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The Impact of Game-Based Learning and AI Support on Students' Understanding of Fractions

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ABSTRACT

Fractions are a foundational mathematical concept that many elementary students struggle to understand (Piaget, 1952). Traditional instruction often relies on memorization and repetition, which reduces engagement and limits conceptual understanding. The platform introduces an interactive learning platform that utilizes adaptive difficulty and an AI-powered chatbot to support students. While artificial intelligence tools are becoming increasingly common in education, most general systems focus on providing answers rather than ensuring students understand the reasoning behind them (Burns, 2026). The chatbot encourages students to explain concepts, promoting understanding instead of answer retrieval (Vygotsky, 1978). The platform includes instructional units, quizzes, and final assessments to measure learning outcomes. To evaluate the system's effectiveness, a study was conducted. It involved students in grades four through six. Fifteen students tested the platform, with eight using the adaptive chatbot and seven using the standard chatbot. Results showed that students using the adaptive chatbot achieved an average of 93.5% on the final assessment, whereas those using the general model achieved only 83.0%. Results indicate that explanation-based AI tools can strengthen conceptual understanding in mathematics.

Introduction:

Mathematical education, particularly in foundational topics such as fractions, presents persistent challenges for elementary-level students (Piaget, 1970). Fractions require students to understand relationships between parts and wholes, equivalence, and numerical comparison, which are more complex than whole-number operations. Because of this, many students develop procedural understanding without achieving deep mastery (Piaget, 1952). This often leads to common misconceptions. Common misconceptions include incorrectly adding numerators and denominators or misunderstanding fraction values.

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Repetition, memorization, and the use of worksheets are frequently emphasized in classrooms. These practices may improve short-term results, but they do not support long-term understanding. As educational environments incorporate digital tools, there is growing interest in utilizing artificial intelligence and game-based learning to improve engagement and comprehension (Labadze et al., 2023; StudentScholarships, 2025). However, many existing AI educational systems function as answer-providing tools. These systems often reduce engagement by supplying solutions without requiring students to articulate their reasoning. Research in learning sciences suggests that self-explanation, active recall, and guided reflections significantly improve outcomes (Vygotsky, 1978).

This project addresses this gap by developing a game-based learning platform for fractions that integrates an adaptive AI chatbot. In addition, ethical considerations in game-based learning systems, such as fairness, engagement design, and user experience, play an important role in how educational tools are developed and implemented (Jimottewill, 2024). Unlike traditional AI tutors, the chatbot in this system is designed to prompt students to explain their reasoning, reflect on their answers, and engage in step-by-step thinking. The goal is to evaluate whether explanation-driven AI improves student understanding compared to a standard chatbot system (Wang et al., 2025).

Adding on, accessibility plays a critical role in supporting diverse learners within mathematics education (United Nations, n.d.). Many students require different levels of guidance, pacing, and explanation styles, which can be difficult to consistently provide in a traditional classroom setting. An AI chatbot offers a scalable solution by giving individual support in real time, allowing students to receive help whenever they need it (Ajala, 2025). This reduces barriers to learning and ensures that students who may be hesitant to ask questions in class still have access to clear explanations and assistance.

Furthermore, the use of a chatbot that emphasizes explanation rather than direct answers aligns with cognitive learning principles (Vygotsky, 1978). Encouraging students to verbalize their thinking and justify their reasoning strengthens conceptual understanding and helps identify misconceptions early. By integrating these strategies into an interactive, game-based environment, the platform not only increases engagement but also promotes deeper learning.

Overall, this project highlights the potential of combining AI chatbots with game-based learning to address common challenges in fraction education. By focusing on accessibility, personalized support, and explanation-driven learning, the platform aims to improve both student understanding and confidence. This research contributes to ongoing efforts to design educational technologies that not only engage students but also support meaningful and lasting learning outcomes.

ISSN: 2455-8834

Volume:11, Issue:07 "July 2026"

Method:

Participants:

The participants ranged from approximately nine to eleven years old. The target demographic of the experiment included fourth and fifth-grade students, with a small number of 6th-grade students as well. A total of fifteen participants took part in the study, with most participants recruited from Virginia. All participants were informally assessed prior to the study and were identified as having limited or no prior proficiency in fraction-related concepts. This ensured that all participants began with a relatively similar baseline understanding of the subject matter.

Participants were randomly assigned to two groups. The first group was the experimental group, including eight students. This group used the adaptive AI chatbot system. The second group was the control group, including seven students. This group used a standard AI system that gave general responses. Random assignment was used to reduce selection bias and ensure compatibility between groups.

Materials and Technology

Two distinct versions of a web-based learning platform were developed for this study. Both versions contained identical instructional content related to fractions, including introductory lessons, interactive practice problems, guided quizzes, and a final assessment. The control version included a standard chatbot interface powered by the general AI model ChatGPT. The ChatGPT chatbot used direct explanations, answers, and step-by-step solutions upon request.

In contrast to the control group, the experimental version included an adaptive AI chatbot designed specifically for educational reinforcement (Labadze et al., 2023). The adaptive chatbot encourages students to explain the material back to the system to assess their level of understanding. The adaptive chatbot utilizes AI to personalize learning for each student. Instead of giving every learner the same questions and explanations, it analyzes responses and adjusts difficulty based on student performance. This placement is based on a preliminary self-assessment. The results provide both the student and the system with a measure of prior knowledge, allowing the chatbot to tailor instruction to individual needs. The self-assessment also promotes metacognition, or the ability to think about and evaluate one's own learning. By reflecting on what they know and do not know, students become more aware of their strengths and weaknesses, which can improve learning outcomes. The student's self-assessment results are provided to the adaptive chatbot, which analyzes the identified knowledge gaps. Using this information, the chatbot tailors its responses and learning support to each student's specific areas of weakness, creating a more personalized learning experience. If a student struggles with a concept, the chatbot can provide simpler explanations, additional examples, or extra practice

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Volume:11, Issue:07 "July 2026"

activities. If the student demonstrates mastery, the chatbot can introduce more challenging material to encourage continued growth. This process is critical for ensuring genuine comprehension, as students often misjudge the extent of their understanding of newly learned material.

Procedure:

The study followed a structured single-session format. Each participant accessed their assigned version of the learning platform and completed the instructional modules on fractions. Students then worked through interactive practice problems and quizzes using their assigned chatbot system. During this process, participants in the experimental group were consistently prompted to reflect by explaining their reasoning. Students then responded to follow-up questions generated by the adaptive chatbot. In contrast, participants in the control group primarily received answers and explanations without additional prompts.

After completing the learning activities, all participants took the same post-test assessment. The assessment included multiple-choice and short-answer questions designed to measure conceptual understanding of fractions, such as identifying equivalent fractions, comparing fraction values, and solving applied problems. Students completed the post-test individually without assistance. Their responses were collected, scored for accuracy, and analyzed to compare performance between the experimental and control groups.

Results:

The post-test consisted of ten multiple-choice and short-answer questions assessing students' understanding of fraction concepts. Each question was assigned a point value, and student responses were scored based on accuracy and completeness of explanation when required. Scores were converted into percentages to allow comparison across participants. The experimental group (n = 8) had a mean score of 93.5%, while the control group (n = 7) had a mean score of 83.0%.

An independent sample t-test was conducted to evaluate whether the difference between group means was statistically significant. The analysis showed a statistically significant difference between the experimental and control groups, $t(13) = 2.32$, $p < .05$, suggesting that the adaptive chatbot group performed significantly better on the post-test.

Discussion:

The findings of this study suggest that explanation-based AI tutoring systems can significantly enhance students' conceptual understanding of fractions. The adaptive chatbot encouraged active

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Volume:11, Issue:07 "July 2026"

engagement by requiring students to think, rather than passively receiving answers. This aligns with established educational theories, including constructivist learning theory, which emphasizes that learners build understanding through active participation and reflection.

The improved performance of the experimental group supports prior research indicating that self-explanation and guided questioning strengthen conceptual learning. By prompting students to justify their thinking, the adaptive chatbot likely reinforced mental connections between visual, numerical, and conceptual representations of fractions.

In contrast, the control group's reliance on direct-answer feedback may have limited deeper cognitive processing. While students may have completed tasks more quickly, they had fewer opportunities to engage in reflective thinking, which is essential for long-term retention and knowledge transfer.

Despite these positive findings, several limitations should be considered. First, the sample size was relatively small, which limits generalizability. Second, the study was conducted over a short duration, meaning long-term retention was not measured. Third, differences in individual familiarity with digital tools may have influenced user experience and outcomes. Finally, the study focused exclusively on fraction concepts, and results may differ across other mathematical domains.

Conclusion:

This study demonstrates that integrating an adaptive, explanation-driven AI chatbot into a game-based learning platform can improve elementary students' understanding of fractions. Students who were required to actively explain their reasoning showed higher conceptual performance compared to those who used a standard AI chatbot.

The results highlight the importance of designing educational AI systems that prioritize cognitive engagement, reasoning, and reflection rather than simply providing direct answers. Game-based learning environments combined with adaptive AI support have strong potential to enhance mathematical understanding at the elementary level.

Future research should expand the sample size, include diverse demographic populations, and examine long-term learning retention. Additionally, further development could explore extending adaptive AI systems to other mathematical domains such as decimals, ratios, and algebraic thinking.

ISSN: 2455-8834

Volume:11, Issue:07 "July 2026"

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