Development of an intelligent tutoring system for primary education

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Abstract. Combined developments across several fields, such as educational research and computer sciences, have led to an evolving landscape of personalized learning and the educational context. Yet, traditional educational settings still struggle to ensure that all students receive adequate support to succeed academically, with most research on personalized learning systems focusing on higher education, often neglecting primary education. This study aims to leverage the use of an artificial intelligence-powered Intelligent Tutoring System (ITS) to enhance the personalization of mathematics learning for third and fourth grade students. For this purpose, an ITS prototype is devised, exploring how student knowledge can be modeled and structured, relying on existing theories, and how personalization should occur during student-system interactions. By applying a design thinking approach, we will assess user experiences and system performance throughout the development process via user interviews and usability testing, involving both students and teachers. We will conduct A/B testing using two versions of the prototype: one with AI-driven personalization and one without. User behavior will also be tracked through questionnaires and analytics tools during testing. The insights gained from data analysis will help evaluate the learning experience delivered by an ITS that utilizes AI-driven techniques for personalization. With these findings, we aim to contribute to the design of ITS tools tailored to the needs of primary education.

Keywords: Intelligent tutoring system (ITS); Personalized learning; Education; Artificial Intelligence; Young Learners.

1 Introduction

As education systems evolve, personalized learning has become central in discussions about improving educational effectiveness and shaping future innovations. This growing interest is reflected in the rising number of publications on the topic [1][2], making personalization an increasingly prominent, or aspirational, standard in schools [3]. One major challenge in education is ensuring that all students receive the support they need to succeed academically. Traditional classrooms often struggle with many students for each teacher, making it difficult to provide individualized instructions. Consequently, students who face learning difficulties are at risk of falling behind.

To address these challenges, Intelligent Tutoring Systems (ITS), powered by Artificial Intelligence (AI), have emerged as a primary technology designed to enhance the efficacy of learning and teaching. Evidence supporting ITS effectiveness shows that these systems offer a viable solution to bridge the gap between traditional

instruction and the need for personalized learning experiences, making quality education more accessible. This study aims to leverage the use of an artificial intelligence powered ITS to personalize math learning for third and fourth graders. The system is designed to support students with guided practice and adaptive assistance, promoting autonomy over time; and teachers automating design, selection and delivery, thus reducing the need for constant intervention.

2 Related Work

2.1 Personalized Learning

The concept of personalized learning can be defined as a learner-centered pedagogical approach, that tailors learning content, methods, assessments and pace to each student's strengths, needs, and interests, aiming to develop competence and maximize potential [4] [5]. Adaptive learning refers to digital tools and systems that use algorithms to monitor progress and dynamically adjust instructions according to collected data [6][7]. Research shows students learn more with individualized instruction. Schmid et al. [2] found that most reviewed studies reported positive discoveries in terms of academic outcome and engagement. Arroyo et al. [9] studied a multimedia adaptive tutoring system for mathematics showing improved outcomes for individuals who used the system. Zhang et al. [10] reported general positive effects of adaptive learning technologies and ITS on learning, including in math and English for students with and without disabilities. Research has predominantly focused on higher education, especially in subjects like Mathematics, Computer Science and Language Learning, using artificial intelligence and machine learning techniques, which have taken the form of intelligent tutoring systems [1][3][10][11].

2.2 Intelligent Tutoring Systems

An ITS is a software program that executes essential tutoring functions, such as asking questions or assigning tasks, dynamically adjusting these functions based on student input and providing personalized feedback [12]. To meet each student's evolving learning needs, the system continuously monitors their progress, allowing it to address specific learning gaps and reinforce concepts. The efficacy of the system lies in its ability to model certain factors associated with each student [13], [14].

A common ITS design is based on a four-module architecture, including student, tutor, domain, and interface modules [15]–[18], which guides the structure of the system presented in Section 3.

According to Paladines et al. [12] and Wenting et al. [19], ITS effectiveness depends on how student knowledge is structured and modeled. Common modeling techniques include expectation/misconceptions models comparing responses to predefined notions, model-tracing tutors that trace student actions against predefined expert rules, constraint-based modeling, that defines logical conditions for correct solutions and flag violations as learning gaps, and Bayesian network modeling that

represent uncertainty, reflecting the system's best estimation of whether the student understands it or holds a misconception.

3 System Design and Current Implementation

The system architecture follows the common layout of an ITS, composed of four main modules.

The Tutor module uses student performance data to guide the learning process by selecting appropriate pedagogical strategies. In this case, it provides hints at diverse levels of guidance and determines the next exercise in the quiz sequence based on the learner's previous response. This module also captures user input and performance metrics. One example of this adaptation is the hint system, a functional subcomponent that provides hints at increasing levels of specificity. The information related to the question, such as the statement, solution, format, and available options (if applicable), is embedded into a structured prompt, which serves as input for a large language model (LLM) along with relevant context. To increase the efficacy of the generated hints, two prompting techniques were employed: chain-of-thought and few-shot prompting. The overall prompt structure is illustrated in Fig. 1. This system aims to implement a scaffolded mechanism, where hints become progressively less available or necessary as the lesson or quiz advances.

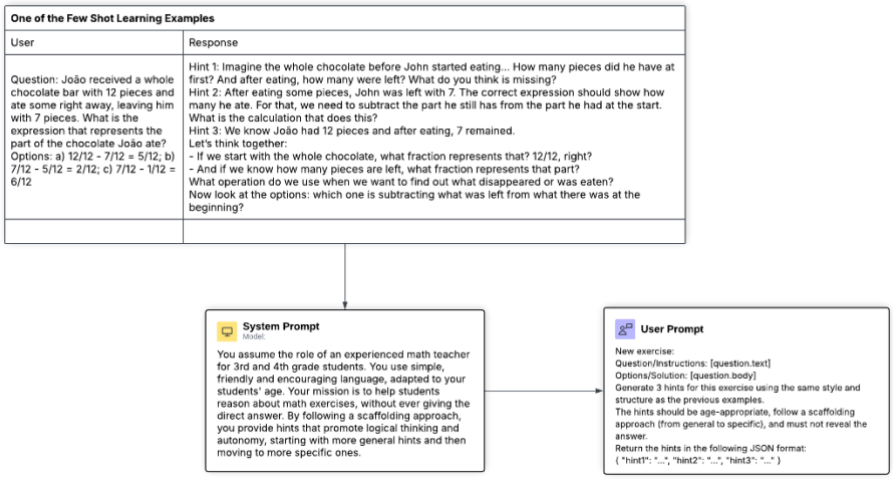


Fig. 1 – *Prompting strategy to generate hints. The few-shot examples illustrate how to structure the hints. The user input introduces a new exercise and asks the model to generate hints using the same structure, returned in JSON format. The system input defines the assistant's role and pedagogical tone.*

The Domain module contains structured knowledge, essential for learning a specific topic, serving as a benchmark for comparing students' responses. This module is based on the fourth-grade mathematics curriculum and includes a set of

exercises organized by topic. Each exercise is tagged with the following metadata: difficulty level, thematic category, exercise type, and learning objective. A correct solution is associated with each exercise, serving as a reference for evaluating the student responses. This data is also used by the tutor module to generate personalized hints.

The User Interface module manages communication between the student and the system, where content presentation significantly influences student performance. Targeting young learners in third and fourth grades, the interface prioritizes simplicity. Education content is structured into lessons, each consisting of a topic explanation, examples and interactive exercises. The design minimizes cognitive load, using simple labels and a color scheme that supports usability. Exercises vary in format to keep students engaged, being the most interactive element of the system.

The student module stores relevant information about the student, reflecting their state of knowledge at a particular point. It receives data from the Tutor module, updating not only the learner's subject proficiency but also storing engagement metrics (e.g., questions completed) and interaction logs (e.g., time per question and hints used).

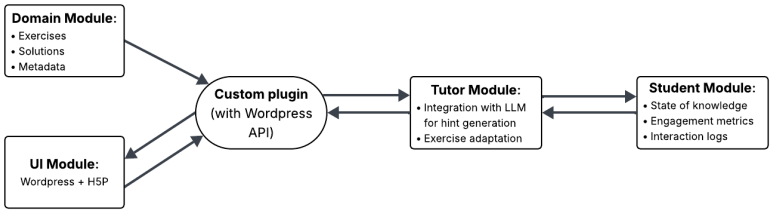


Fig. 2 – Flowchart illustrating the architecture of the system

4 Future Work

The next project phase will advance the exercise selection mechanism for optimal follow-up exercises. LLM prompt-based techniques will extract structured features (metadata) from exercises, serving as an input to perform automated clustering, supporting exercise selection by grouping related items. These features, aligned with prompting methods, allow automatic generation of new exercises from templates or questions created by the teacher. Due to the inconsistency associated with LLM generated content, the teacher should perform a subsequent manual validation of the exercises generated.

It will also refine the student model to more accurately represent learner knowledge. To model knowledge on a continuous scale, it will capture dependencies between topics by implementing a Bayesian Network-based approach, allowing updates in one topic to influence related areas. By considering the limitations of real-time inference and the small amount of training data, a simplified version will be developed.

User experience and system performance will be assessed via user interviews and usability testing, involving both students and teachers. A/B testing will use two

versions of the prototype for comparing AI-driven personalization. Future iterations may explore gamification, such as scoreboards, and visual clues, based on the number of attempts.

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