provided concepts or procedural steps that were vague, incomplete, or not clearly related to the specific problem. This indicates a limited ability to structure and articulate effective problem-solving strategies, possibly due to insufficient understanding or unclear interpretation of the problem's requirements.

According to research by Parlan et al., (2019), it is stated that basic knowledge of the material greatly influences students' procedural knowledge (Parlan et al., 2019). Students who have good procedural knowledge will understand the learning strategies used and can automatically use learning strategies and can use and choose appropriate problem solving procedures. In addition, students can be said to have procedural knowledge in learning when they can choose and apply appropriate procedures correctly when they solve a problem (Braithwaite & Sprague, 2021).

3.1.3. Conditional Knowledge

Data on students' conditional knowledge on hydrocarbon material was obtained from the results of the metacognitive knowledge essay test on conditional knowledge indicators. The Percentage of students can be seen in the following table.

Table 7. Percentage of Student Scores in the Conditional Knowledge Category

Question Number	Score					
	0		1		2	
	Σ	%	Σ	%	Σ	%
1b	3	23.08	2	15.38	8	61.54
2c			13	100		
Average	1.5	11.54	7.5	57.69	4	30.77

Based on table 7, the average percentage of students' scores at the conditional knowledge level was 11.54% at the low level and 57.69% at the medium level, and 30.77% at the high level. The score of 0 obtained by students was caused by students providing answers to why the concept was chosen to solve problems. However, the answers given do not match the information contained in the problem. Students who get a score of 1 are able to explain why they chose this concept, but there is a misconception regarding the addition reaction process that occurs between ethene and bromine. Meanwhile, students who get a score of 2 are able to explain why they specifically chose that concept. Examples of student answers with scores of 0, 1, and 2 on question number 2b are presented in the following Table 8.

Table 8. Examples of Student Responses on Conditional Knowledge Category

Score	Description of Response	Example Response
Score of 1 on question number 1b	The answers given by students were less specific and did not fully address the problem given. The following is an example of a student's answer that received a score of 1.	In the student's answer with a score of 1, it can be seen that the student has given clear and specific reasons for using the concept, but the reasons for using the concept are less specific. while the desired answer is that ethene reacts with bromine through an addition reaction so that the double bond breaks and combines with bromine so that the ethene compound changes color to brown.
Score of 1 on question number 2c	The student chose this concept has led to the desired answer, but is less specific.	The desired answer is "because to answer the position of the carbon atom in the hydrocarbon chain, it can be seen from the location of the C atom in the bond. A carbon atom bonded to one other carbon atom is called a primary carbon atom, a carbon atom bonded to the other two carbon atoms is called a secondary carbon atom, etc.

Conditional knowledge is students' knowledge about when and why to apply various cognitive actions (Aprilia, 2024; Sun & Li, 2019). It was found that the average percentage score obtained by students at the conditional knowledge level was 11.54% who got a score of 0, 53.84% of students got a score of 1, and 30.77 students got a score of 2. It can be interpreted that the majority of students were able to explain why they used the strategy or concept to solve the given problem. On questions related to the addition reaction between ethene and bromine, less than 40% of students got a score of 0. This habit is caused by students memorizing concepts without knowing the meaning and proof activities. This is in line with the statement by Wardana et al., (2021) that conditional knowledge is knowledge about when to use a procedure, skill or strategy and when not to use it, why the procedure is used, and why one procedure is better than another (Mahasneh, 2020).

The percentage of students' overall score for each metacognitive characteristic indicator is then interpreted using the percentage criteria for the metacognitive characteristic category. Overall, the range of characteristic categories for class XI MAN 4 Kampar students is presented in Figure 1.

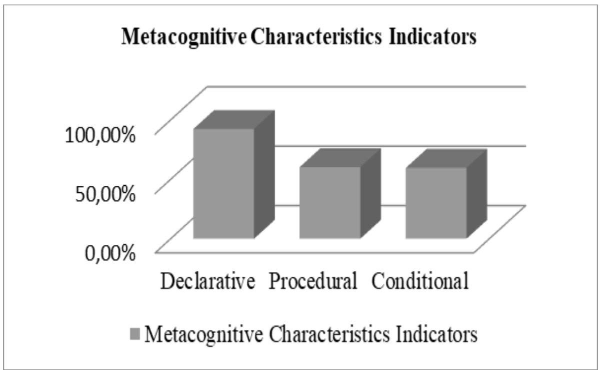

Figure 1. Diagram of Total Scores for All Students on Metacognitive Characteristics Indicators

Based on the picture in the diagram, the results show that the average percentage of students' score for each indicator with nominal declarative indicators is 92.40% in the very good category, procedural indicators are 60.26% in the poor category, and conditional indicators are 59.62% in the poor category very.

4. Conclusion

The characteristics of metacognitive abilities of class XI MIA 2 MAN 4 Kampar students seen through the metacognitive characteristic indicator instrument for each indicator shows that the average value of the declarative indicator is 92.40% with a very good category, the procedural indicator is 60.26% with a less category, and the conditional indicator is 59.62% with a very less category. This illustrates that class XI MIA 2 MAN 4 Kampar students can find out about their abilities as learners based on factors that impact performance, but students are still unable to maximize knowledge about strategies, and knowledge about when and why to use the most appropriate strategy so that they can overcome their weaknesses or shortcomings in chemistry learning. For students with low metacognition, chemistry teachers explicitly show how to think when solving problems or understanding concepts. In addition, teachers can provide metacognitive feedback, focusing on the final result and the process of how students arrive at the answer. The results of this study can be used to develop better chemistry learning strategies, such as using metacognitive rubrics by providing rubrics that help students evaluate how they understand chemistry concepts, develop strategies to solve problems, and correct mistakes.

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