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APPLICATION OF METACOGNITIVE STRATEGIES AND ARTIFICIAL INTELLIGENCE IN THE LEARNING PROCESS

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Abstract. This article examines the application of metacognitive strategies in the instruction of rational inequalities for 9^{th}-grade students. The study presents a pedagogical model that integrates artificial intelligence (AI) tools – specifically ChatGPT and Desmos – to support students' self-reflection and self-regulation. Conducted as a qualitative classroom-based observation over 12 lessons, the study explores how these digital tools may act as cognitive supports within mathematical problem-solving. The focus is on describing the dynamics of student engagement and reflective thinking in an authentic classroom environment rather than on providing controlled empirical measurement of the outcomes.

Keywords: metacognitive strategies; artificial intelligence; personalized learning; problem-solving strategies

1. Introduction

In the rapidly evolving landscape of education, the development of metacognitive competencies has become an important objective in preparing students for lifelong learning and complex problem solving. Metacognition – often described as "thinking about one's thinking" – includes the ability to plan, monitor and evaluate cognitive processes. In mathematics education, metacognitive awareness is strongly associated with success in problem solving, transfer of knowledge and the ability to reflect critically on learning strategies.

At the same time, artificial intelligence (AI) is reshaping educational practices. From intelligent tutoring systems to conversational agents like ChatGPT, AI technologies offer new opportunities for personalization, feedback and dynamic learning environments. However, the integration of AI into instruction should be guided by pedagogical principles in order to ensure that technology serves as a meaningful support for learning rather than simply as a novelty.

This article explores the intersection of metacognitive instruction and AI-supported learning through a qualitative pedagogical observation. It presents a structured teaching model that incorporates ChatGPT and Desmos to encourage students' metacognitive engagement during the study of rational inequalities. Rather than measuring statistical outcomes, this study offers descriptive insights into how digital tools can support strategic thinking and reflective practice within an authentic classroom environment.

2. Context

The primary aim of this study is to explore how the integration of artificial intelligence tools within a metacognitive instructional framework relates to students' reflective engagement during mathematical problem-solving. The study does not attempt to measure the effectiveness of the approach under controlled conditions; instead, it focuses on describing observable patterns of classroom interaction and strategy use.

The instructional design centers on rational inequalities – a topic in secondary school mathematics that requires students to analyze algebraic expressions, consider domain restrictions, construct sign charts and evaluate multiple solution paths. These characteristics make the topic particularly suitable for activating metacognitive processes, since students must engage in planning (selecting approach), monitoring (checking intermediate steps or graphical behavior) and evaluation (assessing correctness and efficiency of the solution).

Within this framework, AI tools such as ChatGPT and Desmos were incorporated into regular mathematics lessons to support reflective dialogue and visual verification. ChatGPT was used mainly to generate explanations, compare alternative strategies and prompt verbalization of reasoning, while Desmos supported graphical exploration and hypothesis testing. The use of these tools was not mandatory for every task; rather, students were encouraged to use them selectively and to reflect on their usefulness in different problem-solving situations.

The implementation took place in a Bulgarian secondary school with one group of 18 ninth-grade students (aged 15-16) during their regular mathematics classes over a period of 12 lessons. The activities followed the national curriculum and were integrated into standard instructional practice. For contextual reference, a second ninth-grade class (17 students) studied the same topic through traditional instruction without the integration of AI tools. This class did not function as a formal control group, as differences in prior academic preparation and group characteristics were known in advance. Therefore, any observed contrasts between the two groups should be interpreted descriptively rather than as experimentally validated comparisons.

The insights presented in this study are based primarily on teacher observation, informal classroom dialogue and students' spontaneous reflections during and after problem-solving activities. No standardized assessment instruments or formal surveys were applied. The intention was to capture the natural dynamics of learning in authentic classroom conditions and to describe how students interacted with AI tools within a metacognitive instructional setting.

3. Theoretical framework

The study is grounded in established theoretical perspectives on metacognition, self-regulated learning and technology-supported cognition. These perspectives provide a conceptual lens for interpreting the classroom observations presented in this study.

Metacognition, as introduced by Flavell (1979), refers to one's knowledge about their own cognitive processes and the regulation of these processes during learning. In educational contexts, metacognition involves the ability to plan, monitor and evaluate one's thinking during learning activities. In mathematics education, metacognitive awareness plays an important role because students must select appropriate strategies, monitor intermediate steps and evaluate the correctness of their solutions.

According to Schraw and Dennison (1994), metacognition consists of two main components: metacognitive knowledge and metacognitive regulation. Metacognitive knowledge includes awareness of strategies, tasks and personal cognitive characteristics, while metacognitive regulation refers to the processes used to control learning, such as planning, monitoring and evaluating one's actions.

Closely related to metacognition is the concept of self-regulated learning. Zimmerman (2002) describes self-regulated learners as individuals who actively participate in their learning process through goal setting, strategic planning and self-monitoring. In the context of mathematics education, self-regulated learning involves selecting solution strategies, verifying intermediate results and reflecting on the effectiveness of different approaches.

Bloom's revised taxonomy (Anderson and Krathwohl, 2001) also highlights the role of metacognitive knowledge in higher-order thinking. Within this framework, metacognitive processes are associated with advanced cognitive activities such as evaluation and strategic decision-making. Encouraging students to reflect on their reasoning and evaluate their problem-solving strategies is therefore considered an important component of effective mathematics instruction.

Recent developments in educational technology have created new opportunities for supporting metacognitive processes through artificial intelligence and digital learning environments. Research on technology-enhanced learning suggests that advanced learning technologies can provide opportunities for learners to monitor their progress, receive feedback and regulate their strategies during problem solving (Azevedo et al., 2019).

Generative artificial intelligence tools, including conversational agents such as ChatGPT, have increasingly been discussed in educational research as resources that may support interactive learning and reflective dialogue (Bettayeb et al., 2024). Recent reviews of the literature indicate that ChatGPT-based interventions are being explored as learning support tools capable of promoting student engagement and higher-order thinking in various educational contexts (Deng et al., 2024).

Holmes, Bialik and Fadel (2019) emphasize the potential of AI to support deeper learning, especially when integrated with pedagogical models that emphasize student agency, inquiry and reflection. However, as Roll and Wylie (2016) note that the educational value of AI tools depends strongly on the instructional context in which they are implemented. Without appropriate pedagogical framing, technological tools risk reinforcing superficial engagement rather than meaningful learning processes.

From a metacognitive perspective, generative AI systems may provide opportunities for learners to externalize and regulate their thinking processes. Conversational AI tools may stimulate reflective dialogue and encourage learners to reconsider their problem-solving strategies. Such interactions can support planning, monitoring and evaluation processes associated with metacognitive regulation. (Monib et al., 2024).

Recent interdisciplinary studies further suggest that the integration of AI with metacognitive strategy instruction may be particularly relevant for Generation Z learners, whose cognitive styles favor interactivity, autonomy and digital fluency (Chardonnens, 2025).

Within mathematics education specifically, artificial intelligence technologies are increasingly investigated as resources that support conceptual understanding and problem-solving processes. A systematic literature review by Mohamed et al. (2022), highlights the growing integration of AI-based systems in mathematics learning environments, especially in contexts involving visualization, adaptive feedback and interactive exploration of mathematical concepts.

The integration of AI into instruction can also be viewed through a sociocultural lens, particularly Vygotsky's (1978) theory of the Zone of Proximal Development (ZPD). From this perspective, learning occurs through mediated interaction with tools or partners that support cognitive development. AI-based systems and digital learning environments may function as mediating resources that help learners bridge the gap between their current level of understanding and more advanced forms of reasoning.

Visualization tools also play an important role in supporting mathematical thinking. Platforms such as Desmos enable students to explore functional relationships dynamically and to test hypotheses about mathematical behavior through graphical representations. Research on digital graphing tools suggests that interactive visualization environments can support conceptual understanding and exploratory learning in mathematics classrooms (Chechan et al., 2023).

ChatGPT's dialogic structure can encourage verbalization of strategies, enabling students to externalize thought processes in ways that align with self-explanation – a metacognitive behavior associated with improved problem-solving outcomes (Chi et al., 1989).

In the Bulgarian educational context, the integration of AI into pedagogy is still developing, yet several recent studies have highlighted its potential. Previous studies have suggested that digital tools can be interpreted not only as technological additions, but also as cognitive partners – resources that engage students in reflective dialogue, facilitate self-verification and open space for alternative reasoning (Petrova, 2024; Petrova & Pavlova, 2024; Pavlova, 2024).

The instructional model in this study was developed in alignment with these theoretical perspectives. It combines metacognitive strategy prompts with the use of AI-based tools such as ChatGPT and Desmos in order to encourage planning, monitoring and evaluation during mathematical problem-solving activities. The aim is not to measure the effectiveness of these tools in controlled conditions but to describe how they may function within authentic classroom practice to support reflective engagement with mathematical tasks.

4. Methodology

The study follows a qualitative descriptive design aimed at exploring how artificial intelligence tools can be integrated into mathematics instruction within a metacognitive framework. The purpose of the research is not to measure learning outcomes under controlled conditions, but rather to describe classroom dynamics and students' engagement with problem-solving processes when digital tools are used during the lessons.

The instructional model presented in this study builds on the idea that AI tools – when integrated purposefully – may function as cognitive supports that encourage reflective thinking and learner autonomy. The two tools selected for this study, ChatGPT and Desmos, complement each other in function: ChatGPT engages students in dialogue and strategic reasoning, while Desmos provides dynamic visual representations of algebraic structures and relationships. Together, they support key aspects of metacognitive activity: planning before solving, monitoring during the process and evaluating after completion.

The study focused on the topic of rational inequalities, which is part of the standard mathematics curriculum for 9th-grade students. This topic was selected because it requires students to engage in multi-step logical reasoning, construct sign charts and consider domain restrictions when solving algebraic expressions. These characteristics make rational inequalities particularly suitable for encouraging reflective problem solving and metacognitive engagement. The instructional implementation was conducted in a Bulgarian secondary school with a group of 18 ninth-grade students (ages 15-16) during their regular mathematics classes. These students followed the standard curriculum and participated in the model as part of their usual learning activities.

For contextual reference, a second ninth-grade class (17 students) studied the same topic through traditional instruction without the integration of AI. Due to differences in prior preparation and overall academic performance between the classes, the second group did not function as a formal control group but rather served as a contextual reference for interpreting observed classroom practices.

The instructional process did not deviate from the expected lesson format but included specific moments for:

- Planning: Students were encouraged to consider possible approaches before solving a task (e.g., choosing between algebraic manipulation or graphical visualization).
- Tool-based exploration: Learners used ChatGPT to generate explanations (Fig.1, Fig.2), verify procedural steps or compare alternative strategies. Desmos was used to visualize algebraic expressions, observe sign changes and analyze solution sets (Fig.3 and Fig.4).
- Reflection: Students were prompted to evaluate the effectiveness of the tools and the strategies they used, either through written notes or short discussions during or after the lesson.

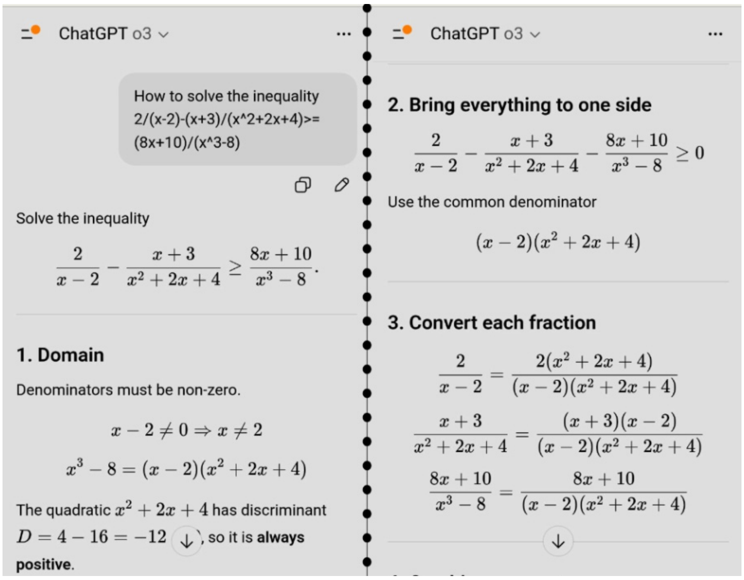

Figure 1. Student's prompt in ChatGPT

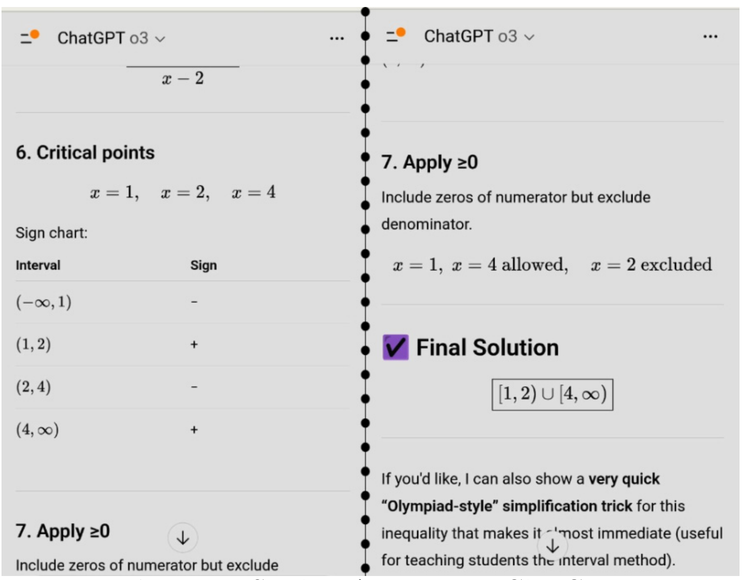

Figure 2. Students' prompt in ChatGPT

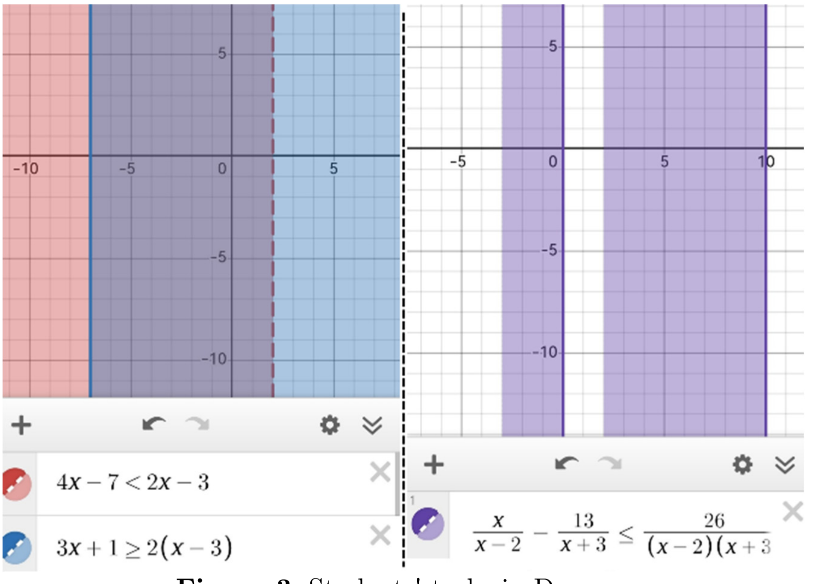

Figure 3. Students' tasks in Desmos

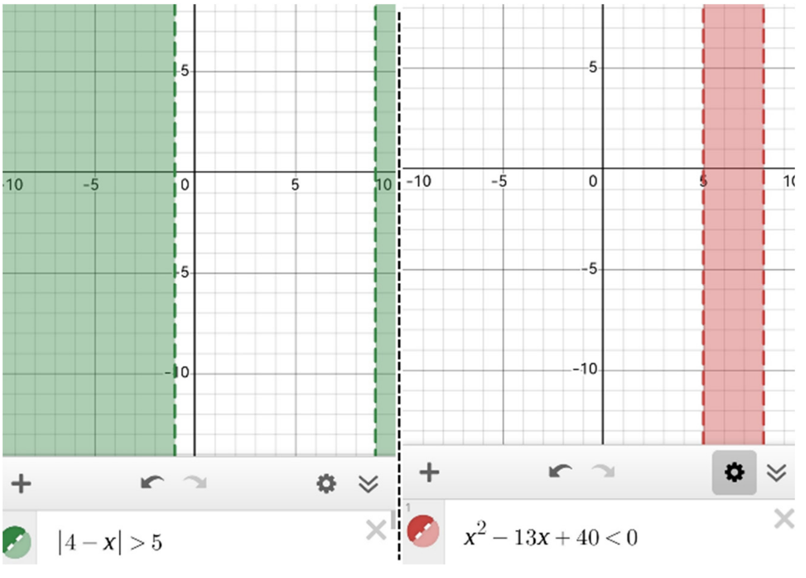

Figure 4. Students' tasks in Desmos

The integration of AI was natural and flexible – students were not required to use the tools for every task, but were guided to reflect on how and when such tools supported their thinking. Teacher facilitation focused on metacognitive prompts such as "Why did you choose this method?", "What did the graph show you?" or "How else could you verify this result?". These prompts were intended to encourage students to articulate their reasoning and reconsider their strategies while solving the problems.

The insights presented in this study are based primarily on classroom observation and informal student reflections during and after the lessons. The observation included elements of participant observation, as the researcher was also the classroom teacher responsible for facilitating the instructional activities. This dual role allowed for close monitoring of students' interactions with the tasks and the digital tools used during the lessons.

No standardized assessment instruments or formal surveys were used. Instead, qualitative impressions were gathered from several sources, including verbal interactions with students during problem-solving activities, classroom discussions related to the use of AI tools and notes or reflections written by students in their notebooks or shared verbally during the lessons. These observations provided insights into how students engaged with the tools, evaluated their strategies and reflected on their problem-solving processes. Students frequently commented on the usefulness of ChatGPT and Desmos while working on tasks, for example asking whether they could verify their solutions graphically or comparing explanations generated by ChatGPT with their own reasoning.

5. Results

Classroom observations during the instructional implementation revealed several patterns in the way students approached mathematical problem solving when digital tools were available.

During the lessons, students worked on a variety of inequality problems, such as:

- Task 1: $x^2 - 13x + 40 < 0$
- Task 2: $|4 - x| > 5$

- Task 3: $\frac{x}{x-2} - \frac{13}{x+3} \leq \frac{26}{(x-2)(x+3)}$
- Task 4: $4x - 7 < 2x - 3$

While solving these tasks, students combined algebraic procedures with the use of digital tools that supported visualization and explanation.

Desmos was frequently used to visualize algebraic expressions and examine the behavior of rational functions. By observing the graphical representation of expressions, some students checked the intervals obtained through sign charts and discussed the relationship between algebraic and graphical representations of the solutions.

ChatGPT was mainly used as a conversational support tool during the problem-solving process. Students occasionally asked the system to clarify procedural steps, explain algebraic transformations or suggest alternative ways to approach a task. In several cases, these explanations became a starting point for short classroom discussions in which students compared the AI-generated explanations with their own reasoning.

The use of both tools occasionally encouraged students to examine their solutions from different perspectives. Some students first solved a problem algebraically and then used Desmos to confirm the result graphically, while others used ChatGPT to review specific steps before continuing with their calculations.

In the reference class, where the same topic was taught without the integration of AI tools, students generally followed a more procedural approach to solving rational inequalities. Their work focused primarily on algebraic manipulation and the construction of sign charts. Although the tasks were completed successfully, fewer instances of graphical verification or strategy comparison were observed during the lessons.

6. Conclusions

The present study explored the integration of metacognitive strategy instruction with artificial intelligence tools in the context of teaching rational inequalities in 9th-grade mathematics. The instructional model combined conversational support through ChatGPT with graphical visualization through Desmos, aiming to encourage students to engage more actively with their problem-solving processes.

Classroom observations indicated that the availability of these digital tools created opportunities for students to approach mathematical problems through multiple representations and to discuss their reasoning during the learning process. In particular, the use of Desmos supported graphical exploration of algebraic expressions, while ChatGPT provided an additional source of explanations that students could compare with their own approaches.

The observed classroom interactions indicated that the use of such tools may encourage students to reconsider intermediate steps, verify their reasoning and discuss alternative solution strategies. These tendencies were observed during regular classroom activities and were closely connected to the teacher's use of metacognitive prompts that guided students' reflection on their problem-solving processes.

At the same time, the study should be interpreted within the limitations of its qualitative design. The observations were conducted in authentic classroom conditions without the use of standardized measurement instruments, and the participating classes differed in their prior level of preparation. Consequently, the findings should not be interpreted as evidence of statistically validated effects but rather as a descriptive account of how AI-supported instructional strategies may function in everyday classroom practice.

Despite these limitations, the study illustrates the potential of combining artificial intelligence tools with metacognitive strategy instruction in mathematics education. The described approach demonstrates how digital technologies can be integrated into regular lessons in ways that support reflective engagement with mathematical tasks.

Future research could further investigate this instructional model by involving larger groups of students, longer observation periods and additional data collection methods. Such studies may provide deeper insight into the role that AI-supported environments can play in supporting students' reflective and strategic approaches to mathematical problem solving.

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