Educational Dimensions in the Age of Generative Artificial Intelligence: A Systematic Review for Policy Development

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Abstract. *The first generative artificial intelligence chatbot (ChatGPT) was launched in November 2022. Since then, generative AI has had a significant impact on the educational process, sparking intense debates about its benefits and drawbacks. This paper uses a systematic review methodology to synthesize evidence across multiple educational dimensions, including current research trends, data privacy, ethical concerns, equity challenges, classroom applications, and future directions for generative AI. The results are discussed inside a framework that primarily understands generative AI as a transformative learning technology, emphasizing the need for robust policies to ensure its ethical and effective integration into elementary education.*

1. Introduction

Generative artificial intelligence (GenAI), mostly represented by Large Language Models (LLM), is a technology designed to produce new content across multiple modalities (e.g., text, image, audio, video, and code) that closely mirrors human-created outputs [Feuerriegel et al., 2024]. A prominent example of this technology is ChatGPT, a Generative Pre-trained Transformer (GPT) model fine-tuned for conversational applications through a combination of supervised learning and reinforcement learning from human feedback [Yenduri et al., 2024]. Given its versatility in handling natural language tasks, ChatGPT, along with other generative AI technologies such as Gemini, DeepSeek, Claude, Llama, Ernie, and Grok, has been adopted across diverse fields. These technologies provide support in areas such as legal documentation analysis [Chien and Kim, 2024], journalism and media content creation [Shi and Sun, 2024], medical decision-making [Ghebrehiwet et al., 2024], and beyond. However, the use of generative AI also raises concerns in these areas, with initial studies already exploring potential impacts, such as undermining the authority and expertise of professionals in their respective roles [De Cremer et al. 2023].

Similarly, generative AI presents both benefits and challenges in the education domain. A recent event at the University of Edinburgh on the future of education[1] explored the role of AI as an educational tool. During this opportunity, three experts in digital education unanimously agreed that, at present, the drawbacks outweigh the potential advantages offered by this technology. This discussion extended beyond the negative

[1] https://www.ed.ac.uk/events/lecture-series/edinburgh-futures-conversations/the-future-of-education/ai

effects of generative AI on students, also addressing its impact on the role of teachers as professionals, highlighting how much of the creativity involved in preparing educational materials is being replaced by an entirely transactional process. Other prestigious universities are also examining these issues and advancing research to identify proper approaches for integrating generative AI into the elementary educational system. For instance, the Transformative Learning Technologies Lab (https://tltlab.org) at Columbia University, is sponsoring the establishment of the first Brazilian Observatory on AI in Elementary Education.

This paper aims to provide evidence to support and enhance the discussion on the use of generative AI, focusing on elementary education. Therefore, we relied on principles of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [Page et al., 2021] to ensure a rigorous, transparent, and reproducible approach to synthesizing different dimensions ofthis theme from existing research. The results of this review are mainly used to support the discussion on the development of new policies for the proper integration of generative AI as a tool for the elementary educational system.

2. Methodology

Principles of the PRISMA framework were used to guide the systematic review process due to its robust structure and emphasis on minimizing bias. Our primary objective was to examine the applications and implications of generative AI in the elementary educational domain. The scope includes studies addressing the ethical, pedagogical, and technological impacts of generative AI. Only peer-reviewed articles published from 2023 onward were considered, as the widespread adoption of generative AI began with the launch of ChatGPT in November 2022. A comprehensive search was conducted in the IEEE, ACM and Scopus datasets. This search was restricted to titles and abstracts of English-language publications and the search string was:

(“generative artificial intelligence” OR “generative AI” OR “Large Language Model” OR “LLM”) AND (“education” OR “educational” OR “teaching” OR “school”) AND ("Elementary" OR "Primary" OR “Lower" OR "Junior" OR "Infant")

Titles and abstracts were then screened for relevance, followed by a full-text review of eligible studies. For the last filtering, as the inclusion criterion, we used the existence of evidence-based information to generate answers for all or part of the following research questions. These questions were clustered into four main dimensions:

- Dimension A - Ethics and privacy:
  - RQ1: What are the ethical challenges related to the integration of generative AI in education?
  - RQ2: What are the challenges regarding data privacy and ownership?
  - RQ3: What are the risks of increasing inequalities?
- Dimension B – Public Policy:
  - RQ4: What are the main public policies that have been implemented or are being implemented regarding generative AI in education?
  - RQ5: What are the possibilities, risks, and limitations of private sector and civil society organizations participating in policy definition?

- Dimension C – Practical experiences in classroom:
  - RQ6: How has generative AI been employed in classrooms and other learning environments?
  - RQ7: What can successes and failures teach us?
- Dimension D – Main generative AI technologies:
  - RQ8: What are the new technical advancements with positive potential for education?
  - RQ9: What is the timeline for the launch of new technologies and products? What are the trends for the coming years?

It is worth noting that most of the papers concentrated on a subset of these questions, as detailed in the results section.

3. Results

3.1. Selection Process

The PRISMA flow diagram (Figure 1) illustrates the systematic review selection process, detailing the number of records identified, screened, excluded, and included at each stage. Our analysis of the excluded papers revealed that the primary reason for exclusion was the presence of the "Primary" and "Lower" terms, which often indicated studies unrelated to elementary education. However, these terms were essential for ensuring comprehensive coverage during the identification process.

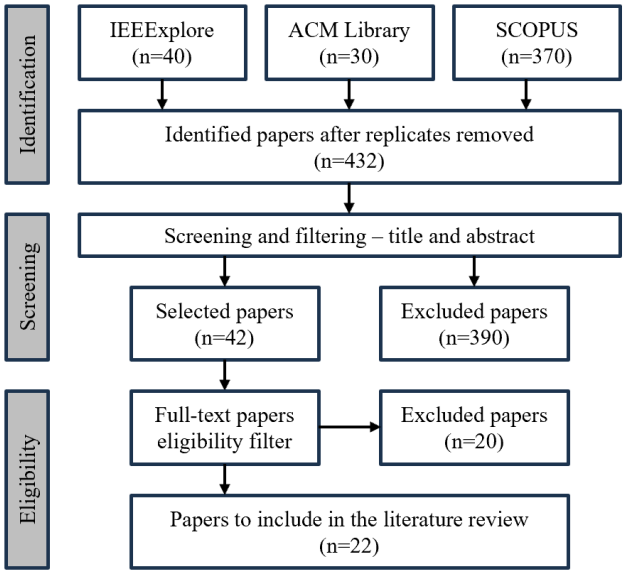

Figure 1. The PRISMA flow diagram

3.2. Ethical Challenges (RQ_1)

Several papers discuss ethical concerns that include over-reliance on ChatGPT-like applications and bias in AI training datasets, which may not reflect cultural diversity and could affect personalized learning. There are also concerns about AI negatively impacting students' critical thinking development and cognitive mastery due to the lack of proper

pedagogy and explanation. However, only a few of them propose pragmatic solutions for such concerns. For example, Chen et al. (2023), Liu et al. (2024), and Yang et al. (2024) emphasize the need for human review and collaboration to mitigate these issues, highlighting a **human-in-the-loop model**. In other words, while AI can support the learning process, human educators must provide oversight, guidance, and ethical intervention to ensure that AI tools align with educational goals. This approach is also important to intervene and clarify responses, demonstrating the ethical challenge of ensuring AI-generated content is accurate, comprehensible, and pedagogically sound. Unfortunately, the human-in-the-loop model is not a scalable approach and works only in small contexts (classrooms with few students). A more advanced method explores the use of special datasets, designed to mitigate these concerns using **model fine-tuning** to automatically include pedagogical guidance [Xei et al. 2024]. However, the task of obtaining such datasets is very complex, as discussed in [Jurenka et al. 2024]. Thus, several papers indicate the promotion of **critical thinking and digital literacy** [Lee and Zhai 2024] as a solution. The study of [Yang and Banks 2024], for example, included a generative AI policy in the syllabus to explicitly define appropriate and inappropriate practices, while Du and Lv (2024) introduced ethical guidelines that emphasize the importance of leading students in correctly perceiving and using generative AI. However, ethical use of guidelines may be ineffective if they are not reinforced through hands-on activities and interactive discussions since young students learn best through experiential learning [Morris 2020], rather than abstract guidelines alone.

Derived Policy: *The initial use of generative AI by primary school students should be closely supervised by human experts or automated pedagogical guidance systems to ensure effective and responsible learning.*

3.3. Privacy and Ownership Challenges (RQ_2)

Papers have identified data leaks and privacy protection as major challenges, emphasizing the difficulties in ensuring the confidentiality of students' and teachers' data. Particularly, they mention concerns about data privacy when using models like GPT, highlighting the need for **local-scale LLMs** developments such as Vicuna and Alpaca to mitigate such issues [Gao et al. 2023]. The study in [Liu et al. 2024], for example, describes the development of a **dedicated web application** to ensure data privacy. In this case, all sensitive data, including personal configurations and chat logs, were **stored locally**, rather than on external servers, ensuring strict data privacy. Moreover, interactions with GPT-4 occurred exclusively through OpenAI's API (Application Programming Interface), adhering to rigorous privacy standards. Another complementary solution is the **desensitization** of student data to protect privacy by replacing sensitive information with virtual identifiers before uploading to AI systems [Huang and Yu 2024]. Similarly, papers also highlight concerns regarding authorship and ownership, mainly associated with AI-assisted writing, showing that teachers are worried about the integrity of students' work when AI generates most of the content. Few solutions are discussed, like the establishment of **guidelines for differentiating between student and AI-generated content** to address issues of data privacy and ownership [Han et al. 2024]. Therefore, this is an important opportunity for research.

Derived Policy: Educational *generative AI-oriented applications must use dedicated, local LLM-based support, which control or identify the exacerbated use of generated-data.*

3.4. Inequality Challenges (RQ_3)

Papers, such as [Han et al. 2024; Huang and Yu 2024], highlight concerns that AI could exacerbate educational inequalities, as under-resourced communities may lack the technological infrastructure needed to support LLMs' **high computational demands**. This disparity limits access to generative AI in education. For instance, Lee and Zhai (2024) highlight the **financial burden** of ChatGPT's subscription fee, which may be unaffordable for under-resourced teachers and students, further deepening educational inequalities. While past studies propose theoretical solutions, such as student support strategies [Taiye et al. 2024] and the development of inclusive frameworks [Kong and Yang 2024], they do not present practical implementations, which remain scarce. Therefore, while the literature shows that facilitating conditions, such as access to computational resources, strongly influence generative AI usage [Du and Lv 2024], real-world cases that present innovative solutions for the inequality issue are still lacking.

Derived Policy: *The use of generative AI should balance computational demands and efficiency when selecting an underlying LLM, prioritizing public versions or government agreements for free access whenever possible.*

3.5. Current Policy (RQ_4)

The few papers that discuss policy agree about the need for collaboration among policymakers, educators, and technology experts to ensure that generative AI is used safely and constructively to support primary education. Examples are UNESCO's advocacy for AI education and the Australian frameworks [Kong and Yang 2024, Dai 2024], which provide initial **guidelines that emphasize transparency, fairness, accountability, and the protection of human dignity**. However, they suffer from a lack of specificity for practical implementations [Kong and Yang 2024]. Another example of regulations is the "Digital Literacy for Teachers Standard" developed by the Chinese Ministry of Education, which aims to **enhance teachers' ability** to use digital technology effectively [Lyu et al. 2024]. However, this document is solely dedicated to the teachers' instruction. China's National Educational Digitalization Strategic Action is another policy in China that aims to **enhance educational digitalization**, including the use of AI in moral and civic education [Zhang et al. 2024]. A more dramatic policy was the **ban on ChatGPT** in NYC schools as an example of regulatory action [Li and Zhang 2024]. However, this may have a counter-effect on educational evolution. Unfortunately, no data is available to evaluate such an approach. Organizations such as the Institute of Education Sciences (IES) and Digital Promise, both in the USA, are forming communities of educators to explore and critically examine the applicability of AI in education from a pedagogic perspective. This suggests a gradual rather than radical integration of AI in educational systems [Han et al. 2024].

Derived Policy: *Development guidelines must go beyond what must be done, also indicating how this could be done in terms of pedagogical strategies.*

3.6. Risks of Private Sector Influence on Policy Definition (RQ_5)

No paper analyzed in this review discusses the possibilities, risks, and limitations of private sector and civil society participation in generative AI education policy. However, evidence from other domains [Trayer et al. 2009] suggests that, without strong public oversight, generative AI policies risk being shaped by corporate interests, prioritizing

profit-driven models over educational equity. The analysis of case studies on this issue could provide insights and empirical evidence to clarify the role and impact of these stakeholders.

3.7. Practical Use (RQ_6)

Table 1 summarizes applications of generative AI in primary schools that present concrete validations. These papers mainly discuss the **validation importance** of their approaches before use. While approaches that support teachers [Li and Zhang 2024] are only validated by this population, approaches aimed at students [Onishi et al. 2024] tend to have **double validation by teachers and students**. The main validation method across studies predominantly relies on surveys and interviews, with only a few employing quantitative strategies. Notably, studies such as [Liu et al. 2024] and [Bai et al.] analyze student performance scores after using generative AI tools. Surprisingly, **none of the studies analyze interactions** (e.g., dialogues) between students and generative AI tools as a validation method. Indeed, several studies consider **validation as one of the main limitations** of their studies (e.g., lack of diversity [Liu et al. 2024]).

Table 1. Summary of generative AI (GenAI) in primary education

Reference	Target	Objective	Main validation type
Chen et al. 2023	Teacher	Create personalized material (AI literacy)	Evaluation surveys
Williams et al. 2024	Student	Enable creative collaboration with GenAI	Pretest-posttest design
Quin et al. 2023	Both	Create material, provide learning assistance	Qualitative survey
Gao et al. 2023	Teacher	Grade answers	Precision measures
Li and Zhang 2024	Teacher	Integrate GenAI in the learning process	Acceptance survey
Zhang et al. 2024	Teacher	Create and assess educational materials	Interview
Benjamin et al. 2024	Student	Develop a constructionist curriculum for GenAI learning	Semi-structured interview
Huang and Yu 2024	Teacher	Analyze effects of GenAI in assisting teachers	Interview
Dai 2024	Student	Develop a pedagogical approach (AI literacy)	Tasks data and survey
Yang and Banks 2024	Teacher	Integrate GenAI in the learning process	Self-study
Onishi et al. 2024	Teacher	Analyze classes using GenAI	Manual evaluation rank
Du and Lv 2024	Student	Integrate of GenAI in the learning process	Acceptance survey
Liu et al. 2024	Student	Integrate of GenAI in the learning process	Statistics on task scores
Bai et al. 2024	Student	Analyze effects of GenAI in assisting students	Traditional exams

Derived Policy: *Generative AI-based approaches should be validated before use, with a double perspective validation (teachers and students) when they aim to support students. Such validation must use methods that explore different approaches rather than rely on subjective surveys/interviews, also considering diverse contexts (e.g., level of knowledge of students regarding the employed technology).*

3.8. Success and Failures (RQ_7)

It is important to note that the experiments are limited in terms of number of participants and cultural context. For example, the final set of papers is mostly from China, which certainly has an educational system influenced by its ancient culture and traditions [Bahtilla and Xu 2021]. Thus, findings of their approaches may not be completely valid for other educational contexts. Apart from that observation, papers mostly report the success of their approaches. Table 2 emphasizes successful aspects obtained by the reviewed papers and the excerpts that support such an aspect.

Table 2. Summary of successful aspects obtained by the reviewed papers

Teachers can create better courses and material using generative AI
"*Teachers noted an improved capacity to design courses that can enhance students' attention, relevance, confidence, and satisfaction, suggesting that the teacher development programme equipped them with strategies and tools to make learning more engaging and meaningful for their students.*" [Kong and Yang 2024]
"*It {GenAI} can enrich teaching materials, use local materials, increase the intimacy of the classroom, and deepen the understanding of textbooks*" [Zhang et al. 2024]
"*Comparative experiments between ChatGPT-3.5 and ChatGPT-4 indicated significant improvements in model performance, demonstrating the potential of using LLMs as a teaching aid.*" [Bai et al. 2024]
Generative AI supports the self-evaluation of teachers
"Through the iterative dialogue with the AI system, teachers can constantly explore and reflect on the actual teaching situation." [Huang and Yu 2024]
Generative AI improves the students' writing skills
"*The LLM group exhibited substantial and sustained improvements across various facets of writing.*" [Liu et al. 2024]
Generative AI improves the students' engagement
"*The positive feedback from the pilot study highlighted Doodlebot's intuitiveness and ability to engage learners.*" [Williams et al. 2024]
Generative AI improves several students' learning aspects
"The experimental group demonstrated significantly higher performance in AI knowledge, skills, and ethical awareness. They also exhibited a significant increase in AI learning confidence and intrinsic motivation and a significant decrease in learning anxiety." [Dai 2024]
"We designed, produced, and delivered six lessons on generative AI technologies which appear to demonstrate improvements in practical and critical competencies for students." [Benjamin et al. 2024]

However, the successful use of generative AI depends on several factors. The study of Li and Zhang (2024), for example, showed that teachers' performance expectations (how effective they believe the technology will be in improving their teaching) and effort expectations (how easy or difficult they believe it will be to use the technology) positively impact their intention in adopting this technology. However, "facilitating conditions" (e.g., computer labs, high-speed internet access) have the most significant effect on this intention. Du and Lv (2024) conducted similar investigations with students and their results also indicated that "facilitating conditions" have the strongest impact on the students' consideration of generative AI use.

Some studies also identified limitations (failures) since, as discussed in [Quin et al. 2023], it is not easy to definitively conclude whether generative AI, such as ChatGPT, is advantageous or detrimental to education when it is **freely used by students**. The study

of Gao et al. (2023), for example, analyzed the precision of the grading methods using generative AI and concluded that such methods present a high percentage of false positives (incorrectly assigns high scores or marks to answers that should not be considered correct) in their grading. This makes generative AI methods for grading unfavorable, as we may not be able to successfully identify students who need feedback to improve their conceptual understanding. The study of Onishi et al. (2024) corroborates this affirmation, arguing that "*while GenAI can augment human capabilities, it* ***cannot replace human expertise*** *due to its limitations*.". Based on this and other limitations discussed in the reviewed papers, a hypothesis for the generative AI failure in education is its power to exacerbate the current viciousness of the education system rather than bringing new directions for such education. The following excerpt from the University of Edinburgh's Futures Conversations series event summarizes well this idea[2]:

"*My chief concern about generative AI in the context of U.S. education is that it exacerbates what I think is an existing, rather tragic problem with our education system. It has become nearly entirely transactional, where discrete activities are done for reward, like a grade..... the transactional system of U.S education has proved entirely alienating.... we now have this tool that allows students to fulfill the many of these transactions. We've built for them, and that we've decided are meaningful by* ***simply entering a prompt and clicking a button and sharing that result***." John Warner, 2024.

Therefore, apart from the success indicated in some studies, we argue they are still limited in terms of learning domain variety (e.g., writing) and quantitative and qualitative sampling (e.g., cultural populations) to support a definitive conclusion about this topic.

Derived Policy: *While teachers remain fundamental to the learning process, generative AI should pursue strategies that support their role, fostering greater student autonomy and a more reflective approach to learning*.

3.9. Current Advances (RQ_8)

Several papers evaluate the use of generative AI in its most traditional form (free chatbots/conversation) [Bai et al. 2024] or in request-generation of content [Chen et al. 2023]. However, other papers try to advance this use for unconventional forms. Xei et al. (2024) discuss **fine-tuning techniques** to enhance AI models for better alignment with students' language levels and needs. Similarly, Lee and Zhai (2024) mention the possibility of developing **LLM-based tools tailored for specific scientific content** and instructional methods, as well as the role of open-source models like Llama, Bloom, and Falcon to promote equitable and transparent AI use. Lee (2024) also addresses the importance of fine-tuning but focusing on its computational demanding aspect. Therefore, the idea is to reduce computational requirements while maintaining performance with the development of models like Llama2 and Polyglot optimized for educational contexts. Li and Zhang (2024) focus on the potential of generative AI in automation, interactivity, and personalized learning through tools such as **intelligent tutoring systems**, which could integrate functions such as **automated grading** and **real-time progress monitoring**. These ideas corroborate with the advancements of **AI-driven personalized teaching**, automatic generation of digital teaching materials, and real-time student learning data analysis to improve classroom interventions [Huang and Yu 2024]. However, as

[2] https://efi.ed.ac.uk/event/the-future-of-education-ai/

discussed in the previous section, personalization alone does not ensure an efficient learning process. Thus, studies like Dai (2024) are initially evaluating **pedagogical advancements** to improve AI literacy, which present a positive educational innovation.

Derived Policy: *generative AI education must include educational-oriented paradigms in their implementation strategies (e.g., fine-tuning) to interact with students.*

3.10. Future Trends (RQ_9)

In general, papers suggest future efforts to develop prompt engineering techniques and LLM-based tools to support educational applications, with a focus on enhancing instructional design and implementation [Lyu et al. 2024]. No specific timeline is mentioned, but the papers note the rapid growth in AI-powered educational investments and suggest continuous improvements in AI integration strategies. Apart from prompt engineering advances, a clear trend is the adjustment through classroom trials and expanded datasets to further enhance AI assistants [Xei et al. 2024, Lee 2024, Onishi et al. 2024]. Indeed, the use of refinement (fine-tuning) approaches can release the real power of generative AI in education [Jurenka et al. 2024]. However, this approach depends on specialised, qualified educational datasets, which are hard to obtain [Vasselli et al. 2023]. Moreover, this refinement also requires a reward model that can provide an evaluative signal on how well every single response is produced by a generative AI model and rated in terms of its pedagogical value. A last important trend is the use of enhanced multi-modal capabilities and reasoning abilities, offered by the most recent LLMs. This feature can support what we call “Differentiated Learning”, a strategy to deliver the best type of media according to the preferential learning style of each student.

Derived Policy: *generative AI-oriented educational systems must be designed to create and continuously maintain high quality specialised multimodal educational datasets that can support the fine-tuning of future educational models.*

4. Discussion

The policies, defined according to evidence from review studies, encourage the development of an educational framework that facilitates the unified design process of solutions aimed at covering at least part of them. Our research group is investigating such solutions based on the novel concept of *generative metacognitive virtual tutor (GMVT)*. Metacognition in education refers to the awareness and regulation of one's own thinking and learning processes. It involves students' ability to plan, monitor, and evaluate their learning strategies to improve academic performance. Educators leverage metacognition to foster deeper learning, critical thinking, and problem-solving skills [Fleur et al. 2021]. Therefore, GMVTs can (1) encourage students to set learning goals, monitor their progress, and adjust strategies (e.g., use of medias, exercises, summarizing) based on their understanding; (2) assist learners in developing strategies to approach complex problems by breaking them down into manageable steps; and (3) motivate students to reflect on what they have learned and identify areas where they need improvement.

The following schema (Figure 2) relates to our six initial types of metacognitive prompts to assist students with planning, monitoring, and evaluating their learning. This schema mainly corresponds to the pedagogical model of a virtual tutor and its real implementation will also consider the student model (e.g. cognition level) during interactions. This discussion is out of the scope of this paper.

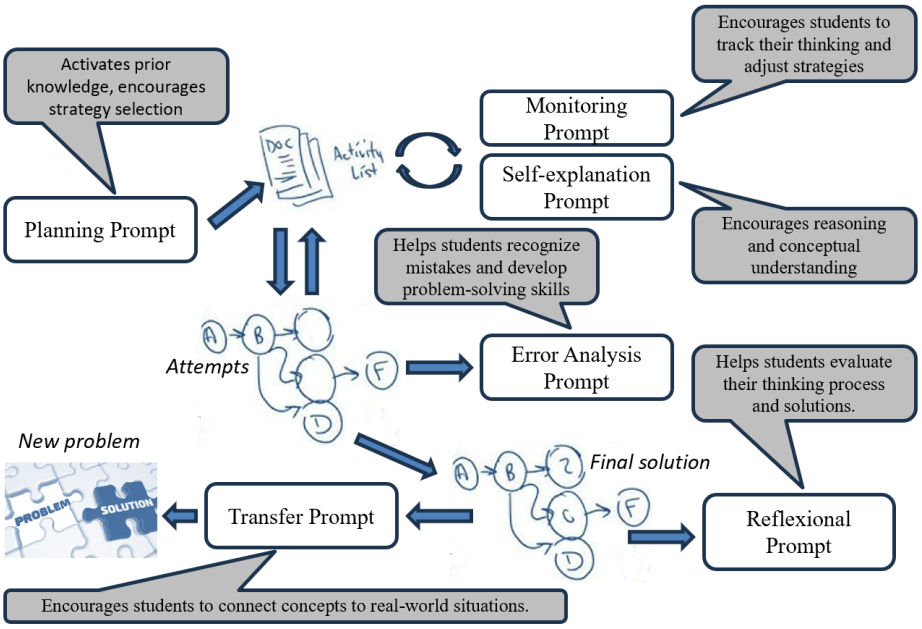

Figure 2. Schema of a generative metacognitive approach for virtual tutors

These prompts are used in AI-driven interactions, where a virtual tutor, guided by metacognitive principles, adapts such prompts based on students' responses. Note that there are stages (before, during, and after learning interactions) where each of these prompts are better applied. Simplified examples of prompts are: "*What key information do you want to see in this problem*?" (planning prompt - before), "*How are you checking your work as you go?"* (monitoring prompt - during), *"How confident are you in your answer? How do you know it's correct?"* (reflexional prompts - after). The combination of generative AI with metacognitive principles, inside a virtual tutor framework, could support a design process that relies on most of the policies outlined in this review. By enabling personalized tutoring, generative AI can adapt prompts to individual student contexts (e.g., age and cognitive level), ensuring tailored learning experiences. A key advantage of this approach is that LLMs can run locally, mitigating data privacy concerns, while the metacognitive framework minimizes excessive reliance on AI-generated content. In fact, metacognition serves as an educational paradigm that can guide the fine-tuning of LLMs, fostering deeper learning engagement. The implementation of this framework remains our primary research focus, which will also explore new forms of validations that rely on the analysis of dialogues created over the interaction tutor-student.

5. Conclusions

This paper presents a set of policies derived from recent literature, highlighting a significant lack of pedagogical guidance for integrating generative AI into education. In this scenario, virtual tutors emerge as a powerful resource, capable of both transmitting knowledge and fostering critical thinking throughout students' educational journeys. Such approaches are particularly crucial in elementary education, as they equip students with the skills needed to navigate and leverage generative AI technologies, which hold immense potential for educational advancement if correctly used.

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