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Meta-prompting in Education: the role of Artificial Intelligence in students' metacognitive development for effective question formulation

Meta-prompting nell'educazione: il ruolo dell'intelligenza artificiale nello sviluppo metacognitivo degli studenti per una formulazione efficace delle domande

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ABSTRACT

In recent years, growing attention has been directed toward the use of Artificial Intelligence (AI) to support the development of metacognitive skills in students, particularly in the formulation of effective questions. This research examines studies published between 2019 and 2025 on the concept of "meta-prompting" in education, analyzing how AI can serve as a tool to enhance students' ability to reflect on their own learning and pose quality questions. The main strategies and theoretical models for

integrating AI into metacognitive processes are identified, along with empirical evidence of benefits achieved (improved self-regulation, question generation capacity, and academic performance). At the same time, emerging challenges are discussed, including the risk of AI dependency and "metacognitive laziness," and the pedagogical implications of such technologies. The results suggest that AI, if designed and used consciously, can facilitate meta-prompting and promote more self-reflective learning, contributing to the development of more autonomous students who are aware of their own cognitive process.

Keywords: metacognition, prompting, artificial intelligence, question formulation, self-reflective learning, meta-prompting, intelligent tutor.

RIASSUNTO

Negli ultimi anni, una crescente attenzione è stata rivolta all'utilizzo dell'Intelligenza Artificiale (AI) per supportare lo sviluppo di competenze metacognitive negli studenti, in particolare nella formulazione di domande efficaci. Questa ricerca esamina studi pubblicati tra il 2019 e il 2025 sul concetto di "meta-prompting" in educazione, analizzando come l'AI possa fungere da strumento per potenziare la capacità degli studenti di riflettere sul proprio apprendimento e porre quesiti di qualità. Vengono identificate le principali strategie e modelli teorici per l'integrazione dell'AI nei processi metacognitivi, insieme alle evidenze empiriche sui benefici ottenuti (miglioramento dell'autoregolazione, della capacità di generare domande e delle prestazioni accademiche). Allo stesso tempo, si discutono le sfide emerse, tra cui il rischio di dipendenza dall'AI e di "metacognitive laziness", e le implicazioni pedagogiche di tali tecnologie. I risultati suggeriscono che l'AI, se progettata e utilizzata in modo consapevole, può facilitare il meta-prompting e promuovere un apprendimento più autoriflessivo, contribuendo allo sviluppo di studenti più autonomi e consapevoli del proprio processo cognitivo.

Parole chiave: metacognizione, prompt, intelligenza artificiale, formulazione di domande apprendimento autoriflessivo, meta-prompting, tutor intelligente.

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1. INTRODUCTION

The convergence between artificial intelligence and metacognition in the educational field has attracted growing interest in recent years (Yang & Xia, 2023). Metacognitive abilities—that is, students' capacity to understand and control their own learning processes—are considered fundamental for effective and autonomous learning. In particular, students' question formulation is viewed as a key manifestation of metacognition, as it implies reflection on content and one's own needs for clarification or deepening. Traditionally, teachers have used metacognitive prompts

(guiding questions, explanation requests, etc.) to stimulate self-reflection and comprehension monitoring in students. Today, AI systems offer new opportunities to provide this kind of support in a personalized and adaptive manner (Mazari, 2025).

The term "meta-prompting" in the educational context refers precisely to the strategic use of prompts (stimuli, instructions, or questions) aimed at making students reflect on their own thinking and learning strategies while formulating effective questions. In other words, meta-prompting encourages students to think about how to pose questions, thus developing metacognitive awareness of the inquiry process. With the advent of virtual tutors and advanced chatbots, it becomes possible to implement meta-prompts in real-time during learning: for example, an AI agent can ask students to justify a certain question posed or to evaluate the completeness of their own query, stimulating a cycle of reflection and revision. Recent studies suggest that integrating AI in this way could optimize the learning experience and improve students' metacognitive abilities (Yang & Xia, 2023). However, questions remain about how to effectively design such AI-based interventions and possible unintended consequences, such as excessive dependence on technology.

In light of these premises, the present work intends to systematically examine recent literature on AI-supported meta-prompting in educational settings. The objectives are:

- To analyze how AI can be used to develop metacognitive skills in the construction of effective prompts and questions by students;
- To examine the strategies adopted, theoretical models proposed, and empirical evidence on AI integration in metacognitive learning processes;
- To discuss the main advantages, emerging challenges, and pedagogical implications related to the use of AI for meta-prompting.

In particular, the role of AI systems in serving as metacognitive "coaches," providing feedback and reflective guides, and how this affects the development of self-regulation in students will be explored.

1.1. The concept of meta-prompting

The term "meta-prompting" is used here to define the metacognitive process through which a user learns to formulate, evaluate, and refine their own queries (prompts) directed to generative AI systems, in order to obtain optimal responses relative to their learning objectives. This concept fits within the broader framework of metacognition (Flavell, 1979; Brown, 1987), extending its application to interaction with artificial cognitive systems.

The ability to construct effective prompts requires a complex set of skills: deep understanding of the subject matter, clarity in articulating objectives, awareness of the AI system's limitations, ability to critically evaluate received responses, and capacity to remodulate one's own requests. This is, in other words, a recursive process that implies constant metacognitive regulation (Nelson & Narens, 1990).

Although the theme of human-AI interaction has been extensively explored in the Human-Computer Interaction (HCI) literature, the specific application of these principles to the educational context and, in particular, the development of metacognitive skills in AI use remains relatively unexplored territory. Some pioneering research has begun to address the question of prompt effectiveness in the context of intelligent tutoring systems (VanLehn, 2011; Baker *et al*., 2016), but the rapid evolution

of large language models (LLMs) has opened completely new scenarios that require a rethinking of the skills necessary for effective interaction.
In a recent study, Wang *et al*. (2022) demonstrated how prompt quality significantly influences responses generated by language models, highlighting the importance of developing effective questioning strategies. Similarly, Liu *et al*. (2021) emphasized how the ability to construct adequate prompts represents a new form of digital literacy essential for learning in contemporary society.

2. METHODS

A systematic bibliographic search was conducted using four main academic databases: Web of Science (WOS), Scopus, ERIC, and IEEE Xplore. The search covered the period 2019-2025, in order to include the most recent and pertinent studies on the topic. Combinations of English keywords (the predominant language of scientific publications on the subject) were used, such as "metacognition," "prompting," "question generation," "artificial intelligence in education," "metacognitive prompts," and "student questioning skills." On ERIC (Education Resources Information Centre), the search was refined by selecting only peer-reviewed sources pertaining to the use of intelligent agents in metacognitive support. Table 1 presents the search terms used for each conceptual domain.

DOMAIN	SEARCH TERMS
Artificial intelligence and educational technologies	"artificial intelligence", "AI", "machine learning", "large language model*", "LLM*", "generative AI", "ChatGPT", "educational technology", "ed-tech", "technology enhanced learning", "TEL"
Metacognition and self-regulation of learning	"metacognit*", "self-regulat*", "self regulat*", "SRL", "metacognitive awareness", "metacognitive knowledge", "metacognitive regulation", "executive function*", "cognitive monitoring", "reflective thinking", "critical thinking"
Prompt formulation and human-machine interaction	"prompt*", "meta-prompt*", "metaprompt*", "prompt engineering", "query formulation", "question asking", "question posing", "human-AI interaction", "human-machine interaction", "HCI"

Tab. 1 - Search Terms by Conceptual Domain

The search results were filtered by including experimental studies, theoretical review articles, and case analyses that explicitly addressed the use of AI to support meta-prompting practices or development of metacognitive abilities in students. Publications not pertinent (e.g., works focused exclusively on improving AI model performance through meta-prompting, without links to education) and contributions prior to 2019 were excluded, except for some background references. In total, approximately 15 relevant articles were identified, from which data were extracted regarding: the application context (e.g., school, university, professional training), the type of AI technology employed (intelligent tutor, conversational chatbot, learning analytics system, etc.), the meta-prompting strategies implemented, the outcomes measured (metacognitive abilities, quality of questions formulated, academic performance, etc.), and the main conclusions of the authors. Figure 1 maps the entire selection process.

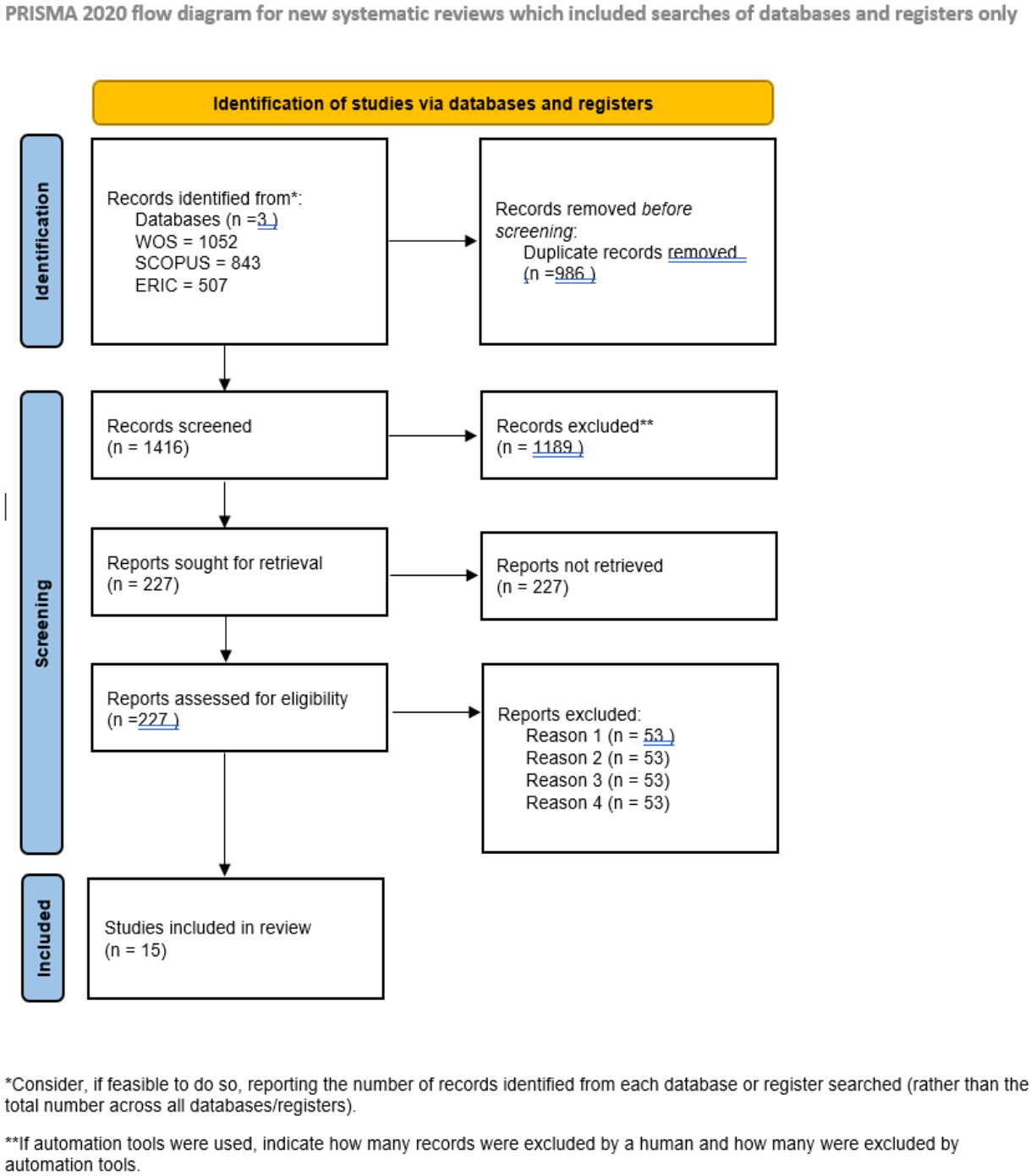

Fig. 1 - Prisma Flow

For the synthesis of results, a qualitative integrative review methodology was adopted, which allows combining quantitative evidence (e.g., experimental results on effectiveness) with qualitative and conceptual elements (such as proposed theoretical models). In the following section, results are presented organized around key emerging themes: AI-based strategies and tools for meta-prompting, empirical evidence of effectiveness, reference theoretical models, and finally, advantages and challenges identified. Next table (Table 2) holds the details of the paper included.

#	Author (year)	Country	Setting / Participants	Study design	AI tool & meta-prompting approach	Outcomes measured	Main findings
1	Knoth et al. (2024)	Germany	NR – conceptual paper	Conceptual / theoretical analysis	ChatGPT-like LLM; prompt-engineering scenarios	—	Higher AI-literacy is theorised to yield higher-quality prompts
2	Kim et al. (2025) "Prompt Patterns"	USA	19 university students	Mixed-methods	ChatGPT for academic writing; self-critical meta-prompts	Prompt patterns; text-quality scores	High-literacy students produced richer prompts and more coherent essays
3	Kim et al. (2025) "Perspectives"	USA	30 undergraduates	Qualitative focus groups	ChatGPT writing assistant; reflective prompts	Perceived benefits & challenges	Students viewed ChatGPT as a "reflective reviewer" fostering self-monitoring
4	Jin et al. (2024)	21 countries	1 073 post-grad. students	Cross-sectional survey + SEM	Multiple GenAI writing apps; SRL prompts	SRL scale; AI usage; writing quality	Advanced SRL → greater GenAI use → higher writing quality & motivation
5	Hwang et al. (2025)	Taiwan	119 nursing students	Mixed-methods experiment	ChatGPT-guided question-generation	Critical-thinking test; metacognition scale; cognitive load	Intervention ↑ question quality & metacognitive awareness, ↓ cognitive load
6	Yin et al. (2024)	China	62 biology majors	RCT	Metacognitive chatbot (Socratic dialogue)	Knowledge retention & transfer; interest; competence	Chatbot outperformed control on all learning & motivation outcomes
7	Tripathi et al. (2024)	India	96 secondary & tertiary students	Quasi-exp. (6 wks)	AI analytics tool with real-time metacognitive feedback	MAI; grades	Significant gains in metacognitive awareness and course grades vs control
8	Liao et al. (2024)	China	78 CS freshmen	Pre/post with comparison	ChatGPT scaffold for computational thinking	CT-skills test; reflection logs	Prompt-based scaffolds improved computational-thinking scores
9	Fan et al. (2024)	China / Canada	117 university students	Mixed-methods lab RCT	GenAI writing aide; usage logs	Motivation; writing processes & quality	Essay quality ↑ but signs of "metacognitive laziness" in some students
10	Yang & Xia (2023)	China	135 high-schoolers	Pre/post	AI support system with self-evaluation prompts	Metacognitive-strategy scale; quiz scores	Significant ↑ in metacognitive strategy use and quiz performance
11	Juhaňák et al. (2025)	Czech Rep.	78 undergraduates	RCT	LLM-based prompt tutor	Learning-outcome test; SRL index	Metacognitive prompts boosted learning outcomes vs control
12	Jin et al. (2023)	South Korea	16 university students (various majors)	Qualitative exploratory (storyboard "speed-dating" + semi-structured interviews)	Ten prototype AI applications designed to scaffold SRL; students evaluated scenarios (planning, monitoring, reflection)	Perceived SRL support across metacognitive, cognitive & behavioural domains	Learners judged AI apps helpful for planning, monitoring and reflection, but less for motivation; highlighted need for identity-, activeness- & position-aware design
13	Mazari (2025)	Spain	28 adult learners	Action-research cycles	Various AI tools; reflective journals	Reflection depth; self-reported SRL	Progressive ↑ in depth of reflection across cycles
14	Tankelevitch et al. (2024)	UK / Germany	32 staff + students	Lab study + think-aloud	Prototype LLM UI with meta-feedback	Cognitive load; metacognitive actions	Interface nudges ↑ monitoring and prompt refinement
15	Wang & Zhao (2023)	NR (online)	48 volunteers (crowdsourced)	Online experiment	GPT-3 with metacognitive prompting	Answer accuracy; confidence calibration	Meta-prompts ↑ answer accuracy & calibration of confidence

Ta. 2 - Included papers

3. RESULTS

3.1 RQ1 AI uses for developing metacognitive skills

From the literature analysis, various key insights emerged on each researched aspect.

Effective prompt formation: studies agree that students' ability to design targeted prompts is closely linked to digital literacy and familiarity with AI. Knoth *et al*. (2024) observe that greater AI literacy predicts higher quality prompts, capable of guiding the model to more pertinent responses. Similarly, Kim *et al*. (2025) documented that students with high AI literacy levels (High Literacy, HL) show more sophisticated interaction modalities compared to Low Literacy (LL) students: the HL group actively criticizes their own prompt and AI-generated content, reviewing ambiguities and continuously restructuring their work. For example, during drafting they requested ChatGPT to reorganize essay structure (modifying paragraph order), evaluate coherence with provided evaluation rubrics, and reformulate ambiguous parts. This highlights an iterative design cycle: students hypothesize an initial prompt, compare the automatic response with their own objectives, and further refine the request. Lee and Palmer (2025), in their review, emphasize that well-structured prompts can transform educational interaction with generative models and recommend explicitly teaching students pragmatic prompt engineering skills (Lee & Palmer, 2025).

Metacognitive value of meta-prompting: prompt creation is described as an intrinsically reflective activity. Jin *et al*. (2023) report that students perceive AI systems as tools that can support metacognitive regulation, particularly in establishing learning objectives, monitoring progress, and adapting strategies in progress. In some cases, AI encourages students to pose more targeted questions, thus improving their awareness of informational needs. A recent study investigates how AI pushes students to reflect on their own texts: they appreciated the model's instant feedback, which guides them to self-correct linguistic errors and iteratively co-construct the final content. Fu et al. (2024) also highlight that AI applications "promote metacognitive abilities by making students reflect on their own learning experiences" (Fu *et al*., 2024), integrating goal-setting and continuous monitoring. From study comparisons, it emerges that meta-prompting activates planning strategies (clear definition of prompt objectives), control (evaluation of AI response adherence to expectations), and subsequent reflection (analysis of cognitive deviations). Educational research shows that the use of metacognitive stimuli autonomously created by students tends to improve short-term learning outcomes, suggesting the effectiveness of such techniques.

AI mediation for self-regulation and critical reflection: evidence indicates that guided AI use can enhance self-regulation. Kim *et al*. (2024) report that during final text revision, students perceive the generative model not only as a grammar corrector, but as a "reflective reviewer" that signals inconsistencies and requests iterations. This iterative process of product refinement leads students to exercise self-evaluation skills. Similarly, Jin *et al*. (2023) observe that students recognize AI's utility in accelerating mechanical activities (e.g., resource search, editing), freeing time for higher-order thinking, data reorganization, and critical information selection. In practice, AI serves as a tutor that proposes formative feedback in progress, making evaluation criteria explicit (e.g., rubrics) and supporting reflection on processes. At the same time, there are ethical and cognitive concerns: Chardonnens (2025) warns that uncritical AI use can weaken student autonomy, as exclusive reliance on the system reduces the ability to autonomously plan and monitor learning (Chardonnens, 2025).

For this reason, both systematic reviewers and authors suggest a balanced approach: educational activities must couple the use of generative AI with interventions that stimulate metacognitive reflection (e.g., discussions with teachers, guided questions) (Chardonnens, 2025). Not surprisingly, the literature recommends introducing AI literacy and prompt engineering courses in university curricula, so that students learn not only to use tools but to manage them strategically (Lee & Palmer, 2025).

3.1. RQ2 Strategies, theoretical models, and empirical evidence on AI integration in metacognitive learning processes

From the examined literature, various strategies emerge through which AI is integrated to promote meta-prompting and self-regulation abilities in students. A widespread strategy is the use of educational chatbots designed to provide metacognitive feedback during study. For example, Yin *et al*. (2024) developed an intelligent chatbot capable of interacting with biology students by posing reflective questions and providing real-time feedback on student responses (Yin *et al*., 2024). In this approach, the chatbot simulates a Socratic dialogue: first it asks students to evaluate their understanding of a learning module, then—based on the self-evaluation provided—proposes deepening questions or study strategies (metacognitive feedback phase). Such adaptive prompts aim to induce students to monitor their understanding and apply control strategies (e.g., returning to unclear concepts), thus embodying a form of automated meta-prompting.
Another identified strategy consists of using intelligent tutoring systems or AI-enhanced learning platforms that guide students in question generation and planning their own learning. Hwang et al. (2025) describe an approach where university nursing students are taught to use a Generative AI model (like ChatGPT) to assist in formulating clear and pertinent questions in the nursing field (Hwang *et al*., 2025). In this context, AI serves as a guided prompting tool: students formulate questions that AI helps refine, suggesting improvements or filling informational gaps, and in turn students learn to evaluate the quality of generated questions. This methodology—defined by the authors as a "prompt-based learning approach"—emphasizes the student's active role in AI interaction: AI provides suggestions and hints, but it's up to the student to decide how to integrate such suggestions to improve their questions. Similar approaches, based on the principle of conversational learning with AI, have also been experimented in computer programming education (Liao *et al*., 2024), where an agent like ChatGPT can propose solution paths or guiding questions to help students develop problem-solving reflectively, and in language learning, through systems that offer hints on how to formulate questions or phrases and then invite students to reflect on alternatives.
In summary, the identified AI meta-prompting strategies include:

- Chatbots and metacognitive conversational agents, which pose reflection questions and encourage self-evaluation during study (Yin *et al*., 2024);
- Guided question generation tools, where AI assists students in formulating and revising their own queries, for example suggesting more precise prompts or indicating missing elements (Hwang *et al*., 2025);

- Intelligent tutors with metacognitive scaffolding, i.e., systems that, in addition to providing content, present students with explicit planning requests (e.g., "What is your objective for this session?") and revision ("Have you verified if your solution answers all parts of the problem?"), often dynamically adapted based on student actions.

AI integration in educational metacognitive processes is accompanied by the elaboration of theoretical models that guide their design. A recently introduced conceptual thread is that of "hybrid intelligence" where learning is seen as the result of synergistic cooperation between human and artificial agents (Fan *et al*., 2024). Fan *et al*. (2024) highlight how this vision is still at an initial stage: the mechanisms and consequences of close human-AI collaboration on the metacognitive learning plane are not entirely clear (Fan *et al*., 2024). This has led to identifying the need for co-regulation frameworks where AI does not replace, but integrates and amplifies, the student's self-regulation strategies. For example, Yang and Xia (2023) propose a cooperative teacher-AI interaction model within an educational support system: AI provides real-time monitoring and granular analysis of student learning processes (things difficult to obtain with traditional methods), while the teacher intervenes with targeted pedagogical strategies, based on such information (Yang & Xia, 2023). This theoretical model emphasizes the importance of balancing automation with human control, ensuring that AI-generated prompts are effectively contextualized in educational activity.

Another relevant theoretical contribution comes from the human-computer interaction field: Tankelevitch *et al*. (2024) argue that Generative AI systems place high metacognitive requirements on users, who must continuously monitor and evaluate the quality of produced responses and adapt their prompts accordingly (Tankelevitch *et al*., 2024). The authors suggest that this metacognitive load can be managed by designing AI systems that themselves incorporate metacognitive support strategies. For example, an advanced chatbot interface might include self-explanation features (AI explaining why it provided a certain response) or self-evaluation (AI indicating a confidence level in its own response), to provide users with useful feedback for regulating their own inquiry process. This approach reflects a principle of "metacognitive AI," where the intelligent agent partly models expert tutor behaviors, making visible and accessible suggestions typically linked to metacognition (such as verification checklists or recalls to alternative solution strategies).

Overall, theoretical models converge on the idea that AI should be intentionally designed as a metacognitive enhancement tool. This means that developers of AI-equipped educational technologies should incorporate meta-prompting elements from the beginning: for example, providing that the system periodically asks students to reflect on what they just learned, to formulate a summary question, or to estimate their understanding level before moving to the next topic. Such models offer guidelines for creating metacognitively oriented learning environments, where AI and teacher work in synergy to stimulate continuous awareness and regulation of their own learning in students.

Regarding empirical evidence, several experimental studies conducted between 2019 and 2025 provide empirical evidence of benefits deriving from AI use in supporting meta-prompting and, more generally, the development of metacognitive abilities in students. A first category of results concerns improving the ability to generate effective questions. For example, in the study by Hwang *et al*. (2025) cited previously, nursing students who followed educational activities integrated with AI-generated prompts (within prompt-based learning) showed a clear increase in the quality and clarity of formulated questions compared to a traditional control group (Hwang *et al*., 2025). In particular, the

AI-guided approach enhanced students' critical thinking and metacognition abilities, measured through pre- and post-intervention evaluations: AI-supported students obtained significantly higher scores in indicators such as relevance and complexity of posed questions, in addition to reporting lower perceived cognitive fatigue in completing assigned tasks (Hwang *et al*., 2025). This suggests that AI can alleviate part of the mental workload (e.g., helping to structure questions), allowing students to concentrate their cognitive resources on the most critical aspects of the study content.

Similarly, a quasi-experimental study conducted by Tripathi *et al*. (2024) on students of various educational levels showed that using an AI tool specifically designed to provide real-time metacognitive feedback leads to a significant increase in metacognitive self-awareness measured through standardized questionnaires (Tripathi *et al*., 2024). In this study, a group of students used for six weeks an AI system that analysed their learning patterns (responses, response times, strategies declared during think-aloud) and returned personalized suggestions - for example, advice on how to improve understanding or reminders to recheck completed work. Compared to the control group that studied conventionally, AI-assisted students showed a significant increase in metacognitive awareness scores (awareness of their own strategies and strengths/weaknesses) and improvement in academic performance (Tripathi *et al*., 2024). This empirical result supports the idea that AI can serve as a "cognitive mirror" for students, making otherwise hidden processes more visible and thus facilitating greater self-regulation.

Additional evidence comes from the experimental sciences field. Yin *et al*. (2024) conducted an experiment with 62 university students divided into two groups: one interacted with an educational chatbot equipped with metacognitive feedback during biology learning activities, the other performed the same activities without additional metacognitive support. Results showed that the experimental group (with metacognitive chatbot) obtained significantly better results both in knowledge retention and knowledge transfer to new problems, compared to the control group (Yin *et al*., 2024). Furthermore, these students reported higher levels of intrinsic interest toward the subject and greater perception of personal competence (Yin *et al*., 2024). It's important to emphasize that such benefits were obtained without increased perceived stress load: no significant differences emerged in "pressure" reported by students between the two groups (Yin *et al*., 2024). This indicates that meta-prompting strategies implemented by the chatbot (e.g., asking students to self-evaluate and offering personalized study suggestions) were received positively, improving motivation and learning without overloading the student.

Overall, empirical evidence agrees in showing positive effects of AI integration on metacognitive skill development and learning performance. Among documented benefits are: increased ability to pose high-quality questions and think critically (Hwang *et al*., 2025), greater awareness of one's own cognitive processes and strategies (Tripathi *et al*., 2024), better academic results in terms of knowledge acquisition and transfer (Yin *et al*., 2024), as well as increased motivation and student engagement. It's relevant that some studies also observed cognitive load optimization: thanks to AI, students face tasks feeling them less burdensome and more manageable (Hwang *et al*., 2025). These empirical results provide concrete support for the pedagogical use of AI as a meta-prompting tool and suggest that, if well-designed, technology can effectively support students in becoming more reflective and autonomous learners.

3.2 RQ3: Advantages, challenges, and pedagogical implications

Based on the strategies and evidence discussed, clear pedagogical advantages emerge related to AI use for meta-prompting. In summary, AI can offer continuous and personalized metacognitive scaffolding, difficult to achieve with human resources alone, especially in contexts with many students. Intelligent agents can adapt to each learner's pace and level, posing the right questions at the right time to stimulate individual reflection. This can lead to more autonomous students in learning, capable of formulating targeted questions and self-regulating even outside the supported environment (transferring such abilities to other study contexts). Furthermore, AI can provide a judgment-free environment where students feel free to express doubts and reflect aloud, knowing that received feedback is neutral and focused on improvement. From teachers' perspective, having AI systems that track and signal students' metacognitive difficulties (e.g., indicating who isn't asking questions or who shows reasoning inconsistencies) offers valuable data for targeted classroom interventions. In an inclusive perspective, such tools could help bridge metacognitive gaps, particularly supporting students with less self-awareness or difficulties in study organization.

On the other hand, the literature warns about some challenges and risks associated with this innovative approach. A recurring theme is the danger of AI dependency. If students become accustomed to constantly receiving external indications and suggestions, they might struggle to develop full metacognitive autonomy. Fan *et al*. (2024) introduced the concept of "metacognitive laziness" to describe the tendency, observed in some cases, to passively rely on AI while renouncing engagement in personal planning, monitoring, and evaluation processes (Fan *et al*., 2024). In their study, for example, university students who had used ChatGPT as support for a writing task obtained improvement in immediate performance (slightly higher quality essays), but without a corresponding increase in knowledge acquisition or transfer ability (Fan *et al*., 2024). This suggests that AI had partly "compensated" for the student's cognitive effort, who however had not internalized new learning strategies. In situations like this, AI risks serving as a shortcut that bypasses the metacognitive process rather than enhancing it. An additional challenge concerns the quality and reliability of feedback provided by AI: if a meta-prompting system weren't well-calibrated, it could generate misleading or excessive advice, creating confusion in students or making them lose confidence in the tool. It's therefore crucial that systems be developed based on solid educational evidence and carefully tested in real contexts.

The pedagogical implications of AI use in meta-prompting require careful reflection. First, teacher training on the use of such tools is necessary: the effectiveness of AI-dependent meta-prompting increases when teachers know how to integrate it into their educational design, orchestrating interaction between students and artificial agents. Teachers must be able to interpret data provided by AI (e.g., reports on students' metacognitive strategies) and intervene to support those who need it most, in addition to knowing how to manage any technical or behavioral problems related to AI use. Second, AI literacy should also be promoted among students: they should understand the basic functioning of the AI assistant and its limits, developing a critical rather than fideistic approach. For example, it might be useful to explicitly teach students how to evaluate chatbot suggestions (instead of applying them blindly) and how to regulate their own prompts to obtain better responses - which, in itself, is a metacognitive exercise. An additional implication concerns ethics and privacy: AI

systems often collect data on student behavior; it's imperative to guarantee protection of this data and transparent use for research or educational personalization purposes.
Finally, at the institutional level, AI integration for meta-prompting raises questions about how to effectively evaluate acquired metacognitive skills. If part of the self-regulation process occurred in dialogue with an AI, traditional individual evaluations might not capture all developed abilities. One might consider implementing authentic assessments where students are allowed (or required) to use AI tools, observing how they employ them to solve complex problems and reflect. This would provide a more realistic measure of metacognition in the digital age. Ultimately, pedagogical implications require a holistic approach: it's not enough to introduce technology, it's necessary to rethink educational practices, teacher training, evaluation tools, and policies so that AI meta-prompting fully realizes its potential without incurring undesired effects.

4. DISCUSSION

The results of this investigation highlight a complex picture: the use of AI in educational meta-prompting offers important opportunities to improve learning but requires caution and pedagogical intelligence in its application. On one hand, the analysed studies convincingly demonstrate that AI can act as a catalyst for metacognitive development. Through immediate feedback, stimulating questions, and adaptivity, systems like chatbots and intelligent tutors succeed in engaging students in self-reflection practices they might otherwise neglect. This is particularly valuable in contexts where the teacher-student ratio is unbalanced (large classes, online courses): AI can provide individualized support on a large scale, helping to bridge the metacognitive attention that individual teachers alone would struggle to guarantee to everyone. Furthermore, AI can make the learning process more active and student-centered: instead of passively receiving information, students are constantly solicited to question themselves and make decisions (what question to ask, how to proceed, if they really understood a concept) in an interactive dialogue. In this sense, AI encourages an inquiry-based approach to learning, where student curiosity and investigation guide the path, supported however by a safety net provided by the virtual agent.
On the other hand, the discussion has highlighted that AI is not a panacea, and its impact depends heavily on how it's implemented and integrated. A naive or excessively enthusiastic implementation risks generating effects contrary to those desired. For example, giving too much control to AI could reduce the exercise of students' own metacognitive abilities: if every time students encounter difficulty the system intervenes with a suggestion, students might lose the habit of struggling with the problem and developing autonomous solution strategies. The central challenge consists in finding the right balance between support and autonomy: AI should be sufficiently present to guide and make students reflect, but sufficiently "invisible" to leave room for initiative and independent thinking. This implies, for example, modulating the intensity of meta-prompts (frequency, level of detail) based on student profile and progress: a beginner student might benefit from frequent and specific prompts, while a more advanced one might need only simple occasional hints, to avoid overloading them or undermining their self-confidence.
A crucial point that emerged is the need for further long-term research. Most of the considered studies, although rigorous, observe effects in the short term (from a few sessions up to a few weeks of use). The question remains open about what the impact of AI-assisted meta-prompting is in the long term: do students who regularly use such tools continue to improve their metacognitive abilities? Do they

maintain such abilities even when AI is not available? Or do they become accustomed to the point of suffering in its absence? Future literature will need to investigate, for example, whether prolonged use of metacognitive chatbots can lead to automation of self-regulation strategies (which would be a desirable outcome, a sign that students have internalized the process) or whether an element of dependency always remains. Comparative studies will also be useful: comparing different meta-prompting modalities (e.g., AI vs. human teacher vs. guided self-reflection without AI) to understand in which contexts and for which students AI offers significant added value.

Finally, the discussion emphasizes the importance of a multidisciplinary approach: this theme intersects pedagogy, cognitive psychology, and computational sciences. Designing effective meta-prompting tools requires collaboration between education experts (to define which prompts are pedagogically sensible), psychologists (to understand how students react to different types of feedback and how they develop their metacognition), and computer engineers (to translate these requirements into functional and reliable AI systems). Only dialogue between these disciplines can lead to optimal solutions. Furthermore, actively involving educational stakeholders (students, teachers, school administrators) in the development process helps align technology with real needs and facilitates practical adoption in schools and universities.

5. CONCLUSION

In conclusion, the concept of AI-supported meta-prompting represents a promising frontier in educational innovation, with the potential to transform how students develop awareness and control over their own learning. The present research has highlighted that, between 2019 and 2025, numerous initiatives and studies focused on this theme have emerged, indicating generally positive results. The use of AI as a tutor or metacognitive learning companion can significantly strengthen abilities such as effective question formulation, self-evaluation, and adaptation of study strategies. These abilities, in turn, contribute to forming more autonomous, critical students capable of lifelong learning.

However, the benefits of AI meta-prompting are neither automatic nor guaranteed. As discussed, the key lies in careful implementation and harmonious integration with traditional teaching. AI must be seen as an amplifier of good pedagogical practices, not as a substitute for human educational interaction. Only by maintaining the central role of active students and expert teacher guidance can we avoid the risk that technology induces passivity or superficiality in cognitive processes. In other words, the success of AI-mediated meta-prompting depends on balance: enough AI to support and challenge students, enough human metacognition to make learning authentically meaningful.

Implications for future research include exploring new models of metacognitive evaluation in AI-enhanced environments, studying the effectiveness of these tools in different disciplines and age groups (e.g., in primary school or professional training, where there are few studies so far), and continued attention to ethical aspects. It's fundamental to monitor how extensive AI use influences motivation, self-confidence, and student learning identity in the long term.

Ultimately, the use of artificial intelligence for meta-prompting promises to be a powerful ally for educators and learners, provided we know how to govern it with pedagogical wisdom. Like any tool, its impact will depend on the use we make of it: in the hands of an aware educational community, AI can truly contribute to forming more metacognitive minds, that is, more capable of thinking about their own thinking and effectively directing their own learning.

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