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Metacognition and science teaching: identifying metacognitive skills through a teaching sequence

Metacognição e ensino de ciências: identificação de habilidades metacognitivas através de uma sequência didática

Metacognición y enseñanza de las ciencias: identificación de habilidades metacognitivas a través de una secuencia didáctica

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Abstract

The development of metacognition involves cognitive processes related to knowledge, production, and regulation of actions, contributing to awareness and self-evaluation of learning by individuals in the school context. This study aims to identify the

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development of metacognitive skills in high school students through a didactic sequence in science education. The work adopts a qualitative interpretative approach, developed in a class composed of 33 first-year high school students in a public institution located in the interior of Rio Grande do Norte (RN). To this end, a didactic sequence with metacognitive questions was used to collect data from the implemented activities, evaluating them through Content Analysis. The results demonstrated the manifestation of metacognitive thinking in the students, considering that there was reflection on the information and adoption of the necessary strategies to promote learning, with subsequent self-regulation of the activities and skills promoted in the intervention practice. Thus, this work presents a methodological possibility that involves metacognition in science education within the school environment, focusing on enhancing awareness and cognitive abilities resulting from educational experiences.

Keywords: Metacognitive questioning. Chemistry teaching. Metacognitive experiences.

Resumo

O desenvolvimento da metacognição envolve processos cognitivos relacionados ao conhecimento, à produção e à regulação das ações, contribuindo para a tomada de consciência e a autoavaliação da aprendizagem dos sujeitos no contexto escolar. Este estudo tem como objetivo identificar o desenvolvimento de habilidades metacognitivas de estudantes do ensino médio por meio de uma sequência didática no ensino de ciências. O trabalho adota uma abordagem qualitativa interpretativista, desenvolvido em uma turma composta por 33 estudantes do 1º ano do ensino médio, em uma instituição pública localizada no interior do Rio Grande do Norte (RN). Para isso, utilizou-se uma sequência didática com questionamentos metacognitivos para coletar os dados das atividades implementadas, avaliando-os por meio da Análise de Conteúdo. Os resultados demonstraram a manifestação do pensamento metacognitivo nos estudantes, tendo em vista que houve a reflexão das informações e a adoção das estratégias necessárias para a promoção da aprendizagem, com a posterior autorregulação das atividades e habilidades promovidas na prática interventiva. Assim, o trabalho é uma possibilidade metodológica que envolve a metacognição no ensino de ciências no ambiente escolar, com foco na qualificação da consciência e das capacidades cognitivas decorrentes das experiências educativas.

Palavras-chave: *Questionamentos metacognitivos. Ensino de química. Experiências metacognitivas.*

Resumen

El desarrollo de la metacognición implica procesos cognitivos relacionados con el conocimiento, la producción y la regulación de las acciones, contribuyendo a la conciencia y la autoevaluación del aprendizaje en el contexto escolar. Este estudio busca identificar el desarrollo de habilidades metacognitivas en estudiantes de bachillerato a través de una secuencia didáctica en educación científica. El trabajo adopta un enfoque cualitativo interpretativo, desarrollado en una clase compuesta por 33 estudiantes de primer año de bachillerato en una institución pública ubicada en el interior de Rio Grande do Norte (RN). Para ello, se utilizó una secuencia didáctica con preguntas metacognitivas para recopilar datos de las actividades implementadas, evaluándolas mediante análisis de contenido. Los resultados demostraron la manifestación del pensamiento metacognitivo en los estudiantes, considerando que hubo reflexión sobre la información y adopción de las estrategias necesarias para promover el aprendizaje, con la consiguiente autorregulación de las actividades y habilidades promovidas en la práctica de intervención. Por lo tanto, este trabajo presenta una posibilidad metodológica que involucra la metacognición en la educación científica dentro del entorno escolar, enfocándose en potenciar la conciencia y las habilidades cognitivas derivadas de las experiencias educativas.

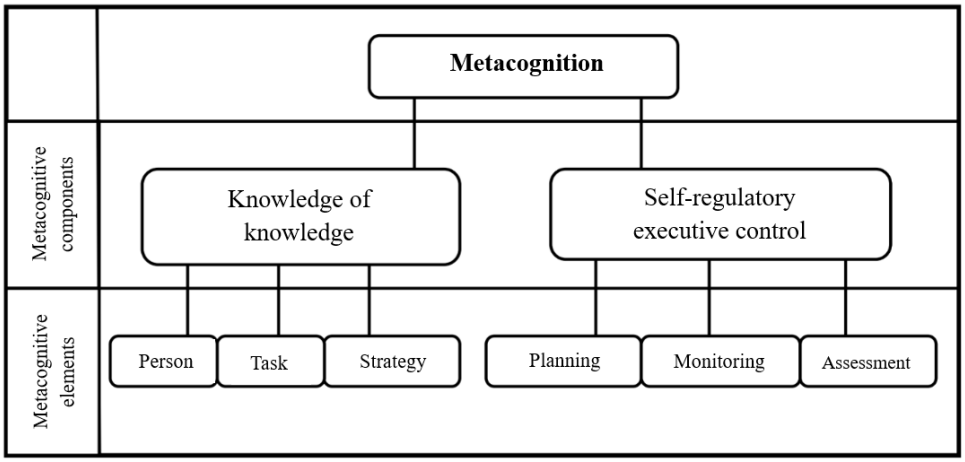
Palabras clave*: Cuestionamiento metacognitiva. Enseñanza de la química. Experiencias metacognitivas.*

1. Introduction

John Hurley Flavell was one of the first theorists to focus on the study of individuals' cognitive structure, contributing, in 1971, to the origin and conceptualization of the term "metamemory" or "metacognition," which marked the beginning of discussions aimed at assimilating scientific knowledge and metacognitive experiences (Flavell, 1971; Rosa, 2011). From this perspective, metacognition was then conceptualized as "[...] the knowledge of one's own knowing, or, in other words, learning to learn" (Portilho; Silva; Batista, 2023, p. 4), investigating the information, skills, and operational limitations present in consciousness. According to Flavell and Wellman (1975), metamemory is not a linear, homogeneous, or single-path process, since it involves the interplay of emotions, associations, and mental operations, enabling individuals to recall knowledge and develop the skills necessary for success in activities.

Thus, the enhancement of metacognition stems from individuals' own biological evolution, as well as from the tasks and experiences encountered in learning environments, influencing the transformation of knowledge, behaviors, and competencies—which in turn fosters the recognition of the significant potential of metacognitive thinking (Corrêa; Passos; Arruda, 2018). With the aim of systematizing the internal mechanisms, metacognition has been divided into two specific components, namely: 1. Knowledge of knowledge—linked to one's own knowledge, beliefs, and subjectivities; and 2. Executive and self-regulatory control—representing the planning, monitoring, and evaluation of individual actions to enhance learning (Flavell, 1979; Rosa, 2011). Figure 01 below outlines the metacognitive components and elements responsible for knowledge construction.

Figure 01 – Classification of Metacognitive Components and Elements



Source: Rosa (2011, p. 58).

Figure 01 presents the metacognitive elements that make up metacognition, categorized by predetermined components. The variables "person," "task," and "strategy" are part of the "knowledge of knowledge" component, while the variables "planning," "monitoring," and "evaluation" are part of the "executive and self-regulatory control" component.

The metacognitive element of the individual represents an internal dynamic of beliefs, abilities, and personal characteristics, stimulating the exercise of memory and self-awareness regarding one's own learning (Portilho, 2024). Next, the "task" variable highlights the information available within the cognitive structure for carrying out activities, serving as an opportunity to assess and manage the quality of the knowledge assimilated by individuals (Flavell, 1979). Boszko (2019) discusses the metacognitive element of "strategy," stating that this variable reflects the mobilization of appropriate actions and tools for task resolution.

Rosa and Ghiggi (2018) define the three variables of the second metacognitive component: i. planning—related to planning the actions and strategies necessary to achieve the intended goals; ii. monitoring—related to the ability to manage and control actions; and iii. evaluation—considered a stage of self-regulation of knowledge, involving an examination of the results obtained and the challenges encountered.

Over the past 40 years, the Brazilian educational context has embraced and valued metacognition in instructional planning, recognizing its relevance to teaching and learning processes as a useful tool for reflection and the consolidation of scientific knowledge within the cognitive structure (Reis & Strohschoen, 2024). Nora, Broietti, and Corrêa (2021) highlight the contributions of metacognition to the teaching and learning of educational knowledge, since, as knowledge is brought back into consciousness, students and teachers can recall, plan, and regulate the learning assimilated into the cognitive structure, enabling reflection on the potential and difficulties associated with a given topic or practice.

Due to its interdisciplinary nature, metacognitive thinking can be developed in various fields of knowledge, including science education, through playful, investigative, and problem-solving tasks, thereby fostering motivation and interaction in the classroom and supporting the development of scientific knowledge and skills in educational settings (Rosa; Villagrá, 2020; Brabo, 2018). Therefore, for teachers to enhance their metacognition, it is first and foremost necessary to understand the contributions and limitations of metacognitive tools in the educational setting, which consequently influences the (re)structuring of teaching practices and the effective implementation of diverse activities (Portilho; Silva; Batista, 2023).

According to Rosa and Villagrá (2018), the use of metacognitive questions can serve as a teaching tool for student learning, acting as a guide for questions focused on the information and skills developed within the cognitive framework, with a positive influence on the planning, management, and evaluation of actions and limitations in the school environment. In Table 01 below, Rosa (2011) highlights which questions facilitate the manifestation of metacognitive thinking, based on their metacognitive components and elements.

Table 01 – Metacognitive Questions by Component and Element of Metacognition

Metacognitive component	metacognitive elements	Questions
Knowledge of the knowledge	Person	Can you relate this topic to another one you've already studied? What do you know about this topic or issue? How do you feel about this material? Does it have any limitations?
	Task	Do you understand the task? Can you identify what needs to be done? Is the knowledge you've learned sufficient to complete this activity? Do you find it easy or difficult to carry it out??
	strategy	What techniques would effectively solve the problem? What strategies could be used? Have you used this strategy before? Are the strategies sufficient to complete the task?
Executive and self-regulatory oversight	Planning	Can you plan a course of action? How can you approach this task to achieve your goal? Are the strategies sufficient or insufficient for understanding the material? Can you envision how to complete the activity?
	Monitoring	Do you understand how the activity works? What are the objectives of the task? Did you feel the need to review or explore certain concepts? Why are you participating in this activity?
	Assessment	Were the objectives achieved? Can you describe the results obtained? Will it be necessary to study the material further? What knowledge did you gain by the end of the activity?

Source: Rosa (2011).

The metacognitive questions presented in Table 01 have been used in various academic studies on science education (Biazus; Rosa; Darroz, 2022; Rosa; Villagrá, 2020; Nora; Broietti; Corrêa, 2021; Silva; Bizerra, 2022; Silva, 2021; Rosa, 2011), given their relevance and effectiveness in mobilizing knowledge assimilated into consciousness, as well as in promoting skills and facilitating activities. The interest in working with metacognitive questions stems from the need to enhance students' self-awareness; thus, these questions serve as a teaching strategy for understanding, identifying, and evaluating thought, thereby providing insights into the potential and difficulties experienced in school settings (Rosa, 2011).

However, Brazilian literature still lacks academic materials that utilize metacognition or metacognitive thinking in science education, specifically in the field of chemistry, which limits the expansion of this topic and its importance in the development of individual cognitive mechanisms. Thus, the purpose of this study is to facilitate the analysis, discussion, and dissemination of students' metacognitive experiences through questionnaires, which are the result of diverse educational practices focused on activating memory, self-regulation, and the specific abilities of students in school settings.

For this reason, this study began with the following question: How do metacognitive questionnaires enable the identification and analysis of metacognitive skills in high school students? In line with this research question, the objective is to identify the development of metacognitive skills in high school students through a teaching sequence in science education.

2. Metodology

2.1 Nature, context and research participants

The study employed a qualitative approach with an interpretive focus, aiming to explore the social constructions experienced in an educational context, as well as to interpret the relationships and verbal descriptions provided by the participants (Gil, 2017). The study was conducted in a chemistry class at a school located in the interior of Rio Grande do Norte (RN), with a 1st-year high school class consisting of 33 students who voluntarily agreed to participate in the research. To ensure anonymity, the participants were designated as E1, E2, E3... in the presentation of the results. It should be noted that the project was approved by the Research Ethics Committee (CEP/UERN), with Certification of Submission for Ethical Review (CAAE) number 75525523.3.0000.5294 and substantiated opinion number 6,667,516.

2.2 Data collection tools

To collect data for this study, the metacognitive questions developed by Rosa (2011) were used; these were incorporated into and administered via Google Forms. The use of this strategy made it possible to identify different skills related to the students' psychological processes. Table 02, below, details which questions were asked during the teaching sequence (TS).

Table 02 – Examples of the metacognitive questions used

Metacognitive Questioning I
• What do you know about this topic or problem? • Is what you've learned enough to complete this activity? • What techniques would effectively solve the problem? • Are you motivated to complete the assigned activity?
Metacognitive Questioning II
• Why use this technique to complete the task? • Are the strategies used sufficient? Do you need to explore other techniques? • What are the objectives of this activity? • Did you feel the need to revisit or explore certain concepts?
Metacognitive Questioning III
• Did the final result meet expectations? • Can you describe the results of the task? • Are the strategies sufficient, or do they need to be changed? If so, what techniques could be used? • What knowledge was gained at the end of the activity?

Source: Adapted from Rosa (2011).

2.3 Methodological procedures

The methodological procedures of the SD were organized into three (3) stages: i. Introductory activities; ii. Organization and development; iii. Final activities. It is worth noting that the planning and implementation of a project-based learning (PBL) unit serve as a pedagogical strategy, enabling the gradual construction of knowledge through the structuring of predetermined activities (Zabala, 1998). In each stage, in addition to the educational activities, various metacognitive questions were posed to assess the knowledge, strategies, and skills of the class under study. The topic addressed was energy sources; therefore, all materials were related to the historical, sociopolitical, economic, and environmental aspects of energy resources. The total duration of the SD was 18 hours. Table 03 below summarizes the methodological approaches used in the study.

Table 03 – Overview of the instructional sequence (IS) used in this study

Stages	Atctivitie/ resources	Order of the questions	Metacognitive questions covered
Stage 1 – Introductories practices	Word cloud, poem, and interactive lesson.	metacognitive questioning I	What do you know about this topic or problem? Is what you've learned enough to complete this activity? What techniques would effectively solve the problem? Are you motivated to complete the proposed activity?
Stage 2 – Organization and Development	Interactive lecture, narrative questions, and mock jury.	metacognitive questioning II	Why did you use this technique to complete the task? Are the strategies you used sufficient? Do you need to explore other techniques? What are the objectives of this activity? Did you feel the need to revisit or explore certain concepts?
Stage 3 – final practices	Construction and Sharing of Models.	metacognitive questioning III	Did the final result meet expectations? Can you describe the results of the task? Are the strategies sufficient, or do they need to be changed? If so, what techniques could be used? What knowledge was gained at the end of the activity?

Source: Created by the author (2024).

2.4 Data analysis tools

To analyze the results obtained, Bardin's (2011) Content Analysis was used, given the qualitative and empirical nature of the research. This evaluative tool is a methodological technique that analyzes different forms of communication, based on the interpretation of the content of messages (Bardin, 2011). The author organizes the technique into three stages: 1. Pre-analysis; 2. Exploration of the material; and 3. Processing of the results (inference and interpretation), with the goal of understanding and categorizing the metacognitive nature of the class under study

During the preliminary analysis, the results from the Google Forms questionnaires were organized, providing an important opportunity to conduct a general analysis of the students' initial ideas. In the exploration of the material, the categories and subcategories encompassing the research data were systematized. For the categories, we chose to use the nomenclature of metacognitive elements (person, task, strategy, planning, monitoring, and evaluation), given that the objective of this study is to identify which metacognitive skills are developed through the implemented activities. Through a flexible reading of the results, subcategories were created with the aim of encompassing, evaluating, and sharing the diversity of cognitive processes developed by the class. That said, it is worth noting that the subcategories represent the metacognitive aspects identified in the students' responses.

No tratamento dos dados, realizou-se a leitura flutuante dos documentos selecionados para a avaliação, verificando todos os resultados fornecidos pelos participantes nos questionamentos metacognitivos. Nesta fase,

pretendeu-se identificar os componentes e elementos metacognitivos nas descrições dos participantes, enquadrando-as nas variáveis da metacognição (pessoa, tarefa, estratégia, planificação, monitoração e avaliação), ou seja, utilizaram-se os elementos metacognitivos como categorias. Ressalta-se que as subcategorias foram criadas a *posteriori*, pois elas se originaram a partir da análise exaustiva das descrições verbalizadas pela turma. A seguir, o Quadro 04 ilustra as subcategorias elaboradas.

Table 04 – Categories and subcategories derived from data analysis

Categories	Subcategories
Person	Activating Metacognitive Knowledge
Task	Identification and interpretation of tasks
Strategy	Strengths and weaknesses of the practices implemented
Planning	Planning effective actions and tools
	Proposal of strategies to solve the problem
Monitoring	Control and monitoring of procedures to achieve the objective
	Verification of the strategies' effectiveness
Assessment	Review and self-regulation of learning

Source: Research Data (2026).

3. Results and Discussion

This section presents the results obtained through the metacognitive questions, which were divided into subcategories. It also provides examples of the descriptions provided by the students. Based on the content analysis, eight subcategories were created that encompassed the six metacognitive elements. Consequently, the data were organized and discussed based on the established subcategories and were also related to literature.

3.1 Activation of metacognitive knowledge

In the metacognitive questioning from the first stage of Table 03, aspects related to the "person" variable were observed, as the students shared the prior knowledge they had assimilated into their cognitive structure. It is believed that this process demonstrates the activation of metacognitive thinking, highlighting internal cognitive processes, subjectivities, and the unique characteristics of each individual.

According to theorists Biazus, Rosa, and Darroz (2022), the process of activating metacognitive knowledge is spontaneous and automatic, driven by external mechanisms such as metacognitive questioning, which contribute to students' self-awareness of their operational abilities in educational settings, thereby helping to diversify, structure, and enhance science education. It is noteworthy that 96.9% of the class was able to recall the knowledge they had acquired. Below, as an example, students E15, E7, and E9 shared their impressions regarding the topic covered.

> *"Renewable and non-renewable energy sources are topics that were covered throughout elementary school and served as the basis for developing this activity" (E15).*

> *"My knowledge is very limited, because it's been a long time since I studied energy sources [...]" (E7).*

> *"I'm passionate about this subject matter, and the way it's approached also makes a difference; that said, I'm really excited and interested" (E9).*

In the previous responses, we observe the sharing of the class's individual characteristics regarding the subject, which highlighted the mobilization of memory in retrieving the knowledge necessary to complete the activity. This metacognitive process of retrieving information stored in the mind represents a natural activation mechanism through which students are able to assess the knowledge they have acquired and identify similarities with new concepts. In addition, 6% of the students stated that information regarding the topic was scarce, either due to the quality of their learning of the concepts or because of the time that had elapsed since they had studied the subject in depth. From this perspective, knowledge, myths, and confrontations are stimulated in cognition, fostering the development of memory, emotions, and the difficulties experienced in a given topic or practice, which subsequently enhances metacognitive skills in different educational contexts (Nora; Broietti; Corrêa, 2021; Flavell, 1979).

In this subcategory, descriptions were observed that expressed motivational aspects related to the activities implemented; according to metacognitive theory, this finding is considered a characteristic element of the "person" variable, as it represents an internal process within each participant. According to Vieira (2021), emotional experiences, such as motivation, are directly related to performance and achievement in science education, as they involve the intrinsic relationships of the cognitive structure, contributing to the recall and consolidation of learning in school settings. When asked about the emotional experience during classes, student E33 emphasized that the organization of the activities

> *"[...] it breaks away from traditional classes and gets everyone engaged (in a way that's more exciting) in the subject, which is very interesting and even helps with understanding" (E33).*

As can be seen from the transcribed testimony, the act of recalling memories not only facilitates the sharing of knowledge but also allows students to express their feelings regarding previous activities carried out in chemistry classes. This provides an opportune moment to identify, understand, and evaluate the school environment, with the aim of proposing viable solutions to foster learning. In this context, the importance of socio-emotional aspects in the class's learning is evident, as they serve as a factor promoting engagement and participation in classes covering this subject.

3.2 Identification and Interpretation of tasks

The second subcategory focuses on the class's understanding and interpretation of the tasks carried out, making the presence of the "task" variable evident in the analysis of the materials produced. Consequently, it was observed that the class understood the objectives and procedures of the introductory activities, which also influenced the students' participation and constructive interaction within the educational setting. The level of understanding or difficulty directly influences the success of the task; for if understanding is not achieved during the activity, the student may fail to develop the skills necessary for its completion, leading to feelings of discouragement, inadequacy, and inferiority regarding the scientific concepts being studied (Xavier; Peixoto; Veiga, 2020; Rosa, 2014). The descriptions below illustrate the participants' impressions as they analyzed the proposed tasks, indicating whether or not their knowledge was sufficient to answer the questions.

> *"Yes, I think that with what I know about the subject, I can complete the assignment" (E6).*

> *"[...] Not me, though. I don't know much about it in depth, and I don't remember much about energy sources either" (E1).*

This stage is important for understanding and carrying out various tasks in science education, as it demonstrates the class's understanding of the demands and requirements of the activities, and even provides evidence of whether or not the intended objectives have been grasped (Reis; Strohschoen, 2023). It is a process of retrieving and identifying scientific knowledge acquired in previous classes, which is drawn upon after interpreting the tasks.

Consequently, if a student understands the guidelines of the educational practice, they are likely to engage more fully in the activities. It is worth noting that 91% of the participants demonstrated familiarity with the content, while 9% expressed a sense of difficulty associated with the topic. Regarding the latter, the class described a lack of knowledge related to energy sources, suggesting that scientific concepts regarding energy resources were not adequately addressed during their schooling.

3.3 Strengths and weaknesses of the practices implemented

The third subcategory involves describing the students' strengths and weaknesses in the development of SD, serving as an opportunity to reflect on the information, strategies, and skills mobilized within their cognitive framework. Below are the testimonials of three (3) participants following their participation in the activities. These statements identify which aspects served as catalysts for learning, what actually contributed to personal, academic, and professional development, and represent a process of recalling and assimilating the experiences gained in science education.

> *"After all, a debate offers benefits such as developing communication skills, enhancing critical thinking, broadening perspectives, and strengthening argumentative skills—all of which are extremely important in both professional and social situations" (E17).*

> *"Using this technique helps students understand and master the material, as it makes it easier to retain the information" (E35).*

> *"It's a fun and unique way to study the subject, allowing students to review it in an engaging manner, holding our attention and sparking a debate, while encouraging each person to form their own opinion" (E14).*

The previous responses reveal the positive impressions fostered in the class through educational practices, including examples of the metacognitive skills developed by the students during the educational process, namely: argumentation, communication, critical thinking, and concentration. These perspectives demonstrate the effectiveness of the activities, suggesting that the necessary paths to achieve the desired goal were identified, which highlights the results obtained through metacognitive thinking (Silva; Bizerra, 2022). Furthermore, the potential of the mock trial for the class's social, political, and environmental development is evident, which helped enhance scientific knowledge by mobilizing metacognitive awareness to solve the activity.

In contrast, 8.8% of the class reported facing difficulties during chemistry lessons, whether related to the subject matter or stemming from unfamiliarity with diverse teaching practices, which were considered obstacles to effective learning. This demonstrates a process of retrieving knowledge stored in memory, which plays an important role in understanding the task, since the individual analyzes which knowledge and tools will be appropriate for its completion, as well as reflects on sensory, affective, and motor aspects in promoting cognitive behavior (Corrêa; Passos; Arruda, 2018).

3.4 Planning effective actions and tools

The fourth subcategory encompasses the planning of actions, as well as the analysis of the effectiveness of the practices implemented and is a crucial step for understanding and resolving problems. This is the stage at which students evaluate the systematization of practices, analyzing how the activities carried out benefited the class. Furthermore, this stage determines whether the practices influenced each student's individual metacognitive processes, which allows for an assessment of the activities' effectiveness in promoting learning. Some participants stated that

> *"[...] The lesson plan was very well organized, which made learning even easier. I don't see any need to look for other techniques to teach this material; it was covered excellently" (E29).*

> *"The strategies used were excellent, resulting in great performance and learning" (E24).*

Thus, analyzing the organization of the sequence of tasks contributes to reflection and the construction of meaning; for as the individual comes to understand the logistics and functions of the activities, they interact more effectively, creating opportunities to develop new knowledge and skills during educational procedures. The descriptions above contribute to "[...] the planning of time, the sequence of procedures, and the resources necessary to carry out the task [...]" (Portilho, 2024, pp. 120–121) by the participants, serving as a period for planning actions with a view to organizing metacognitive processes to achieve the objectives and solve the research problems.

In addition, 73.5% of the class stated that the practices and tools were sufficient for assimilating the scientific concepts related to the topic, and 26.5% suggested other techniques that could aid in the content covered in the classroom, such as the use of exercise lists, games, and investigative activities. According to Silva (2021), the activation of these thought processes also illustrates students' preference for certain learning strategies, which significantly aids in knowledge construction by outlining procedures to achieve the intended goals within a process of control and self-regulation aimed at improving metacognition.

3.5 Proposed strategies for solving the problem

The fifth subcategory emerged from metacognitive questioning regarding the participants' conception of educational strategies that, in their view, would be most effective in resolving the problem. As a result, it was possible to identify the class's preference for certain strategies, such as conducting investigative activities (33.3%), playful activities (27.3%), and activities using different teaching resources (75.7%). This reflects the individual characteristics of each student in relation to their learning process and, for this reason, highlights the promotion of metacognitive thinking in the educational setting. Thus, the percentages mentioned above are justified by the fact that the students' responses included aspects covering more than one type of activity; therefore, the total does not add up to 100%. The following are the responses obtained from the metacognitive questions.

> *""Although mock juries are a great learning strategy, it's always good to supplement your knowledge with other methods, such as practice lists, for example" (E25).*
>
> *"I believe the model helped us learn about energy sources, but I think seminars—or even mind maps that we can refer to—would be even more helpful" (E3).*

The previous responses demonstrate the educational aspects focused on personalizing learning, in which each student develops a mental, logical, and practical understanding of what actually enhances the assimilation of academic knowledge. In the excerpts described, it is evident that students needed supplementary materials to assist them in their studies, which reflects an awareness of the gaps left in the learning process—insights that are important for systematizing instructional planning in different educational settings. It is through this process that metacognitive skills are fostered; as participants explore their cognitive structures, they simultaneously develop self-regulation, which is linked to individual functions and abilities (Damm; Ferreira; Moura, 2023).

Consequently, the metacognitive elements of strategy and planning were identified in the evaluation of the responses, highlighting the planning and procedures used by the class to achieve the intended objectives. Therefore, it is necessary to evaluate the quality and adequacy of the strategies employed by the participants, given that the actions taken may or may not contribute to the development of individual learning. In this regard, 91.2% of the students stated that the strategies implemented were sufficient, indicating that the pedagogical activities were effective in facilitating the assimilation of scientific knowledge. It is worth noting that, in several responses, they stated that they had achieved an understanding of the subject matter; however, the process was challenging, given that organization, communication, and time were limited resources that hindered the success of the activities. Soares, Rosa, and Darroz (2023), in describing the dynamics of internal mechanisms in the promotion of knowledge, tasks, and strategies, emphasize that information and language are enhanced through metacognitive thinking, involving comprehension, planning, and self-awareness in science education.

3.6 Control and monitoring of procedures to achieve the objective

The sixth subcategory reflects the descriptions and characteristics associated with the metacognitive variable "monitoring," which were obtained from the questions asked in Stage 2 (Table 03). According to Acco and Rosa (2021), monitoring represents a behavioral aspect of executive function control, with a significant influence on the recognition of information, practices, and constructive relationships, and plays a role in the conscious mobilization of students' individual abilities. In this segment, 73.5% of the class reported that the activities promoted the development of skills; and, when asked about the objectives of the mock trial activity, student E15 replied:

> *"The objectives and outcomes achieved through this activity were: improved communication (since the competitive dialogue among students fostered class cohesion and participation); and the development of arguments that encouraged reflection and awareness of the impacts of the sources studied, thereby fostering the participants' critical thinking skills" (E15).*

This perspective involves the mobilization of the metacognitive element of monitoring, as it illustrates the assessment of the appropriateness of systematized actions, since the individual examines the contributions and challenges during the unfolding of cognitive events, analyzing what knowledge is necessary to achieve the research objectives. In Student 15's response, cognitive monitoring is evident through the assessment of objectives and actions for constructing meaning, reviewing strengths and weaknesses experienced in the planning and evaluation of learning. According to the class's assessment, the activities implemented had a playful and investigative nature, which further stimulated understanding of the topic and the development of skills. The student clearly describes which metacognitive skills were enhanced, namely: communication, argumentation, and critical thinking—fundamental characteristics for learning in the sciences. Thus, control is evident in the way actions are planned and carried out, with a view toward evaluating and correcting potential errors, which subsequently influences the (re)planning process, which emphasizes cognitive objectives (Boszko, 2019).

3.7 Assessing the effectiveness of strategies

The penultimate subcategory made it possible to assess the effectiveness of the strategies used, providing an opportunity to determine whether the actions taken were appropriate for achieving the objective. When asked about the adequacy of the strategies for developing the topic, the class described excerpts that fit within the process of monitoring knowledge

> *"No, because what was presented in class was enough for me to understand and grasp what was being conveyed to everyone there" (E18).*

> *"Yes, it was necessary to review some concepts and seek out new information through articles, the internet, etc." (E24).*

Based on the two previous testimonies, it is evident that the tools used did not accommodate all students, which also illustrates the diversity of learning processes in the school environment—an educational perspective informed by metacognitive thinking. This may encourage a fresh approach to teachers' activity planning, with the aim of addressing the specific characteristics of the class in their learning processes. In light of this, 55.9% of the class stated that the strategies were sufficient, while 44.1% noted that they sought other resources to aid their understanding. These data enable not only the analysis of the participants' mental processes but also the improvement of teaching practice, providing positive constructs for the development of diverse and effective tasks aimed at the self-management of conceptions and actions, in a process that activates the mechanisms underpinning metacognition (Soares; Rosa; Darroz, 2023). The contributions of monitoring to science education are further highlighted in the study by Rosa and Ghiggi (2017), in which they argue that monitoring acts as a metacognitive tool for the meaningful construction of scientific concepts, enabling the mental representation of effective problem-solving strategies and influencing students' autonomy, critical thinking, and awareness of their own knowledge.

3.8 Review and self-regulation of learning

Derived from Stage 3 (Table 03), this final subcategory presents the data obtained from the class's self-regulatory processes, which incorporated the metacognitive element of assessment. Based on the self-assessment conducted, 97% of the participants stated that they had meaningfully assimilated the knowledge, demonstrating an understanding of the content, and only 3% did not identify with the set of activities, reporting that other strategies were more helpful in facilitating their learning. When asked about the results achieved at the end of the learning unit, the students responded

> *"Yes, in my opinion, the presentation and the model were sufficient to help students retain and learn the material covered. I believe this will be an assignment we won't forget because it's much more dynamic compared to the assignments we're usually given" (E6).*
>
> *"The methodology yielded many positive results, such as improved understanding of the subjects, learning by doing, interactions, and teamwork" (E35).*
>
> *"[...] we were able to use our creativity, present our results, develop manual and technical skills, and understand concepts, among other things" (E6).*
>
> *"[...] I found the use of the model to be very positive because something visual sticks in the mind; however, if there were short texts or written explanations, it would help people who didn't understand or who take longer to grasp the concepts through verbal explanations" (E9).*

The responses obtained through the final metacognitive questionnaire highlight aspects related to the assessment variable, revealing an analysis of the conceptions, tools, and attitudes developed by the class throughout the science lessons. In this regard, students identify strengths and weaknesses experienced during the educational process, using mental procedures associated with the self-regulation of knowledge. According to Fabri et al. (2022, p. 3), self-regulation is defined as "[...] a process through which individuals activate, guide, monitor, and, likewise, take responsibility for their own learning," thereby reflecting on the effectiveness of the practices employed. This self-regulation also influences the analysis of the quality of learning itself, examining the concepts, procedures, and challenges experienced in educational settings. It is worth noting that 14.7% of students reported difficulties in assimilating the content using the implemented tools, resorting to other resources, such as educational texts and videos available on various digital platforms.

Furthermore, the "assessment" variable extends to the analysis of the metacognitive questions in Stage 3, revealing self-regulated aspects associated with conceptual understanding of the subject matter and the development of skills in the educational environment, which represents the dynamics of metacognitive processes in teaching. Consequently, the activation of this type of thinking directly influences students' learning processes, as academic knowledge and objectives are enhanced, contributing to understanding, performance, and awareness in science education (Damm; Ferreira; Moura, 2023).

The final metacognitive questioning shed light on perspectives focused on content comprehension, the development of skills, and gaps in learning. These perspectives provided an overview of the metacognitive conceptions developed by the class. In addition to understanding the subject matter and the development of skills, this analysis made it possible to examine the strategies and potential flaws in students' learning processes, enabling the identification of self-control and self-regulation characteristics in their actions, which demonstrates the mobilization of metacognitive information (Rosa, 2011). Gaps in learning highlighted the lack of sufficient resources for understanding scientific concepts, thus revealing the diversity of cognitive processes within the class determining factor for planning new educational activities. According to Vieira (2021), the educational system should promote activities involving reflection, argumentation, and the generation of ideas, encouraging students to draw upon their cognitive structures to access the knowledge necessary to achieve specific objectives, thereby enhancing metacognitive, self-regulatory, and evaluative thinking across various educational settings.

4. Conclusion

This study facilitates the activation of metacognitive thinking through educational strategies, using questionnaires that encouraged students to identify, reflect on, and evaluate the knowledge they had acquired. In this process, students encountered metacognitive questions throughout the intervention, prompting them to recall information and strategies while carrying out the activities, which facilitated the refinement and review of the actions necessary for the construction of learning.

Based on the results obtained, it was possible to identify conceptions that spanned the six metacognitive elements (person, task, strategy, planning, monitoring, and evaluation) in the students' descriptions, illustrated by subcategories related to comprehension, memory, reasoning, the effectiveness of strategies, the development of skills, and the sharing of difficulties encountered during the educational process. These analyzed conceptions reflect the activation of metacognitive knowledge, since, as students self-assess their own learning, they also enhance their metacognitive skills, questioning the strengths and weaknesses regarding specific topics and practices. The data obtained made it possible to identify skills in response to the research questions—for example, recall, internal mobilization, critical thinking, and the review and evaluation of learning—since behavioral capacities could be brought to the surface and enhanced through diverse educational activities, as well as through metacognitive questioning in chemistry instruction, thereby achieving the intended objectives. Thus, metacognitive thinking acts as a catalyst for learning, as it enables the activation and coordination of internal mechanisms, thereby enriching scientific awareness and science education.

Therefore, it can be inferred that metacognition aids, on the one hand, in teachers' instructional practices and, on the other hand, in students' assimilation of educational knowledge, shedding light on each individual's mental schemas and procedures. However, the educational landscape still lacks studies involving metacognition in teaching and learning within science education, hindering the expansion and implementation of metacognitive knowledge. In future studies, we intend to use metacognitive questions at different stages and on various topics in education to investigate the influence of metacognition on students' educational processes, thereby fostering self-awareness and enhancing learning.

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