ISSN 1981-416X
Licenciado sob uma Licença Creative Commons

Dossier **doi.org/10.7213/1981-416X.26.090.DS10EN**

Revista
Diálogo
Educacional

PUCPRESS

periodicos.pucpr.br/dialogoeducacional

Didactic engineering as a strategy for the development of metacognition

Engenharia Didática como estratégia para o desenvolvimento da metacognição

Ingeniería didáctica como estrategia para el desarrollo de la metacognición

Francisca Érica da Silva Maia [a]
Mossoró, RN, Brasil
Universidade Federal Rural do Semi-Árido (UFERSA)

Lázaro Luis de Lima Sousa [b]
Mossoró, RN, Brasil
Universidade Federal Rural do Semi-Árido (UFERSA)

How to cite: MAIA, Francisca Érica da Silva; SOUSA, Lázaro Luis de Lima. Didactic engineering as a strategy for the development of metacognition. *Revista Diálogo Educacional*, Curitiba, PUCPRESS, v. 26, n. 90, p. 1637-1649, jul./set. 2026. https://doi.org/10.7213/1981-416X.26.090.DS10EN

Abstract

This article analyzes the articulation between metacognition and Didactic Engineering as a strategy for the development of pedagogical practices in Science Education. Grounded in references from Cognitive Psychology and Mathematics Education, the study characterizes metacognition as the ability to plan, monitor, and self-regulate one's own learning processes, highlighting its relationship with self-regulated learning. In parallel, Didactic Engineering is presented as a research and intervention methodology structured in stages that enables the systematic and reflective organization, implementation, and

[a] Ph.D. candidate – POSENSINO/UERN, UFERSA, IFRN.Master's degree in Biology Education – PROFBIO/UERN, email: hericamaia@gmail.com
[b] Ph.D. in Physics from the Federal University of Rio Grande do Norte (UFRN), email: lazaro@ufersa.edu.br

evaluation of didactic situations. This theoretical study discusses the convergences between these approaches, showing that their integration makes it possible to align students' cognitive processes with the intentional organization of teaching. Such articulation favors the development of skills such as critical thinking, autonomy, problem-solving, and meaningful learning. In addition, the role of the teacher as a mediator is emphasized, being responsible for promoting learning situations that encourage reflection and self-regulation. It is concluded that the integration between metacognition and Didactic Engineering constitutes a promising framework for pedagogical innovation, contributing to the construction of investigative, reflective, and student-centered learning environments, especially in the context of Natural Sciences.

***Keywords**: Didactic Engineering. Metacognition. Science Education.*

Resumo

Este artigo analisa a articulação entre a metacognição e a Engenharia Didática como estratégia para o desenvolvimento de práticas pedagógicas no ensino de Ciências. Fundamentado em referenciais da Psicologia Cognitiva e da Educação Matemática, o estudo caracteriza a metacognição como a capacidade de planejar, monitorar e autorregular os próprios processos de aprendizagem, destacando sua relação com a aprendizagem autorregulada. Paralelamente, a Engenharia Didática é apresentada como uma metodologia de pesquisa e intervenção estruturada em etapas que permite organizar, implementar e avaliar situações didáticas de forma sistemática e reflexiva. A pesquisa, de natureza teórica, discute as convergências entre essas abordagens, evidenciando que sua integração possibilita alinhar os processos cognitivos dos estudantes à organização intencional do ensino. Tal articulação favorece o desenvolvimento de habilidades como pensamento crítico, autonomia, resolução de problemas e aprendizagem significativa. Além disso, ressalta-se o papel do professor como mediador, responsável por promover situações de aprendizagem que estimulem a reflexão e a autorregulação. Conclui-se que a integração entre metacognição e Engenharia Didática constitui um referencial promissor para a inovação pedagógica, contribuindo para a construção de ambientes de aprendizagem investigativos, reflexivos e centrados no estudante, especialmente no contexto das Ciências da Natureza.

Palavras-chave: Engenharia Didática. Metacognição. Ensino de Ciências.

Resumen

Este artículo analiza la articulación entre la metacognición y la Ingeniería Didáctica como estrategia para el desarrollo de prácticas pedagógicas en la enseñanza de las Ciencias. Fundamentado en referentes de la Psicología Cognitiva y de la Educación Matemática, el estudio caracteriza la metacognición como la capacidad de planificar, monitorear y autorregular los propios procesos de aprendizaje, destacando su relación con el aprendizaje autorregulado. Paralelamente, la Ingeniería Didáctica se presenta como una metodología de investigación e intervención estructurada en etapas que permite organizar, implementar y evaluar situaciones didácticas de manera sistemática y reflexiva. La investigación, de carácter teórico, discute las convergencias entre estos enfoques, evidenciando que su integración posibilita alinear los procesos cognitivos de los estudiantes con la organización intencional de la enseñanza. Dicha articulación favorece el desarrollo de habilidades como el pensamiento crítico, la autonomía, la resolución de problemas y el aprendizaje significativo. Además, se destaca el papel del docente como mediador, responsable de promover situaciones de aprendizaje que estimulen la reflexión y la autorregulación. Se concluye que la integración entre metacognición e Ingeniería Didáctica constituye un referente prometedor para la innovación pedagógica, contribuyendo a la construcción de ambientes de aprendizaje investigativos, reflexivos y centrados en el estudiante, especialmente en el contexto de las Ciencias Naturales.

***Palabras clave**: Ingeniería Didáctica. Metacognición. Enseñanza de las Ciencias.*

1. Introduction

In the contemporary educational landscape, marked by the complexity of educational demands and the need to develop critical, autonomous individuals capable of adapting to increasingly dynamic contexts and engaging in continuous learning, it is essential to rethink pedagogical practices and the processes of teaching and learning. In a context permeated by multiple social, cognitive, and intellectual demands, it is necessary to seek pedagogical alternatives that contribute to the holistic development of the individual. In this regard, the integration of metacognition (Portilho; Da Silva; De Paula Batista, 2023) and Didactic Engineering (Artigue, 1988) presents itself as a promising field of research, as it integrates cognitive, reflective, and methodological dimensions into the development of knowledge.

Metacognition, in general terms, can be understood as an individual's ability to reflect on, monitor, and regulate their own cognitive processes, and is widely recognized as a key factor in meaningful learning. According to Flavell (1979, p. 906), it refers to "knowledge and monitoring of one's own cognitive processes." This concept was later expanded by Weinert and Kluwe (1987), who highlighted the role of active learning regulation, and by Zimmerman (2002, p. 66), who asserted that learners act as active participants in their own learning processes from both metacognitive and motivational perspectives. More recent studies corroborate this understanding by indicating that students who use metacognitive strategies tend to achieve more positive learning outcomes (Pandey & Mohan, 2024).

At the same time, Didactic Engineering, which originated in the field of mathematics education, particularly through the work of Michèle Artigue (1996) is a methodology that integrates theory and practice. According to the author, Didactic Engineering consists of "a process of designing and analyzing teaching devices that allows for the study of learning phenomena under controlled conditions." This approach is directly aligned with the Theory of Didactic Situations, proposed by Guy Brousseau (1997), which emphasizes the importance of interactions between the learner, knowledge, and the environment in the construction of knowledge.

The convergence of metacognition and Didact Engineering (Lima; Dorneles; Da Rosa, 2025) reveals significant potential for the development of more effective pedagogical practices. While metacognition emphasizes the learner's internal processes, Didactic Engineering provides a methodological framework for organizing teaching situations capable of fostering such processes. Thus, practices grounded in these approaches can promote deeper, more autonomous, and more reflective learning.

Conducting studies that integrate these two approaches is justified by the need to understand how intentionally planned pedagogical practices can contribute to the development of metacognitive skills. Furthermore, in light of the guidelines of the National Common Core Curriculum (BNCC) (BRAZIL, 2018), which emphasizes the development of competencies such as critical thinking, argumentation, and autonomy, it is important to investigate methodologies aligned with these objectives.

Thus, this study is justified by its theoretical and practical contribution, as it integrates principles of metacognition and instructional design, providing a foundation for the development of more reflective, inquiry-based, and student-centered teaching practices. It is hoped that this will contribute to the improvement of teaching, especially in the field of natural sciences, by fostering more meaningful learning processes.

The methodology of this study is characterized as a qualitative research approach, applied in nature and exploratory-descriptive in character, grounded in theoretical analysis and the proposal of a teaching sequence structured according to the principles of Didactical Engineering. The research was conducted based on a literature review of metacognition, self-regulated learning, and Didactic Engineering, seeking to identify epistemological and methodological connections among these frameworks. Building on this foundation, a teaching sequence was developed, organized according to the classic stages of Didactic Engineering and incorporating pedagogical strategies focused on the planning, monitoring, and assessment of learning.

The analysis of the proposal was conducted using a theoretical-analytical approach, examining the extent to which each stage of Didactic Engineering has the potential to foster the development of metacognitive aspects. To this end, dimensions associated with metacognition, such as metacognitive knowledge, monitoring, self-regulation, and self-assessment were used as analytical categories. Thus, the study sought to understand how the intentional

organization of didactic situations, grounded in Didactic Engineering, can contribute to the promotion of more reflective pedagogical practices and to the strengthening of student autonomy in different teaching contexts.

2. Theoretical and conceptual foundations of the study

To provide a foundation for this research, two central frameworks are discussed: metacognition and Didactical Engineering. First, the theoretical foundations and educational implications of metacognition are addressed, with an emphasis on its relationship to autonomy and self-regulation in learning. Next, we present the assumptions and educational potential of Didactical structional Engineering, highlighting its contribution to the planning and organization of intentional pedagogical practices.

2.1 Metacognition: Theoretical Foundations and Educational Implications

Metacognition is a central area in the field of cognitive psychology and is widely incorporated into contemporary educational discussions. The term was first proposed by John H. Flavell, who defined it as awareness of one's own cognitive functioning and its monitoring (Flavell, 1979). This definition ushered in a field of research focused on understanding how individuals reflect on their own mental processes and regulate learning.

Subsequently, Brown (1987) expanded on this perspective by emphasizing the mechanisms of executive control and self-regulation, highlighting that effective learning depends on an individual's ability to plan, monitor, and evaluate their cognitive actions. This approach was further developed by Zimmerman (2002), who linked metacognition to self-regulated learning, understood as an active, intentional, and goal-oriented process. In the contemporary context, authors such as Özturk (2024) argue that metacognition should be understood as a dynamic and contextual process. This perspective broadens the concept by aligning it with the educational demands of the 21st century, characterized by complexity, the rapid flow of information, and the need for continuous learning

Traditionally, metacognition is organized into three main components: metacognitive knowledge, metacognitive monitoring, and self-regulation. Metacognitive knowledge refers to an individual's understanding of their own cognitive processes, including learning strategies, personal characteristics, and task demands. Schraw and Moshman (1995) identify three dimensions of this metacognitive knowledge: declarative, procedural, and conditional.

Metacognitive monitoring, in turn, refers to the ability to track and evaluate one's own performance while carrying out activities. In this process, students analyze their understanding, identify gaps in their learning, and adjust their strategies as needed. According to O'Neill et al. (2025, p. 3), this monitoring facilitates the identification of conceptual difficulties and the reorganization of learning strategies, contributing to greater autonomy and effectiveness in the educational process.

Self-regulation refers to the ability to control and adapt cognitive and motivational behavior in response to learning demands. Zimmerman (2002) points out that this self-regulatory process involves three main phases: planning, execution, and self-reflection. Self-regulated learning presupposes that students are capable of consciously managing their own learning process through the intentional use of metacognitive strategies. Zimmerman (2002, p. 66) states that self-regulated learners are active participants, from metacognitive, motivational, and behavioral perspectives, in their own learning process. From this perspective, self-regulated students plan, monitor, and evaluate their actions, maintain motivation to achieve goals, and adopt behaviors appropriate to the learning context. Contemporary studies corroborate this understanding.

Recent studies underscore the importance of metacognition and self-regulation for academic performance. Anderson et al. (2024, p. 272) show that students who engage in metacognitive strategies achieve better learning outcomes, while Nicoara and Nedelcu (2025) identify self-regulation as a predictor of better performance in both in-person and digital educational contexts. Furthermore, recent research indicates that the integration of metacognition and digital technologies enhances self-regulated learning (De Almeida; Grein; Bedin, 2024; Júnior; Vasconcelos;

Menezes, 2025). According to O'Neill et al. (2025, p. 3), well-structured virtual environments can support metacognitive processes by encouraging reflection and self-assessment. This, in turn, expands the possibilities for monitoring performance, critically analyzing one's own actions, and adjusting learning strategies.

The incorporation of metacognition into the educational context entails significant changes in teaching practice (De Almeida; Grein; Bedin, 2024). From this perspective, teachers no longer act exclusively as transmitters of content but instead assume the role of mediators of the learning process. Among the main pedagogical implications are the explicit use of metacognitive strategies, such as task planning and post-activity reflection; encouraging self-assessment, allowing students to identify their difficulties and potential; the adoption of active methodologies, such as problem-based learning and scientific inquiry; and the use of digital technologies to support self-regulated learning (Júnior; Vasconcelos; Menezes, 2025).

These pedagogical practices are supported by the general competencies established by the BNCC (BRAZIL, 2018), a document that guides the holistic education of students by prioritizing not only the acquisition of conceptual knowledge but also the development of cognitive, socio-emotional, and ethical competencies. Among these competencies, critical thinking, intellectual autonomy, reasoned argumentation, problem-solving, and the ability to apply knowledge in different contexts stand out. In this context, metacognition plays a strategic role, as it fosters conscious reflection on the learning process itself, enabling students to plan their actions, monitor their performance, identify difficulties, and select the most appropriate strategies to achieve their goals (De Almeida; Grein; Bedin, 2024).

From this perspective, the development of metacognitive skills contributes to the formation of students who are more autonomous, reflective, and in control of their own academic paths. More than just improving immediate academic performance, metacognition expands an individual's ability to learn continuously, adapt to new demands, and make critical and informed decisions. In a society marked by the rapid flow of information, technological transformations, and the complexity of contemporary problems, educating individuals capable of understanding, regulating, and improving their own learning processes has become a fundamental educational necessity. Thus, metacognition establishes itself as a central element of an education focused on lifelong learning and on preparing individuals to act critically, responsibly, and actively in society (Rodrigues et al., 2023).

2.2 Engineering Pedagogy: assumptions and educational potential

Didactic Engineering emerged in the field of mathematics education in France in the 1980s as a methodology focused on research and intervention in teaching. Its development is widely attributed to Michèle Artigue, who defined Didactic Engineering as an approach capable of linking theory and practice through the stages of design, experimentation, and analysis of teaching situations. It is based on the idea that teaching can be planned in a systematic and investigative manner, allowing the teacher-researcher to understand learning processes through the analysis of concrete situations. For this reason, it differs from traditional approaches by explicitly embracing the experimental, reflective, and interventionist nature of teaching practice (Artigue, 1988).

Furthermore, Didactic Engineering is directly linked to the Didactics of Mathematics, particularly to the Theory of Didactic Situations proposed by Brousseau (1997), which emphasizes the role of interactions among teacher, student, and knowledge in the construction of knowledge. In this sense, the teaching process is not limited to the transmission of content but involves the creation of situations capable of mobilizing cognitive strategies and promoting meaningful learning.

Didactical Engineering offers significant contributions to the planning and organization of learning environments, particularly with regard to the design of pedagogical experiences that are intentionally crafted and theoretically grounded. Among its main contributions are: structured instructional planning, anticipation of learning difficulties, promotion of active student participation, development of cognitive and metacognitive skills, and integration of theory and practice (Artigue, 1988).

According to Artigue (1988), from a methodological standpoint, Didactic Engineering is organized into four main stages: preliminary analysis; design and a priori analysis; experimentation; and a posteriori analysis and validation. These stages structure both pedagogical practice and scientific research, facilitate the

intentional planning of learning situations, and enable teachers to anticipate difficulties, observe the strategies employed by students, and analyze the results obtained.

Preliminary analysis consists of an in-depth study of the content to be taught, taking into account epistemological, pedagogical, and cognitive aspects. At this stage, students' prior knowledge, recurring difficulties, and the characteristics of the educational context are also examined. According to Artigue (1996), this stage is essential for informing didactic decisions, anticipating potential learning obstacles, and setting objectives consistent with the group's profile.

The design and a priori analysis phase involves planning the instructional sequence to be implemented. At this stage, activities, methodological strategies, resources, and possible teacher interventions are defined. In addition, the goal is to anticipate students' responses, difficulties, and strategies they might employ. According to Artigue (1996, p. 247), this phase consists of predicting students' possible responses and actions in light of the proposed instructional variables, highlighting the investigative nature of the methodology.

The experimentation phase involves applying the instructional sequence in a real classroom setting. The number of interventions or sequences implemented may vary depending on the pedagogical objectives established by the researcher. During this stage, the teacher-researcher observes, records, and analyzes interactions, the strategies used by students, and any difficulties that arise. This is a crucial moment for comparing the hypotheses formulated in the a priori analysis with the reality of pedagogical practice.

Finally, post hoc analysis and validation consist of interpreting the data collected during the experiment and comparing these results with the initial hypotheses. This process makes it possible to verify the appropriateness of the pedagogical choices made and to understand the effects of the proposed interventions. Validation, in this context, is not limited to verifying results but involves analyzing learning processes and the conditions that facilitate them. If limitations or inconsistencies are identified, the researcher can reformulate previous stages and reapply interventions, highlighting the dynamic, continuous, and flexible nature of the methodology.

In light of this, Didactic Engineering stands out as an important research methodology in the field of education, as it systematically integrates theory and practice. Unlike purely descriptive approaches, it takes on an interventionist character, in which the researcher acts directly within the teaching and learning process. According to Artigue (2009), Didactic Engineering enables the generation of knowledge about teaching through the analysis of real-world situations, thereby contributing to the improvement of pedagogical practices. Furthermore, this approach fosters the development of professional knowledge, as teachers actively engage in processes of inquiry and reflection on their own practice; Educational Engineering offers significant professional development potential for both students and faculty. For students, it promotes the development of cognitive, metacognitive, and investigative skills; for teachers, it enables the consolidation of reflective, critical, and theoretically grounded practice (De Almeida; Grein; Bedin, 2024). This perspective aligns with the conception of education advocated by Paulo Freire in Pedagogy of Autonomy (Freire, 1996), which understands teaching as a dialogic and formative process in which educators and learners construct knowledge collaboratively.

Literature has expanded the use of Didactic Engineering beyond mathematics education to include areas such as the natural sciences, highlighting its interdisciplinary potential and its relevance in the contemporary educational context (De Lima, 2023; Sousa et al., 2025). In the current landscape, marked by the growing presence of digital technologies, this approach can also be employed in the design of virtual learning environments, enhancing interaction, autonomy, and systematic monitoring of the learning process.

3. Didactic engineering as a catalyst for metacognitive processes

The methodological framework of Didactic Engineering (Artigue, 1988) has the potential to foster metacognitive processes, as it enables the intentional organization of teaching situations that encourage students to reflect on how they learn, monitor their performance, and adjust their strategies in the face of

cognitive challenges. Rather than limiting itself to the transmission of content, this approach organizes teaching in a planned, inquiry-based, and reflective manner, creating conditions for students to actively participate in the construction of knowledge (Brousseau, 1997; Anderson *et al*., 2024).

During the preliminary analysis phase, for example, the teacher identifies students' prior knowledge, difficulties, and potential epistemological obstacles, which enables the design of activities tailored to the students' cognitive level. This initial assessment fosters metacognitive processes by encouraging students to identify what they already know, what they still need to learn, and the potential difficulties involved in the process. These aspects have taken center stage in contemporary educational discussions (Boszko, 2022), especially in light of social transformations and the expansion of digital technologies. In this context, metacognitive development is related to students' ability to plan, monitor, and evaluate their own learning strategies, thereby becoming more autonomous, critical, and aware of their educational journey.

During the design and a priori analysis phase, Didactic Engineering enables the planning of tasks, problems, and pedagogical interventions capable of stimulating cognitive planning. At this stage, teachers can structure activities that require students to formulate hypotheses, select strategies, predict outcomes, and justify their reasoning, thereby promoting the development of metacognitive knowledge and the anticipation of actions (De Almeida; Grein; Bedin, 2024).

During the experiment, instructional scenarios are applied in a real-world context, at which point students put problem-solving strategies into practice, analyze interim results, and adjust their procedures based on the difficulties they encounter. This process directly promotes metacognitive monitoring, as it requires students to continuously monitor their own performance, identify errors, and make decisions to overcome them.

Finally, during the post-analysis and validation stage, both the teacher and the students reflect on the results obtained, the strategies used, and any persistent difficulties. This phase contributes to self-assessment and the strengthening of self-regulation, as it allows for a critical analysis of the process and the identification of opportunities for improvement.

Thus, Instructional Engineering promotes metacognitive processes by integrating intentional instructional planning, reflective problem-solving, and continuous assessment of learning. Its contribution is not limited to the organization of instruction but extends to the creation of environments that encourage students to take on an active, conscious, and self-regulated role in their learning process. Nicoara and Nedelcu (2025) emphasize that metacognitive training helps students plan, monitor, and evaluate their own learning processes, promoting greater autonomy.

As a proposal, Table 1 presents a teaching sequence developed based on the principles of Didactic Engineering, integrating its methodological stages with strategies aimed at developing metacognitive skills. Its structure includes phases of assessment, planning, intervention, monitoring, and evaluation, promoting both the construction of knowledge and systematic reflection on the learning process itself.

Table 1 – Instructional sequence for applying Instructional Engineering in conjunction with metacognition

Stages of Didactic Engineering	Desired Actions
Preliminary Analysis	• Identify students' prior knowledge and difficulties; • Administer an initial diagnostic questionnaire; • Administer a metacognitive questionnaire;
Design and a priori analysis	• Predicting possible scenarios; • Instructional planning;
Experimentation	• Initial problem-posing; • Use of resources; • Metacognitive strategy with a monitoring checklist; • Use of mathematical modeling with reflective questions;

	• Solving contextualized problems with monitoring; • Construction of concept maps; • Administration of a new metacognitive questionnaire and comparison with the initial diagnostic questionnaire; • Conclusion with reflective questions such as: "What did I learn?"; "How did I learn?"; and "What would I do differently?"
Post-hoc analysis and validation	• Data to be analyzed: initial and final questionnaires; responses to reflective questions; completed activities; and teacher notes • Analytical categories: planning; monitoring; control; assessment; and strategy adjustment; • Expected evidence: greater autonomy; verbalization of strategies; conscious error correction; and conceptual improvement regarding the chosen topic;

Source: Authors (2026).

In Table 1, activities were initially planned to assess students' prior knowledge and identify potential difficulties, allowing the teacher to understand the group's characteristics and establish learning objectives consistent with the context under investigation. This stage is fundamental for informing pedagogical decisions, guiding the planning of subsequent actions, and promoting the incorporation of metacognitive aspects into the approach grounded in Didactic Engineering.

During the design and a priori analysis phase, instructional situations were intentionally planned to promote active participation, problem-solving, reasoning, and decision-making. In addition, the study sought to anticipate possible strategies employed by students, recurring conceptual difficulties, and forms of teacher intervention capable of fostering learning progress.

The experimentation phase, presented in Table 1, involved implementing the sequence in a real teaching context, allowing for the observation of interactions among students, content, and pedagogical strategies. During this process, activities aimed at metacognitive development were incorporated, such as periods of individual planning, monitoring of one's own performance, review of strategies, and self-assessment. These procedures helped raise students' awareness of their cognitive processes and fostered greater autonomy in conducting the proposed activities.

Finally, the post hoc analysis and validation made it possible to compare the hypotheses initially formulated with the results observed during the implementation of the proposal. This stage helped assess the appropriateness of the methodological choices made, identify strengths and limitations, and reflect on possible revisions to the instructional sequence.

Thus, the sequence presented in Table 1 is characterized as a structured, inquiry-based pedagogical approach, in which Didactic Engineering provides methodological support for organizing instruction, while metacognition guides strategies aimed at monitoring, controlling, and assessing learning. This integration fosters the creation of more reflective, intentional, and student-centered educational environments and can be adapted to different content areas and teaching contexts.

Thus, educational engineering contributes to the development of critical and reflective thinking, the strengthening of autonomy, the improvement of problem-solving skills, and the development of investigative and collaborative competencies (Artigue, 1996; Brousseau, 1997; Anderson et al., 2024). By designing theoretically grounded instructional sequences, teachers integrate content, skills, and competencies in a cohesive manner, fostering learning experiences aligned with contemporary educational demands. Furthermore, by understanding metacognition as a dynamic process that emerges from the constant interaction between social, pedagogical, and technological factors (Özturk, 2024), our understanding of its relevance in the current educational context is broadened. In this scenario, the teacher's role also transforms, shifting from a practice centered on the transmission of content to a mediating, investigative, and reflective practice. Teachers begin to encourage reflection, self-assessment, and student agency, fostering the development of students who are more autonomous and aware of their own cognitive processes.

3.1 The relationship between didactic engineering and metacognition in science education

The connection between Didactic Engineering and metacognition reveals important epistemological convergences, since both are grounded in constructivist perspectives on learning, in which the student takes on an active role in the construction of knowledge. While metacognition, as proposed by John H. Flavell (Flavell, 1979), emphasizes processes of reflection, monitoring, and self-regulation of learning, Didactic Engineering, systematized by Michèle Artigue (Artigue, 1996), offers a methodological framework for organizing teaching situations that foster such processes. Both approaches also align with the Theory of Didactic Situations, proposed by Guy Brousseau (Brousseau, 1997), in recognizing the importance of the interaction between the learner, knowledge, and the environment in the construction of knowledge.

In this context, Didactic Engineering can be understood as a catalyst for metacognitive processes, since its methodological framework facilitates the design of activities that encourage students to reflect on their own learning process (De Almeida; Grein; Bedin, 2024). Carefully planned problem situations encourage the formulation of hypotheses, the evaluation of strategies, the identification of difficulties, and reflection on mistakes and successes, elements central to both metacognition and self-regulated learning, as discussed by Barry J. Zimmerman (Zimmerman, 2002).

Within the framework of these approaches, the teacher's role as a mediator of the learning process stands out (Moreira, 1999). From this perspective, the teacher no longer acts exclusively as a transmitter of content but instead assumes the role of planner, organizer, and analyst of intentionally structured teaching situations. Their role consists of promoting meaningful interactions between students and the object of knowledge, thereby fostering cognitive and reflective development. This understanding aligns with Lev Vygotsky's (1998) sociocultural perspective, according to which learning occurs through social mediation. For the author, the teacher plays a fundamental role in organizing experiences that enable advances in cognitive development, providing support so that students can initially accomplish what they will later be able to accomplish independently.

Paulo Freire (1996) reinforces this concept by viewing teaching as a practice aimed at creating the conditions for the construction of knowledge, rather than the mere transmission of information. From this perspective, teaching involves setting appropriate challenges, anticipating difficulties, and mediating interactions, thereby fostering the development of cognitive and metacognitive skills.

The organization of tasks, problems, and instructional situations with a metacognitive focus is a central element in this approach. Such activities should be challenging, contextualized, and open to reflection, encouraging students to articulate their reasoning, justify their answers, evaluate strategies, and review procedures. Among the pedagogical strategies that support this process, the use of guiding questions, opportunities for self-assessment, reflective journals, and collaborative activities stand out. Furthermore, the integration of Didactic Engineering and metacognition fosters the creation of reflective and self-regulated learning environments, in which students become more aware of their cognitive processes. According to Zimmerman (2020), self-regulated learning involves the ability to control the cognitive, motivational, and behavioral dimensions of learning. Recent studies reinforce this understanding by demonstrating that this process is cyclical and adaptive in nature, involving planning, monitoring, and self-reflection (Kitsantas et al., 2025).

In science education, this integration is particularly relevant, as it fosters investigative practices and problem-solving, fundamental aspects for the development of scientific thinking (Júnior; Vasconcelos; Menezes, 2025). By participating in activities structured according to the principles of Engineering Pedagogy, students not only apply conceptual knowledge but also develop the ability to analyze procedures, evaluate strategies, and critically reflect on their own learning.

These processes contribute to the development of essential skills, such as autonomy, critical thinking, reasoning, and problem-solving, in line with the BNCC guidelines (BRAZIL, 2018). As a result, the integration of metacognition and instructional design is recognized as a robust theoretical and methodological framework for

pedagogical innovation, as it combines an understanding of internal learning processes with the intentional organization of teaching practices.

By promoting self-regulation, critical reflection, and awareness of one's own learning, this integration fosters the development of students who are more autonomous and better prepared to play an active role in various social and academic contexts. At the same time, by structuring inquiry-based and theoretically grounded learning situations, Engineering Pedagogy contributes to more reflective, intentional, and student-centered teaching practices, emerging as a promising strategy for improving the quality of science education.

3.2 The role of the teacher as a mediator of metacognitive processes

In the context of contemporary pedagogical approaches, teachers play a fundamental role in promoting metacognitive processes, as they shift from acting exclusively as transmitters of content to serving as mediators of learning. From this perspective, their role involves the intentional organization of instructional situations, the presentation of cognitive challenges, and the ongoing monitoring of students' development, thereby encouraging reflection on the learning process itself (Moreira, 1999).

Teacher mediation is particularly important for the development of metacognition, as it helps students plan strategies, monitor their performance, and critically evaluate their results. According to Lev Vygotsky (1998), learning occurs through social interaction and cultural mediation, with the teacher responsible for creating conditions that enable students to advance from already established levels of development to more complex ones. In this sense, the teacher's role promotes the internalization of cognitive and metacognitive strategies that can later be used independently.

From this perspective, the teacher acts as a guide in the reflective process, encouraging students to articulate their reasoning, justify their choices, identify difficulties, and reformulate strategies when necessary. Such actions contribute to strengthening self-regulated learning, which Zimmerman (2002) defines as an active process in which students participate metacognitively, motivationally, and behaviorally in their own learning.

Furthermore, teacher mediation involves providing continuous, qualitative feedback, which is essential for the development of metacognitive awareness. By offering feedback on performance, strategies used, and opportunities for improvement, teachers help students identify conceptual gaps and adjust their learning strategies. As Nicoara and Nedelcu (2025) point out, pedagogical interventions focused on metacognitive training promote greater autonomy, self-monitoring skills, and academic performance.

In the field of Didactic Engineering, this role becomes even more evident, as the teacher actively participates in the planning, implementation, observation, and analysis of instructional situations. Thus, in addition to facilitating content, the teacher investigates learning processes and carries out interventions based on evidence observed during teaching practice. According to Michèle Artigue (1996), Didactic Engineering enables teachers to systematically integrate theory and practice, fostering more inquiry-based and reflective learning environments.

Table 2 summarizes the relationship between Didactic Engineering and the development of metacognitive processes, highlighting the complementary roles played by the teacher and the student throughout the methodological stages of this approach, with a proposal whose central objective is to promote meaningful learning through the development of metacognitive skills, particularly those related to planning, monitoring, and evaluating learning.

Table 2 – The roles of the teacher and the student in engineering pedagogy focused on metacognitive development

Stages of Educational Engineering	Teacher as the mediator	the student as the protagonist
Preliminary Analysis	• Acesses students' prior knowledge, challenges, and contexts; • Sets learning objectives and metacognitive goals;	• Draws on prior knowledge; • Recognizes what they know and what they need to learn; • Sets their goals;

Design and a priori analysis	• Plans intentional learning situations that promote metacognitive processes; • Anticipates students' strategies and potential obstacles; • Defines interventions and resources;	• Plan how you will learn; • Choose strategies; • Anticipate outcomes and challenges; • Formulate hypotheses;
Experimentation	• Implementa a sequência didática; • Observa, acompanha e registra interações e estratégias; • Intervém com perguntas, pistas, feedbacks e desafios;	• Implements the instructional sequence; • Observes, monitors, and records interactions and strategies; • Intervenes with questions, hints, feedback, and challenges;
Post-hoc analysis and validation	• Analyzes students' data and work; • Compares results with initial hypotheses; • Evaluates the effectiveness of the lesson sequence and proposes adjustments;	• Evaluates results and the strategies used; • Identifies successes, mistakes, and their causes; • Reflects on what they have learned and how to improve;

Source: Prepared by the authors based on Artigue (1988; 1996), Brousseau (1997), Flavell (1979), Zimmerman (2002; 2020), Vygotsky (1998), and Özturk (2024).

Table 2 highlights the teacher's role as a mediator of the learning process in the context of Didactic Engineering, acting in an intentional and reflective manner at every stage of the didactic design. The teacher's role involves investigating prior knowledge, identifying difficulties, and defining learning objectives and metacognitive goals. In addition, it is the teacher's responsibility to plan didactic situations, anticipate strategies and obstacles, organize pedagogical interventions, and monitor the implementation of the sequence, observing interactions, analyzing students' strategies, and intervening through questioning, feedback, and challenges. Finally, the teacher analyzes the results obtained, compares them with the initial hypotheses, and proposes adjustments or revisions, with the aim of continuously improving pedagogical practice.

Thus, the teacher's role as a mediator of metacognitive processes is central to the development of pedagogical practices aimed at fostering autonomy, critical thinking, and meaningful learning. By encouraging planning, monitoring, self-assessment, and reflection, teachers help students become more aware of their cognitive processes and better prepared to engage in lifelong learning.

Conversely, Table 2 portrays the student as an active participant, that is, as the protagonist of their own learning, who draws on prior knowledge, recognizes what they already know, and identifies the content or skills they still need to develop. The student is able to plan how they will learn, select strategies, formulate hypotheses, and anticipate possible difficulties. During the experimentation phase, they put their strategies into practice, continuously monitor their performance, and adjust their approach when encountering obstacles. Finally, they evaluate results, identify mistakes and successes, reflect on the strategies used, and recognize opportunities for improvement.

4. Conclusion

An analysis of the foundations of metacognition and Didactic Engineering shows that both serve as relevant frameworks for understanding and improving pedagogical practices in the contemporary educational context. Metacognition emphasizes the importance of developing awareness, monitoring, and self-regulation of cognitive processes, thereby fostering more autonomous, critical, and meaningful learning. In turn, Didactic Engineering serves as a consistent methodology for the planning, implementation, and analysis of teaching situations, enabling teachers to act in an investigative, reflective, and intentional manner regarding their pedagogical practice. Due to its methodological characteristics, this approach demonstrates potential for application in other fields of knowledge, such as the natural sciences.

The connection between these two frameworks is particularly relevant because it integrates an understanding of internal learning processes with the intentional organization of teaching practices. This convergence fosters the

development of essential competencies, such as critical thinking, problem-solving, autonomy, and self-regulated learning, in line with the competencies outlined in educational policy documents.

Finally, the integration of metacognition and didactic design contributes to the creation of learning environments that are more reflective, inquiry-based, and student-centered, with the teacher serving as a mediator. Furthermore, it highlights the importance of ongoing teacher training, geared toward the development of theoretically grounded pedagogical practices aligned with contemporary educational demands. In this sense, this integration represents a promising strategy for improving the quality of teaching and for fostering students who are more autonomous and aware of their own learning processes.

References

ANDERSON, N. et al. Metacognitive skills in learning and pedagogy: a systematic review and analysis. *Journal of Cognition and Culture*, v. 24, n. 3-4, p. 268–285, 2024.

ARTIGUE, Michèle. Ingénierie didactique. *Recherches en didactique des mathématiques*, v. 9, n. 3, p. 281-308, 1988.

ARTIGUE, M. Ingénierie didactique. *In*: BRUN, J. (org.). *Didactique des mathématiques*. Paris: Delachaux et Niestlé, 1996.

BOSZKO, Camila. Metacognição no ensino da física: da concepção à aplicação. *Revista Espaço Pedagógico*, v. 29, n. 2, p. 737-740, 2022.

BRASIL. Ministério da Educação. *Base Nacional Comum Curricular*. Brasília, DF: Ministério da Educação, 2018. Disponível em: http://basenacionalcomum.mec.gov.br/images/BNCC_EI_EF_110518_versaofinal_site.pdf. Acesso em: 8 maio 2026.

BROUSSEAU, G. *Theory of didactical situations in mathematics*. Dordrecht: Kluwer Academic Publishers, 1997.

BROWN, A. L. Metacognition, executive control, self-regulation, and other more mysterious mechanisms. *In*: WEINERT, F. E.; KLUWE, R. (eds.). *Metacognition, motivation, and understanding*. Hillsdale: Erlbaum, 1987.

DE ALMEIDA, Caroline Medeiros Martins; GREIN, Liliane de Fátima; BEDIN, Everton. Metodologias ativas, tecnologias digitas e ferramentas metacognitivas: um curso de formação continuada. *Redin-Revista Educacional Interdisciplinar*, v. 13, n. 1, p. 42-62, 2024.

DE LIMA, Luís Gomes. Engenharia Didática no Estágio Supervisionado da Licenciatura em Física: Possibilidades Didáticas e Reflexões sobre a Realidade da Sala de Aula. *Revista de Produtos Educacionais e Pesquisas em Ensino*, v. 7, n. 2, p. 175-198, 2023.

FLAVELL, John H. Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American psychologist*, v. 34, n. 10, p. 906, 1979.

FREIRE, Paulo. *Pedagogia da autonomia*: saberes necessários à prática educativa. São Paulo: Paz e Terra, 1996.

JÚNIOR, José Ademir Damasceno; VASCONCELOS, Francisco Herbert Lima; MENEZES, Daniel Brandão. Pensamento metacognitivo, com o uso das TDIC: aprendizagem significativa no ensino de Ciências e Matemática. *Revista de Ensino de Ciências e Matemática*, v. 16, n. 4, p. 1-17, 2025.

KITSANTAS, A. *et al. Barry J. Zimmerman's Enduring Legacy*: The Inspiring Fusion of Self-Regulated Learning Theory, Practice, and Mentorship. Educational Psychology Review, 2025

LIMA, Carlos Enio Jorge; DORNELES, Pedro Fernando Teixeira; DA ROSA, Cleci Teresinha Werner. ENSINO DE FÍSICA E METACOGNIÇÃO: CONTRIBUIÇÕES PARA O ENSINO DE FISICA EM CURSOS DE ENGENHARIA. *Revista Dynamis*, v. 31, n. Publicação contínua, p. e12417-e12417, 2025.

MOREIRA, Marco Antonio. *Teorias de aprendizagem*. São Paulo: Editora pedagógica e universitária, 1999.

NICOARA, G. F.; NEDELCU, A. *Metacognitive training in higher education*: a structured literature review. ECER, 2025.

O'NEILL, E. J. *et al. Metacognition design framework to aid metacognitive skill development in university students supported by the virtual learning environment. Educational Technology Research and Development*, 2025.

ÖZTURK, N. Revisiting Flavell's theory of metacognition for metacognitive responsiveness. Journal *of Theoretical Educational Sciences*, 2024.

PANDEY, Kashish; MOHAN, Ashwani. Metacognitive skills in learning and pedagogy: A systematic review and analysis. *Journal of Cognition and Culture*, v. 24, n. 3-4, p. 268-284, 2024.

PORTILHO, Evelise Maria Labatut; DA SILVA, Claudia Sebastiana Rosa; DE PAULA BATISTA, Giovani. A metacognição como metodologia de pesquisa na formação de estudantes e profissionais da educação. *Revista Espaço Pedagógico*, v. 30, p. e14912-e14912, 2023.

RODRIGUES, Luciana do Nascimento et al. Estratégias metacognitivas de autoformação de licenciandos em química: O estágio supervisionado no contexto remoto pandêmico. *Educación química*, v. 34, n. 2, p. 165-180, 2023.

SCHRAW, G.; MOSHMAN, D. Metacognitive theories. *Educational Psychology Review*, v. 7, p. 351–371, 1995.

SOUSA, Rosalide Carvalho de et al. Engenharia Didática de Formação e Teoria das Situações Didáticas: uma prática no ensino de Geometria Espacial com o software GeoGebra. *Revista electrónica de investigación en educación en ciencias*, v. 20, n. 2, p. 17-30, 2025.

VYGOTSKY, L. S. *A formação social da mente*. São Paulo: Martins Fontes, 1998.

WEINERT, Franz Emanuel; KLUWE, Rainer H. *Metacognition, motivation, and understanding*. 1987.

ZIMMERMAN, Barry J. Becoming a self-regulated learner: An overview. *Theory into practice*, v. 41, n. 2, p. 64-70, 2002.

ZIMMERMAN, B. J. Self-Regulated Learning and Academic Achievement. *Educational Psychology Review*, v. 32, p. 321–335, 2020.

Editor Responsável/Editor-in-Chief: Alboni Marisa Dudeque Pianovski Vieira

Recebido/Received: 10.05.2026 / 05.10.2026

Aprovado/Approved: 06.06.2026 / 06.06.2026