

COGNOTUTOR: A SUSTAINABLE SOLUTION FOR IMPROVING METACOGNITIVE SKILLS

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ABSTRACT: Improving self-regulated learning among students is more sustainable when transferable skills, such as metacognitive skills, are developed. Many students face challenges in learning due to lack of effective self-regulated learning strategies. This study proposes the design of CogNoTutoR, a web-based tool aimed at enhancing metacognitive skills in mathematical problem-solving through personalized feedback. The system employs a validated 12-item questionnaire (Content Validation: 0.9; Reliability [Ordinal Alpha]: 0.89) to assess students' initial metacognitive levels and generate tailored feedback. A pilot study involving mathematics lecturers, students, and interface designers is planned to refine the system further. Future developments include the integration of automated grading and the expansion of the application to multidisciplinary contexts, supporting sustainable educational practices.

Keywords: mathematics, metacognitive skills, sustainability, transferrable skills,

1. INTRODUCTION

With the rapid growth of population, non-renewable resources are not growing but stagnating. Sustainability focuses on minimizing waste and pollution, expanding the life cycle of products and regenerating natural systems (Gavkalova et al., 2023). Education systems can contribute to this process in two ways:

- i. Students can be educated on sustainable practices and
- ii. Teaching and learning process can be designed in more sustainable way.

The meaning of metacognition is “knowing about your own thinking process” (Ozturk, 2017). Metacognition is divided into two components: metacognitive knowledge and metacognitive skills (Schuster et al., 2020). Among these, metacognitive skills are identified as transferrable and task-general (Schuster et al., 2020). Improved metacognitive skills can be applied in a variety of contexts, such as reading exercises or laboratory experiments. Hence, improving metacognitive skills in students is more economic and sustainable as it aligns with one of the major principals of sustainability “reuse”.

There are feedback systems designed for improving metacognitive skills in subjects such as mathematics, biology and basic science. MeMo Tutor is a web application integrated with the Moodle for Linear Algebra lessons. It generates personalized feedback and supports account creation for students and teachers, promoting reusability. However, it is limited to the Bahasa Indonesia language and does not assess metacognitive skills (Martha et al., 2019). Elbasri (2019) and colleagues designed a metacognitive agent system that measures metacognitive skills using questionnaires and provides personalized feedback. The system is standalone and lacks reusability and collaboration features (Elbasri et al., 2019). MetaTutor, a standalone application, uses four agents to provide metacognitive feedback, focusing on self-regulated learning (SRL) in blood circulation. While effective for SRL development, it lacks broad subject applicability and collaborative features. Another standalone system was designed to assess the impact of metacognitive scaffolding on self-efficacy, metacognition, and achievement in e-learning. It supports auto-grading and student goal setting but is limited to Colombian language mathematical problem-solving, hindering its adaptability to broader use (Azevedo et al., n.d.). By reviewing existing work, it is clear that available systems do not integrate sustainability in their designs.

The primary objective of this study is to present the design of CogNoTutoR and its feedback mechanism, developed to provide targeted support for students with varying metacognitive skills. Future developments will focus on incorporating features for automated grading, expanding subject-specific modules, and conducting a comprehensive pilot study involving students, mathematics lecturers, and interface designers to refine CogNoTutoR's usability and effectiveness as a sustainable educational tool.

2. METHODOLOGY

The CogNoTutoR system is a web-based tool designed to foster metacognitive skill development, particularly within mathematical problem-solving contexts, by generating personalized feedback tailored to individual students' needs. By incorporating a structured, phase-based feedback approach that includes planning, monitoring, and evaluation, CogNoTutoR aims to enhance students' engagement in self-regulated learning.

2.1 System Structure and Technology Stack

CogNoTutoR employs a robust technology stack designed for scalability and ease of maintenance. PHP (Hypertext Preprocessor) and the Laravel framework drive the backend infrastructure, handling user management, feedback generation, and questionnaire analysis, while the frontend is powered by Bootstrap, ensuring a responsive, accessible user experience. MySQL serves as the database system, storing student responses and feedback for future reference. ChatGPT, integrated through API, provides question-specific feedback by generating responses that align with the goals of each learning phase.

2.2 Feedback Mechanism and Questionnaire

A validated 12-item metacognitive skills questionnaire ((Athukorala et al., 2024) is central to CogNoTutoR's user identification. This questionnaire was designed based on the systematical observations used in thinking aloud protocol in mathematical problem solving (Jacobse & Harskamp, 2012). Students complete this questionnaire upon initial sign-in, which measures essential aspects of metacognitive skills. Responses, stored securely within the system, inform feedback generation, with specific attention to areas that need development. For instance, responses rated as "Sometimes" or "Almost Never" receive targeted feedback in yellow color, while the option "Often" are reinforced in green color.

The questionnaire is structured to provide insights across several domains: self-awareness and planning, monitoring and progress checking, evaluation and reflection.

2.3 Phased Feedback Model

CogNoTutoR's feedback model is structured into three phases, supporting self-regulated learning by delivering context-specific prompts throughout the problem-solving process:

- 1. Planning Phase:** Initial feedback guides students to carefully read the problem, set goals, and strategize their approach. For instance, when faced with combinatorial questions like "How many ways can the letters in 'MISSISSIPPI' be arranged?", the system might prompt students to focus on reading the question thoroughly and identifying key variables, aligning with foundational planning skills.
- 2. Monitoring Phase:** As students' progress, feedback is geared towards ensuring they remain on track. Prompts may encourage students to revisit earlier steps or verify intermediate calculations, enhancing their ability to self-correct.

- 3. Evaluation Phase:** After a solution submission, students receive evaluation feedback designed to foster self-reflection, such as assessing the solution's accuracy and considering alternate methods. This phase includes timed prompts that guide students in reviewing their answers before proceeding to the next question.

CogNoTutor is a password protected application. Teachers and students should create a profile when they first login to the application and they should use their username and password every time they log. This limited access prevents the system from unauthorized access. Teachers can add tutorials, view students' metacognitive skills, add marks and view marks of the students. Students can work on tutorials, view marks for each tutorial and try metacognitive skills level questionnaire.

Currently, CogNoTutor is tailored to mathematical problem-solving, specifically within the domain of number theory. To broaden the tool's applicability, future updates could incorporate modules for additional subjects. And potential issues that can occur due to AI generated feedback is planned to be addressed and possible solutions are to be implemented as a future work. Furthermore, a pilot study involving usability testing and user satisfaction surveys is planned, which will provide empirical data to assess the system's effectiveness in fostering metacognitive skills. Preliminary findings from this study will be integrated into future iterations of the system to refine and validate feedback mechanisms, enhancing CogNoTutor's educational impact.

3. DISCUSSION

CogNoTutor is a tool that provides adaptive feedback to improve students' metacognitive skills in math problem-solving, focusing on self-regulated learning. By utilizing a validated metacognitive skills questionnaire, it evaluates and monitors students' advancement, allowing teachers to give customized guidance on time. The digital system's design reduces paper consumption, supports sustainability objectives, and promotes reuse of resources to enhance efficiency and cognitive ease. CogNoTutor's structured feedback emphasizes planning, monitoring, and evaluation to help students refine problem-solving approaches and develop transferable metacognitive skills for use in multiple subjects. This adaptability supports broader applications; as additional modules can extend their benefits to other learning areas. Future enhancements include usability testing and privacy safeguards, ensuring that the system is both effective and ethical.

4. CONCLUSION

This paper presents CogNoTutor, a web application that aims to enhance metacognitive skills for problem-solving using mathematics as its subject area. Metacognitive learning can be fostered through the structured nature of mathematical problem-solving tasks, which encourages learners to develop their own level of self-regulation and reflection (Kusaka & Ndiokubwayo, 2022). The application starts with the validated 12-item questionnaire, which is used to assess students' metacognitive skill levels and provides students tailored feedback along with the meta-cognitive prompts, problem-specific hints through ChatGPT for adaptive responses in real-time. This way CogNoTutor encourages resource reuse, minimizes cognitive waste and harmonizes with sustainable learning.

As an adaptive tool, CogNoTutor can be scaled to accommodate additional subjects, extending its benefits across diverse educational contexts. This scalability ensures that students can apply and reinforce metacognitive skills in multiple domains, supporting self-regulated learning over time. Moving forward, planned usability testing and empirical validation will provide critical insights into CogNoTutor's effectiveness, reinforcing its role as a resource-efficient and ethical solution within educational technology. With its foundation in sustainability and resource conservation,

CogNoTutoR offers a promising framework for advancing metacognitive skills, meeting both educational and environmental goals.

5. REFERENCES

- Athukorala, U., Fernando, D., & Wijeratne, C. (2024, February 13). Thinking Aloud Protocol Based Self-Report Questionnaire to Measure Metacognitive Skills in Mathematical Problem Solving. *The Asian Conference on Education 2023 Official Conference Proceedings*. The 15th Asian Conference on Education, Japan.
- Azevedo, R., Witherspoon, A., Chauncey, A., Burkett, C., & Fike, A. (n.d.). *MetaTutor: A MetaCognitive Tool for Enhancing Self-Regulated Learning*.
- Elbasri, H., Haddi, A., & Allali, H. (2019). Design of a multi-agent system using the “MaSE” method for learners’ metacognitive help. *International Journal of Electrical and Computer Engineering (IJECE)*, 9(3), 2033. <https://doi.org/10.11591/ijece.v9i3.pp2033-2040>
- Gavkalova, N., Lola, Y., Poliakova, H., Smalskis, V., & Tavshunskyi, O. (2023). Education in the concept of circular economy in times of global crises. *IOP Conference Series: Earth and Environmental Science*, 1150(1), 012016. <https://doi.org/10.1088/1755-1315/1150/1/012016>
- Jacobse, A. E., & Harskamp, E. G. (2012). Towards efficient measurement of metacognition in mathematical problem solving. *Metacognition and Learning*, 7(2), 133–149. <https://doi.org/10.1007/s11409-012-9088-x>
- Kusaka, S., & Ndiokubwayo, K. (2022). Metacognitive strategies in solving mathematical word problems: A case of Rwandan primary school learners. *SN Social Sciences*, 2(9), 186. <https://doi.org/10.1007/s43545-022-00495-5>
- Martha, A. S. D., Santoso, H. B., Junus, K., & Suhartanto, H. (2019). *Designing Metacognitive and Motivation Tutor: A Pedagogical Agent to Facilitate Learning in Blended-Learning Environment in A Higher Education Context*.
- Ozturk, N. (2017). Assessing Metacognition: Theory and Practices. *International Journal of Assessment Tools in Education*, 134–134. <https://doi.org/10.21449/ijate.298299>
- Schuster, C., Stebner, F., Leutner, D., & Wirth, J. (2020). Transfer of metacognitive skills in self-regulated learning: An experimental training study. *Metacognition and Learning*, 15(3), 455–477. <https://doi.org/10.1007/s11409-020-09237-5>
- Veenman, M. V. J., Kok, R., & Blöte, A. W. (2005). The relation between intellectual and metacognitive skills in early adolescence. *Instructional Science*, 33(3), 193–211. <https://doi.org/10.1007/s11251-004-2274-8>