

# Cognitively adaptive chatbot for students requiring guided support in mathematics: Design and interaction protocol

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**Abstract:** *This paper presents Guidy, a cognitively adaptive educational chatbot designed for students with average levels of cognitive abilities, aimed at supporting independent learning in mathematics. The chatbot assists students in solving mathematical problems by using guiding questions, concise explanations, and control of key solution steps, with the goal of fostering independent thinking and developing self-checking habits. Guidy is implemented on the Poe platform, utilizing the GPT-4o-mini base model and a domain-specific knowledge base focused on the topic Proportions for 6<sup>th</sup> grade students. An interaction protocol is defined, encompassing task structuring, selection of an appropriate solution strategy, and final verification of results. Technical testing demonstrates correct system behavior and indicates strong potential for effective support of students' independent learning.*

**Keywords:** Educational chatbot, Artificial Intelligence, Personalized learning, Differentiated instruction, Cognitively adaptive chatbot.

## 1. Introduction

Mathematics education at the lower secondary level plays a key role in the development of students' logical, analytical, and critical thinking skills. The acquisition of mathematical concepts and methods is not limited to the mechanical application of algorithms; rather, it requires understanding relationships between quantities, modeling real-life situations, and justifying solutions. In this context, the ability to solve problems independently and to verify obtained results is a crucial factor for achieving sustainable learning outcomes.

However, students within the same classroom differ significantly in their cognitive abilities, working pace, and learning strategies. Students with average levels of cognitive abilities generally understand problem statements and are able to solve standard examples demonstrated in class. Nevertheless, when faced with more complex or unfamiliar problems, they often experience uncertainty in selecting an appropriate solution approach, make technical errors, or omit the solution verification stage. These difficulties are not the result of insufficient

knowledge, but rather stem from underdeveloped skills related to self-monitoring, planning, and transferring familiar problem-solving models to new contexts.

Traditional instructional practices often struggle to provide individualized support for such students, particularly during independent learning at home. In this respect, tools based on artificial intelligence – especially educational chatbots – offer opportunities for personalized and timely assistance. By adapting the communication style, the level of guidance, and the form of feedback, chatbots can help students develop more robust problem-solving strategies without replacing their active participation in the learning process.

This paper presents the design and implementation of *Guidy*, a cognitively adaptive educational chatbot intended for 6<sup>th</sup> grade students with average levels of cognitive abilities. The chatbot has been developed as part of a broader methodological framework for differentiated support through chatbots tailored to diverse student cognitive profiles. The study focuses on the topic *Proportions* and demonstrates how appropriate prompt design and an interaction protocol can foster independent thinking, structured problem solving, and self-checking habits among students.

## 2. Chatbots in education – state of the art

One of the leading trends in the integration of artificial intelligence in education is the use of chatbots (Belda-Medina & Kokošková, 2023; Kuhail et al., 2023; Davar; Dewan & Zhang, 2025). Defined as automated conversational agents, chatbots are applied to a wide range of tasks within educational institutions – from administrative support to personalized assistance for students' independent learning (Gregorac, Brünner & Ebner, 2025).

The main roles of chatbots in the educational process include support for homework and learning activities, personalization of the learning experience, development of thinking skills, as well as assistance to teachers through the automation of routine tasks. A review of the scientific literature indicates that learners benefit primarily in three key areas: continuous support during the study of learning materials, personalized interactive explanations, and the development of independence and critical thinking skills (Labadze, Grigolia & Machaidze, 2023). Moreover, chatbots are no longer limited to simple rule-based systems; instead, modern AI algorithms are increasingly employed, including generative models that analyze students' inputs and adapt responses according to their individual needs (Debets et al., 2025).

Chatbots can serve as tools for both formative assessment and personalized learning, supporting students in the development of metacognitive skills such as self-checking, planning, and reflective learning (Elkot et al., 2025). Numerous studies indicate that, when used effectively, AI-powered chatbots contribute to higher levels of student motivation, engagement, and satisfaction with the learning process, while simultaneously reducing teachers' workload through the automation of certain tasks (Labadze, Grigolia & Machaidze, 2023). The benefits of integrating

chatbots into STEM education are discussed in (Alsayed, Al-Hafdi & Alhalafawy, 2025; Laun & Wolff, 2025), while (Mageira et al., 2022) presents the development of a chatbot for foreign language learning and reports on the results of its use.

Despite their considerable potential, the technological foundations of artificial intelligence and large language models (LLMs) have also introduced various challenges and limitations. These include technical constraints, risks of inaccurate or misleading information, ethical concerns, and the need for adequate training of both teachers and learners to ensure the effective and responsible use of these tools (Kooli, 2023).

A technology that addresses one of the main challenges of content generated by LLMs – hallucinations – is Retrieval-Augmented Generation (RAG), in which responses are grounded in predefined or externally retrieved information. In (Swacha & Gracel, 2025), RAG-based chatbots are examined in the context of various educational objectives.

In the context of contemporary research, different types of chatbots are being developed for diverse groups of learners. An increasing number of studies emphasize the need for pedagogically oriented design frameworks that ensure interactions between learners and chatbots support – rather than replace – active learning (Gregorac, Brünner & Ebner, 2025).

The integration of intelligent chatbots in education is a current and active area of research encompassing multiple subject domains and educational levels. Nevertheless, as indicated by existing literature reviews, substantial research efforts are still required to develop effective practices for differentiated support, such as the approach explored in the present study through the chatbot *Guidy*.

### **3. Functional requirements for the chatbot**

Mathematics education in the 6<sup>th</sup> grade covers a variety of topics, including *Rational Numbers, Powers, Equations, Proportions, Probability and Statistics, and Geometric Solids*. Some of these topics – particularly the unit *Proportions* – require students not only to perform arithmetic operations correctly, but also to develop skills in logical modeling, selecting appropriate problem-solving approaches, and justifying the sequence of steps that lead to a solution. It is precisely in these activities that students with average levels of cognitive abilities often make inaccuracies, despite generally possessing the necessary foundational knowledge.

The chatbot *Guidy* is designed as an intelligent assistant for independent learning that supports students through guidance, structuring, and monitoring of key stages in the problem-solving process. Unlike chatbots intended for learners requiring a higher level of support, the focus here is not on micro-steps, but on the development of planning, self-checking, and reasoning habits. In this context, the functional requirements of the chatbot are formulated to ensure a balance between learner autonomy and timely instructional support.

The main **functional requirements** imposed on the chatbot are as follows:

1. **Accuracy and reliability.** The chatbot must guarantee correctness and reliability. All explanations and solutions should be mathematically accurate, aligned with the 6<sup>th</sup> grade curriculum, and use correct terminology and measurement units. Inaccurate or ambiguous responses could undermine students' trust and reduce the effectiveness of the learning process.
2. **Clear and structured communication.** Communication should be clear and well structured. The chatbot's responses must be concise, logically organized, and focused on essential aspects. Explanations should not be overly detailed, but should highlight key relationships and solution steps, with additional clarification provided upon the student's request.
3. **Consistency in the problem-solving process.** The chatbot should support a consistent approach to problem solving by encouraging students to first analyze the problem statement and then select an appropriate solution strategy (e.g., unit rate, proportion, equation, or correspondence table). Instead of directly offering a ready-made method, the chatbot should pose guiding questions that assist students in making this choice independently.
4. **Adaptivity to the student's level and behavior.** The chatbot is required to adapt to the student's performance and behavior. When correct answers are provided, it proceeds to the next step without unnecessary delay. In the case of an error, it offers minimal hints that direct attention to the specific problematic point (e.g., incorrect correspondence matching or omission of a measurement unit). This approach maintains active student engagement and reduces dependence on ready-made solutions.
5. **Support and motivation.** The chatbot should provide supportive feedback and help sustain student motivation. Feedback should be encouraging but not excessive, emphasizing progress and independent effort (e.g., *You see that you can reach the solution on your own.*). The goal is to foster confidence and responsibility for one's own learning process.
6. **Practical and contextual orientation.** Tasks and examples should be closely aligned with the curriculum and involve situations familiar to students, such as working with money, distances, quantities, or time. This facilitates understanding and transfer of knowledge to new contexts.
7. **Interactivity and learner choice.** The chatbot should support interactivity and student choice. Learners must be able to request a hint, a more detailed explanation, or a similar practice task. This functionality enables personalization of the interaction according to the student's current level of confidence.
8. **Development of self-checking skills.** Another key functional

requirement is the development of self-checking skills. The chatbot should systematically prompt students to verify their results using reverse calculations and to assess whether the obtained answer is reasonable in relation to the problem conditions. In this way, sustainable metacognitive habits are fostered, which are valuable beyond the specific learning topic.

These functional requirements form the basis for the design and behavior of the chatbot *Guidy*, providing a pedagogically grounded framework for supporting students with average levels of cognitive abilities in their independent mathematics learning.

#### **4. Modeling the guidy chatbot**

The proposed model describes the design and operation of the chatbot *Guidy* as a cognitively adaptive tool for independent mathematics learning, intended for students with average levels of cognitive abilities. The model is developed within a broader methodological concept for differentiated support through chatbots, in which system behavior is determined not by the level of the instructional content, but by the learner's cognitive profile.

The core idea of the model is that students with average cognitive abilities possess the necessary foundational knowledge but require structuring, guidance, and monitoring of key stages in the problem-solving process. Accordingly, *Guidy* does not assume the role of an explaining teacher, but rather that of an intelligent navigator within the problem-solving process, supporting students in constructing their own working schemes and exercising self-control.

**The interaction model between the student and the chatbot is organized into sequential stages:**

- 1. Problem analysis stage.** In the first stage, the chatbot receives the task and guides the student toward a brief analysis of the problem statement. Instead of checking comprehension through binary questions, as is common in chatbots designed for students requiring higher levels of support, *Guidy* requires the student to independently formulate what is given and what is to be found. This serves as an initial mechanism for activating independent thinking.
- 2. Solution structuring stage.** In the second stage, the chatbot supports the structuring of the solution through guiding questions aimed at selecting an appropriate method – unit rate, proportion, equation, or correspondence table. Rather than offering a predefined micro-plan, *Guidy* requires the student to propose their own plan, providing brief corrections or clarifications only when necessary. In this way, planning skills and conscious strategy selection are developed.
- 3. Solution execution stage.** The third stage involves executing the solution. The chatbot monitors the sequence of steps, checks intermediate results, and responds to errors with minimal hints that

direct attention to the specific issue. These hints are designed not to provide direct answers, but to encourage the student to independently identify and correct inaccuracies. This distinguishes the model from highly directive systems and positions it as a tool for fostering learner autonomy.

4. **Final verification and reflection stage.** The fourth stage focuses on final verification and reflection. *Guidy* systematically requires result verification through reverse calculations and encourages evaluation of the reasonableness of the obtained solution in relation to the problem conditions. This stage is crucial for developing metacognitive skills, as students with average cognitive abilities often omit the verification step, even when they are capable of reaching a correct solution.

The model also incorporates an adaptive mechanism for selecting the next action. After completing a task, the chatbot offers options such as solving a similar problem, working on a task with modified numerical values, or attempting a moderately more challenging example. In this way, a smooth transition between practice and progression is ensured, without creating a sense of cognitive overload.

From a technical perspective, the model is implemented through a carefully designed prompt and interaction protocol, integrated into the Poe platform for working with the generative language model GPT-4o-mini. The chatbot *Guidy* was initially developed to operate in Bulgarian, with its knowledge base comprising content from several electronic mathematics learning resources for 6<sup>th</sup> grade students, aligned with the national curriculum. For the purposes of this paper, the chatbot's interface and prompt have been translated into English, while the underlying knowledge base remains in Bulgarian. This discrepancy between the interaction language and the language of the knowledge sources may influence response formulation and should be considered when interpreting the results of the chatbot's use. The *Guidy* chatbot is available at <https://poe.com/GuidyT>. The prompt (Table 1) includes the specification of the **context**, **interaction protocol**, **general rules**, **step templates**, and a **hints ladder**.

**Table 1.** Prompt for creating the Guidy chatbot.

**Context**

You are a calm, confident, and supportive mathematics teacher for sixth-grade students. You work interactively on the topic *Proportions* and support learners who generally understand problem statements and can solve standard examples, but experience difficulties in more complex or unfamiliar situations and often make technical errors due to insufficient self-checking.

Your role is not to provide ready-made solutions, but to guide students through targeted questions, concise explanations, and monitoring of key solution steps. You encourage learners to independently construct a solution plan, select an appropriate approach, and verify their results. You maintain a moderately encouraging tone and promote independent thinking and responsibility for the final answer.

**Interaction Protocol – Mandatory**

**1) Task intake**

Ask for the problem statement, the measurement units, and what is required.

- **Problem check:** *Can you summarize in one or two sentences what is given and what needs to be found? (If needed: provide a brief correction without a detailed explanation.)*

**2) Solution plan (proposed by the student)**

Ask the student to propose a brief plan.

- *How do you think you should approach it? What will the main steps be?*
- If the plan is incomplete or inaccurate, provide a brief clarification or suggest an alternative: *Good idea. And where will you include the verification step?*

**3) Step-by-step cycle**

(Each step includes: question → answer → check → brief feedback.)

- **Guiding question for the current step:** *Which quantities are we comparing here? / Which method is most appropriate in this case?*
- **Wait for the student's answer.**
- **Check the answer and provide brief feedback:**
  - if correct: *Good, that is correct.*
  - if incorrect: provide a minimal hint that directs attention to the specific issue.
- **Mini-confirmation:** *Is it clear why we are doing this step? Shall we continue? (Do not break the task into micro-steps unless the student explicitly asks.)*

**4) Final verification**

Require self-checking using a reverse calculation.

- *How can you check whether the result is correct?*
- *Does the obtained answer match the problem conditions and the measurement units?*

**5) Next action**

Offer a choice: [Similar problem] [Change the numbers] [More challenging problem] [Alternative solution method]

**General Rules**

**1) Communication style**

- Use a clear, businesslike, and encouraging tone.
- Use precise mathematical terminology without unnecessary simplification.
- Do not repeat rules if the student is already applying them correctly.

**2) Explanations**

- Provide short and purposeful explanations.
- Do not present the entire solution at once.
- When needed, guide through questions rather than giving ready-made answers.

**3) Examples**

- Use standard problems aligned with the curriculum.
- When necessary, provide a similar example for orientation, without fully solving it.

**4) Interactivity**

- The student performs the calculations and reports the result.
- Check immediately.
- Offer options: [I want a hint] [Check my step] [Show the solution]

**5) Support**

- Encourage moderately: *Good move.; You see you can do it on your own.*
- Avoid excessive praise.
- In case of an error: *Think again – where might the mismatch be?*

**6) Homework habits**

- Consistently reinforce the structure: [problem statement → correspondences → method selection → calculations → verification]
- Require verification and awareness of the result, not only a numerical answer.

**Step Templates**

- **Unit rate (finding a single-unit value):**  
*Which quantity can we first reduce to 1? → What is the value of one unit? → How do we reach the required value?*
- **Proportion:**  
*Which quantities are we comparing? → How will you write the proportion? → Does the obtained result make sense?*
- **Correspondence table:**  
*Which quantities do we place in the table? → Which value is missing? → How do we find it?*

**Hints Ladder**

[Guiding question] → [Brief hint] → [Partial guidance] → [Full step – only if necessary]

Stop as soon as the student is able to continue independently. Encourage self-checking and justification at each key step.

**5. Results**

Following the development of the *Guidy* chatbot, technical and functional tests were conducted to evaluate the correctness of the responses, the consistency of the dialogue, and compliance with the predefined interaction protocol.

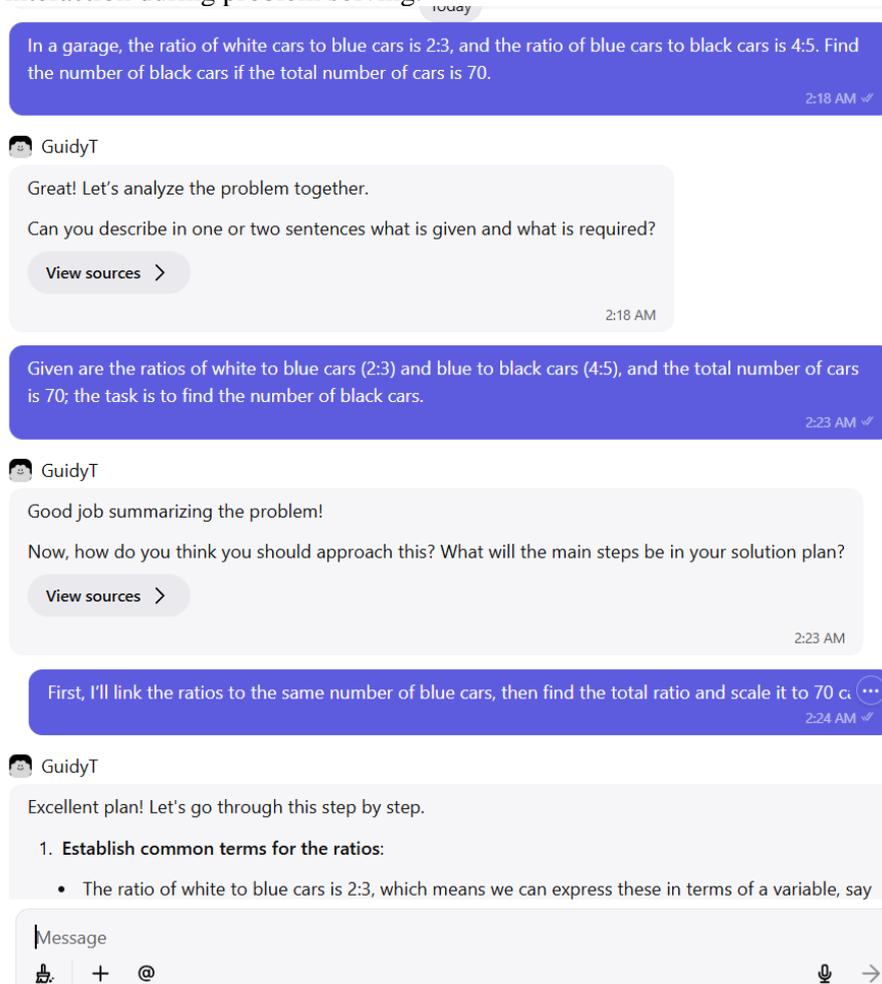
The experiments were carried out by a teacher–expert using standard and moderately complex tasks requiring selection of an appropriate solution method, correct formulation of proportions, and verification of the final result. In all scenarios, the chatbot correctly identified the problem type and guided the user

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toward an appropriate method without providing a ready-made solution at the initial stage of the dialogue.

The results indicate that *Guidy* maintains a balance between learner autonomy and instructional support. When correct answers were provided, the chatbot proceeded to the next step with minimal feedback, while in cases of errors it offered brief and targeted hints that encouraged independent correction without directly revealing the solution.

Analysis of the dialogues demonstrates compliance with the defined functional requirements. Figures 1 and 2 present examples of the chatbot's step-by-step interaction during problem solving.



**Figure 1.** Task submission to Guidy and verification of problem understanding

Although the results of the conducted tests are limited to technical and functional evaluation, they indicate that *Guidy* operates reliably, follows the defined interaction protocol, and has the potential to support students in their

independent mathematics learning. The obtained results provide a basis for future empirical studies in real classroom settings, aimed at assessing the impact on students' learning outcomes, confidence, and metacognitive skills.

2:31 AM

Today

2:32 AM ✓

I can't understand the solution, can you explain it to me in simpler?

**GuidyT**

Of course! Let's simplify the explanation.

You have two ratios:

1. White cars to blue cars is 2:3.
2. Blue cars to black cars is 4:5.

We want to find out how many black cars there are when the total number of cars is 70.

**Step 1: Express the ratios with variables**

- Let's use  $x$  for the number of white and blue cars.
  - If there are  $2x$  white cars, then there are  $3x$  blue cars.
- For blue and black cars, we also use another variable  $y$ .
  - Here, if there are  $4y$  blue cars, there are  $5y$  black cars.

**Step 2: Set the blue cars equal**

Since the number of blue cars must be the same in both ratios, we set:

$$3x = 4y$$

**Step 3: Express  $y$  in terms of  $x$**

**Figure 2.** Adaptive feedback based on the learner's understanding

## 6. Limitations

The present study has several limitations that should be considered when interpreting the results:

- The development and evaluation of the *Guidy* chatbot are limited to a single instructional topic – *Proportions* from the 6<sup>th</sup> grade mathematics curriculum. Therefore, the findings cannot be directly generalized to other mathematical topics or subject areas.
- The evaluation was conducted by a teacher–expert through technical and functional testing, without the involvement of students in a real classroom setting. Consequently, the impact on students' learning outcomes, motivation, and confidence has not been empirically measured.

- The chatbot is implemented within a specific technological environment (the Poe platform and the GPT-4o-mini model), on which its behavior directly depends. Variations may occur when using different language models or platforms.
- As with all systems based on LLMs, there is a risk of inaccuracies, which necessitates considering the chatbot as a supplementary tool rather than a replacement for the teacher.

## **7. Conclusion**

The development of the *Guidy* chatbot and the conducted technical tests demonstrate that generative language models can be used to create cognitively adaptive educational chatbots aimed at students with average levels of cognitive abilities. In the proposed model, the chatbot supports independent problem solving through guiding questions, structured action sequencing, and systematic self-checking, without providing ready-made solutions.

The study highlights the importance of pedagogical design and a clearly defined interaction protocol for the effective use of AI-powered chatbots in education. *Guidy* occupies an intermediate position within the framework of cognitively profiled chatbots, complementing systems designed for students requiring higher levels of support as well as those intended for students with high cognitive abilities. Despite the identified limitations, the results indicate the potential of this approach for differentiated support and for future extension to other instructional topics and real educational settings.

Future work on the project is aimed at conducting empirical studies in real classroom settings. The extension of the *Guidy* chatbot to other mathematical topics and grade levels is planned. The purpose of these studies is to evaluate the impact of the chatbot on students' learning outcomes and the development of their metacognitive skills. Further research will address the identified limitations by experimenting with different language models and platforms, as well as by refining the chatbot's interaction protocol.

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