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Optimization of Fraction Learning for Students with Learning Difficulties in Mathematics: Computer-Assisted Educational Environments

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Abstract: This study examines the impact of digital tools on fraction comprehension among 5th-grade students with learning difficulties in mathematics. It assesses the effectiveness of three teaching methods: educational software, video tutorials, and their combination. The research involved 252 students from 8 state-funded elementary schools, employing a quantitative experimental design with pre- and post-test assessments. Grounded in Constructivist Learning Theory and Technological Pedagogical Content Knowledge (TPACK), this research explored how technology can enhance mathematical understanding. Results indicated that the combined method achieved the highest improvement (58%, $p < .001$, Cohen's d = 3.03), significantly outperforming educational software alone (33%, p = .015, Cohen's d = 2.52) and video tutorials alone (7%, $p = .987$, Cohen's d = 0.14). These findings highlight the substantial benefits of integrating diverse digital tools to effectively support mathematics learning among students facing additional educational challenges.

Keywords: *Technology integration, mathematics education, instructional approaches, fractions, learning difficulties.*

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Introduction

One of the most pressing challenges in contemporary education is adapting to rapid technological changes (Alabdulaziz & Alhammadi, 2021). Declining proficiency in mathematical skills, especially in elementary and middle schools where concepts like fractions are challenging, further exacerbates this issue (Pappa et al., 2024; Rodríguez-Jiménez et al., 2023). The complexity of integrating technology in education is underscored by varied opinions on perceived barriers (Hamutoğlu & Basarmak, 2020). Studies by Bedin et al. (2023) and Meda et al. (2023) highlight the need for a multifaceted approach to enhance educators' skills and technology integration, addressing pedagogical, organizational, and technological aspects to maximize the benefits of technology in education. The integration of technology into education has emerged as a promising avenue for addressing these challenges.

Leveraging digital tools and online platforms offers unique opportunities to enhance teaching methodologies and engage students in more interactive and personalized learning experiences. Previous research has demonstrated the potential of technology-enhanced instruction to improve academic performance and facilitate deeper understanding of complex concepts (Alabdulaziz & Alhammadi, 2021). Studies by Abidin et al. (2017), Adelabu and Alex (2022), and Akçay et al. (2021), and further underscore the significance of technology in mathematics education, highlighting its impact on student engagement, academic achievement, and preservice teachers' perspectives on learning mathematics for teaching.

Drawing on the existing literature and findings from Muchlis et al. (2023), Ran et al. (2022), and Reinhold et al. (2020), this study aims to provide valuable insights into the potential of technology-enhanced learning for teaching fractions to elementary students. By comparing different instructional methods, this research seeks to inform educational practices and policies to enhance mathematics education and promote academic success among elementary school students. Studies by McLaren et al. (2017) and Mensah and Ampadu (2024) highlight the benefits of computer-assisted instruction (CAI) and educational games in improving learning outcomes and engagement. Foster (2024) emphasizes the importance of thoughtful integration strategies for classroom technology.

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Despite substantial investments in educational technology, improvements in students' mathematical performance are not always evident (Cheung & Slavin, 2013; Foster, 2024). Previous research often concentrates on a single digital tool (e.g., only software), thereby overlooking potential synergies and comparative impacts among different interventions (Mensah & Ampadu, 2024; Reinhold et al., 2020). Furthermore, many studies focus on short-term performance outcomes without fully exploring deeper conceptual understanding or real-world problem-solving (Adelabu & Alex, 2022). Such limitations are especially pronounced in populations with learning difficulties, where targeted approaches are lacking (Pappa et al., 2024; Rodríguez-Jiménez et al., 2023).

Accordingly, our quasi-experimental study examines the comparative efficacy of educational software, video tutorials, and their combined use to enhance fraction comprehension among elementary students with learning difficulties. Grounded in constructivist theory and the TPACK framework, this investigation seeks to address both cognitive and practical dimensions of fraction learning. By systematically evaluating multiple technology-based methods, our research contributes to the ongoing dialogue on how best to deploy digital tools to achieve sustained improvement in mathematics education for students who require additional support.

The purpose of this research is to evaluate the effectiveness of various technological tools—specifically educational software, video tutorials, and their combination—in enhancing 5th-grade students' understanding and proficiency in fraction comprehension. Fractions constitute a foundational yet challenging domain of elementary math education (Behr et al., 1983; Siegler et al., 2011). Difficulties in fraction comprehension often impede students' progress in more advanced mathematical concepts (Van de Walle et al., 2019; Wu, 2001). Moreover, learners with identified mathematical learning difficulties face heightened challenges in grasping fraction concepts, thereby increasing their risk of long-term academic struggles (Pappa et al., 2024; Rodríguez-Jiménez et al., 2023). By focusing on this critical topic, the research aims to evaluate how educational software, video tutorials, and their combination can enhance fraction learning and inform best practices for integrating digital tools into mathematics instruction.

The study aims to provide insights into how these technologies can improve fraction learning and inform best practices for integrating digital tools into mathematics education.

The rationale for the research questions in this study is grounded in several critical gaps identified in the existing literature on fraction teaching and technology usage. Previous research has predominantly focused on individual digital tools—such as educational software or video tutorials—often emphasizing short-term performance improvements rather than fostering deep conceptual understanding or the practical application of fraction skills in real-world scenarios (Cheung & Slavin, 2013; Foster, 2024). Moreover, such studies typically do not address the unique needs of elementary students with learning difficulties, leaving a gap in understanding how tailored technology interventions can support this vulnerable group (Abidin et al., 2017).

In response to these shortcomings, the study deliberately compares two distinct methods, educational software and video tutorials, as well as their combined use, to evaluate their individual and synergistic effects on enhancing fraction comprehension among elementary students with learning difficulties. Educational software offers an interactive, adaptive, and self-paced learning environment that provides personalized feedback and engagement (Wang et al., 2018), which is particularly beneficial for students with learning difficulties. In contrast, video tutorials deliver structured, visually guided instruction that clarifies complex concepts and supports visual learning (Santagata et al., 2021). By evaluating these methods both individually and in combination, the study aims to determine whether their integration can create a synergistic effect that further enhances fraction comprehension. Santagata et al. (2021) point out a critical gap in current research, noting that there is limited evidence on how video-based programs influence decision making and instructional practices in mathematics. This gap highlights the need for systematic investigations into the effective use of digital video tools to support teachers in refining their decision-making processes and enhancing their instructional practices in the classroom.

Accordingly, the research questions are designed to systematically address these issues:

RQ1: Which teaching methods are most effective in improving fraction comprehension?

RQ2: What is the impact of each teaching method on enhancing the ability to solve real-world fraction problems?

RQ3: How do students' performances differ between the pre-test and post-test across the three teaching methods?

RQ4: What are the specific benefits of integrating multiple teaching tools (software and video) compared to using them individually?

Literature Review

As technology becomes more integrated into the daily lives of students and teachers outside of school, schools are inevitably influenced by this trend. Some educational theorists suggest that the increasing tech competence among students makes the integration of technology into education unavoidable. Utilizing technology in primary school classrooms has been shown to have a significant impact on students' academic achievement. (Akçay et al., 2021).

Constructivist learning theory asserts that learners actively build their understanding through experiences and reflection (Zajda, 2021), highlighting learning as a contextualized process of knowledge construction. In the realm of education, technology plays a pivotal role in enhancing instructional practices and bolstering online learning environments. Horváth (2023) underscores the importance of adaptive pedagogical strategies during emergency remote teaching, illustrating how educators' digital competence correlates with effective student engagement. Similarly, Fabia (2024) emphasize technology's critical contribution to increasing student satisfaction, self-efficacy, and achieving educational goals in online settings. Although Casler-Failing (2021) demonstrates that integrating Lego robotics can enhance Technological Pedagogical Content Knowledge (TPACK), this finding underscores the broader potential of targeted technology integration to strengthen the synergy between pedagogy and content across diverse educational settings. Collectively, these studies advocate for continuous integration of technology in education to deepen educator competence and enhance learning outcomes, supported by evidence of technology's positive impact on academic achievement in primary education (Akçay et al., 2021).

Technology can be integrated into all levels of education and serves as a crucial teaching tool, especially in mathematics (Abidin et al., 2017). Its integration into math education is vital for two reasons: many students find math challenging, and technological tools can help mitigate this difficulty. Additionally, using digital tools with effective pedagogy can enhance skills such as critical thinking and problem-solving (Viberg et al., 2020).

Computer-Assisted Instruction and Math Teaching

Computer-assisted instruction (CAI) in math involves using educational software, applications, and web-based programs to help students learn and apply math concepts and skills (Hawkins et al., 2017). CAI tailors instruction based on individual student progress and ensures mastery of fundamental math skills (Wang et al., 2018). Technology also enables teachers to connect mathematical concepts to real-world problems, allowing students to explore these concepts more deeply (Mensah & Ampadu, 2024). In addition, adjusting the pace, content, and style of instruction to suit individual learning styles and levels of understanding, and using the appropriate educational programs, computer-based instruction can help low-performing students grasp difficult concepts more effectively (de Barros & Ganimian, 2023). Therefore, it is crucial for schools to choose effective computer programs (Foster, 2024).

Based on the research findings presented by Mensah and Ampadu (2024), which are in line with the earlier work conducted by Leung (2017), it is apparent that computer-assisted instruction (CAI) surpasses traditional teaching methods in the realm of mathematics education due to its notable efficiency. Furthermore, Pramudya et al. (2019) corroborate these findings by emphasizing that CAI not only creates an optimal learning environment but also fosters enthusiasm among students while facilitating the acquisition of additional mathematical skills. Consequently, it can be concluded that CAI plays a significant role in enhancing the overall learning and teaching experience in mathematics, benefiting both students and future educators alike (Adelabu & Alex, 2022).

Teaching and Learning Mathematics through Digital Tools

Research emphasizes the advantages of technology in mathematics instruction. McLaren et al. (2017) found that a computer-based educational game, Decimal Point, led to better learning outcomes and higher engagement compared to traditional methods. In a study with 153 middle school students, those who played the game showed significantly better gains in solving decimal problems and found the game more enjoyable. This indicates that well-designed educational games can offer superior learning opportunities, especially for students with lower prior knowledge.

Similarly, Reinhold et al. (2020) emphasized the effectiveness of interactive and adaptive educational technologies in teaching fractions. Their study suggests that such technologies can significantly enhance fraction concepts, particularly for low-achieving students, by providing a holistic curriculum that extends beyond basic arithmetic procedures. These tools facilitate conceptual change and understanding through constant transition between different representations of fractions, thereby improving the learning experience.

Kong and Liu (2023) investigated the application of a performance-based evaluation platform to promote self-regulated learning (SRL) among primary school children during programming activities. Their mixed-methods study demonstrated that embedding SRL support features within the platform helped students develop problem-solving strategies and algorithmic thinking. The results indicated that this approach effectively fosters students' SRL skills and enhances their ability to complete programming tasks.

During the pandemic, the use of video tutorials became crucial for maintaining educational continuity (Reimers et al., 2020). Video tutorials offer step-by-step guidance for specialized activities, making them effective tools for both academic and affective learning (Tarquini & McDorman, 2019). Research by Brame (2016) supports the use of video tutorials as engaging content-delivery tools that facilitate easier learning compared to traditional print materials. Lalian (2019) and Ljubojevic et al. (2014) found that video tutorials positively affect students' motivation and independent learning abilities, particularly in mathematics, where they improve understanding and achievement.

Furthermore, Sharma (2018) reported that students who regularly watched instructional videos performed better in assessments than those in traditional instruction. Rathour et al. (2024) highlighted that visualization methods in teaching mathematics enhance problem-solving abilities, overall teaching effectiveness, and the development of imaginative and abstract thinking. These methods foster a comprehensive assimilation of knowledge and stimulate greater interest in the subject.

Overall, these studies underscore the significant role of technology in enriching mathematics education. From interactive games and adaptive learning environments to video tutorials and performance-based platforms, these tools not only enhance learning outcomes but also engage students in meaningful and enjoyable ways.

Technology Use and Fractions

Fractions serve as a cornerstone in mathematics, yet many elementary students struggle with their conceptual understanding and practical application (Powell, 2018). The integration of technology—through tools such as educational software and video tutorials—offers promising methods to simplify complex fraction problems and deepen students' conceptual grasp, particularly in real-world contexts (Soni & Okamoto, 2020). Video tutorials, for example, provide varied instructional approaches that actively engage students, boost academic performance, and enhance confidence in mathematics (Bouck et al., 2020). Moreover, incorporating interactive elements like quizzes and gamified learning experiences can motivate students to explore fractions in a dynamic and collaborative environment, further reinforcing their learning (Hwang et al., 2020; Naidoo & Hajaree, 2021). In parallel, educational software offers personalized feedback and adaptive learning paths, ensuring that each student can progress at an individual pace while mastering fraction concepts (Zahda & Natsheh, 2018). Despite these advances, it remains unclear to what extent digital learning games convey different facets of fraction understanding, such as part-whole relations, fraction magnitude, and fraction arithmetic (Thoma et al., 2023). A systematic investigation comparing the effectiveness of educational software and video tutorials, both individually and in combination, in enhancing fraction comprehension among elementary students with learning difficulties is still lacking in the literature.

Methodology

This research aims to provide insights into the role of technology in education, specifically focusing on fraction comprehension among 5th-grade students. By analyzing the effects of different technological tools, the study seeks to inform best practices for integrating technology into mathematics education.

Theoretical Model

The research is grounded in two key theoretical frameworks (Table 1).

- Constructivist Learning Theory: This theory emphasizes active engagement and reflection. It supports the use of interactive digital tools to allow students to explore concepts at their own pace and receive immediate feedback, enhancing their understanding through problem-solving and self-directed learning (Piaget, 1973; Vygotsky, 1978).
- TPACK (Technological Pedagogical Content Knowledge): This model focuses on effectively incorporating technology into education. It provides a framework for using digital tools to enhance teaching methods and learning outcomes, ensuring that technology is used strategically to support educational goals (Mishra & Koehler, 2006).

Table 1. Application of Theoretical Models in Research Methodology

Aspect	Constructivist Learning Theory	TPACK
Research Questions	Focuses on how students interact with technology to understand fractions.	Investigates the role of different technologies in enhancing teaching methods.
Educational Software and Videos	Supports the use of interactive tools that facilitate self-directed learning and problem-solving.	Analyzes the effectiveness of specific technological tools, such as educational software and videos.
Procedure	Ensures that technology supports active, hands-on learning experiences.	Assesses the practical application of technology in educational settings.

Educational Software and Videos

Educational software and videos play crucial roles in enhancing mathematical learning experiences for primary school students. The DreamBox program used in this study is aligned with the Greek national curriculum and is available in multiple languages, including English, focusing on interactive learning through exercises, games, and visual aids. It addresses challenges in learning fractions and other mathematical concepts, offering immediate feedback and personalized learning opportunities. This approach supports collaborative learning and real-world applications, aiming to improve conceptual understanding and problem-solving skills.

Additionally, Khan Academy was used for the videos to teach fractions, a reputable educational platform recognized by the international academic community.

Together, these resources promoted engaging, personalized learning experiences that cater to diverse learning preferences, foster collaboration, and enhance students' mathematical proficiency.

The lessons covered the concept of fraction, parts-of-a-whole, comparison, equivalent fractions, addition, subtraction, multiplication division, and real-world problems involving fractions.

Sample

The 252 students were selected from eight schools in the Attica region of Greece, based on their identified learning difficulties in mathematics, as determined by standardized assessments (Connolly, 2007) and teacher evaluations. After selection, the students were randomly assigned to one of three groups, each consisting of 84 participants. Random assignment was achieved using a random number generator to ensure that each student had an equal chance of being placed in any of the three groups, minimizing selection bias and ensuring comparable groups for the study. The decision to explore three distinct groups—educational software, video tutorials, and their combination—was based on existing literature that emphasizes the unique advantages and potential synergies of different digital tools in the teaching and learning process.

Table 2. Student Demographics by Group

Group	**n**	**Male (%)**	**Female (%)**
Total Sample	252	122 (48.4%)	130 (51.6%)
Educational Software	84	41 (48.8%)	43 (51.2%)
Video Tutorials	84	41 (48.8%)	43 (51.2%)
Combination	84	40 (47.6%)	44 (52.4%)

Procedure

The students who participated in the study completed a pre-test. They were divided randomly into three experimental groups: educational software, video, and a combination of both (educational software & video), each consisting of 84 students. Subsequently, these groups were assigned randomly to the experimental groups. All students had prior traditional classroom instruction.

In the study, regular classroom teachers, who received targeted training on the use of the educational software and video tutorials, conducted the teaching sessions. The research team provided ongoing technical support and monitored the intervention's implementation. Some teachers initially encountered challenges in managing the digital tools, leading to occasional technical disruptions. These issues were addressed through on-site support and refresher training, ensuring smooth and consistent delivery of the intervention across all participating schools.

Weekly Plan of Teaching

The weekly teaching plan was designed in line with international recommendations for technology-based interventions in mathematics, which suggest that effective instruction should provide students with approximately 3 to 4 hours of focused, digital learning per week (Akçay et al., 2021; Cheung & Slavin, 2013). Based on these guidelines, the study implemented an eight-week intervention schedule with the following structure:

- Frequency: 4 sessions per week
- Duration: Each session lasted 1 hour
- Total Weekly Instruction: 4 hours

Sessions were conducted in the school's dedicated computer laboratory immediately following the regular school day. In addition, interactive learning modules incorporated guided problem-solving tasks on multiplication and division of fractions. During these sessions, teachers were responsible for facilitating the digital activities by providing step-by-step instructions, demonstrating how to navigate the interactive tasks, and monitoring student progress. Teachers also offered immediate, personalized feedback and clarified any misconceptions as students worked through the tasks.

Students, on the other hand, actively engaged with the digital platform by solving fraction problems, participating in interactive quizzes, and completing gamified challenges designed to reinforce their understanding of multiplication and division of fractions. These tasks required them to apply learned concepts in a structured, yet adaptive learning environment. Ongoing support and monitoring by the research team ensured effective implementation and adherence to the study protocol. This structured approach ensured consistent, targeted instruction, allowing for adequate practice and reinforcement of concepts while minimizing disruption to the regular curriculum.

Teaching Sessions' Alignment With the Theoretical Models

Table 3 shows the sessions' alignment with the theoretical models as follows:

- Constructivist Learning Theory was applied in sessions that focus on interactive, hands-on learning, where students explore concepts at their own pace.
- TPACK was applied in sessions that strategically integrated technology to enhance teaching methods and learning outcomes, combining digital tools to support traditional instruction.

Table 3. Sessions' Alignment With the Theoretical Models

No	Teaching Session	Description	Corresponding Theoretical Model
1	Introduction	Interactive session using educational software to introduce the concept of fractions, parts-of-a-whole, and visual representations.	Constructivist Learning Theory
2	Comparing Fractions	Activities using software tools to compare fractions using visual aids and games, facilitating active engagement and immediate feedback.	Constructivist Learning Theory
3	Equivalent Fractions	Video tutorials explaining the concept of equivalent fractions, followed by interactive exercises in the software to practice identifying and creating equivalent fractions.	TPACK
4	Adding and Subtracting Fractions	A combination of video tutorials and educational software to teach the addition and subtraction of fractions, providing a mix of instruction and practice.	TPACK
5	Multiplying and Dividing Fractions	Interactive learning through software that allows students to explore multiplication and division of fractions with guided problem-solving tasks.	Constructivist Learning Theory
6	Applying Fractions to	Videos demonstrating real-world applications of fractions, supplemented by software-based exercises to reinforce the concepts through practical examples.	TPACK

Research Instruments

Pre-test and post-test exercises were administered to assess students' fraction comprehension, covering core areas such as identifying fractions, comparing and ordering them, finding equivalent fractions, and applying fraction concepts to real-world problems (Table 4). Although these tasks do not represent exact exercises from specific publications, they are adapted from common challenges identified in the international literature on fraction learning (e.g., Behr et al., 1983; Clarke et al., 2008). The research team and elementary mathematics educators collaboratively designed them, ensuring alignment with curriculum standards and pedagogical recommendations from sources like Burns (2007), Van de Walle et al. (2019), and the National Council of Teachers of Mathematics (NCTM, 2000). This approach guaranteed that the exercises addressed typical fraction difficulties and promoted both conceptual understanding and real-world application.

Table 4 provides examples of pre-test and post-test questions, clearly aligned with specific fraction comprehension goals derived from international literature.

Table 4. Pre-test and Post-test Exercises, Learning Objectives

No	Pre-Test Exercises	Post-Test Exercises	Learning Objective
1	Which part of the circle is shaded?	Shade 3/4 of the circle.	Understand and represent fractions as parts of a whole.
2	Compare 3/4 and 2/3 using <, >, or =	Compare 5/8 and 7/10 using <, >, or =	Compare and order fractions.
3	Arrange the following fractions in ascending order: 1/2, 3/8, 2/3.	Arrange the following fractions in ascending order: 1/4, 2/5, 3/7	Develop skills in ordering fractions.
4	Which fraction is larger: 5/6 or 7/8?	Which fraction is larger: 3/4 or 5/9?	Use comparative reasoning to understand the size of fractions.
5	Find two equivalent fractions for 3/4.	Find two equivalent fractions for 2/3.	Identify and generate equivalent fractions.
6	Simplify the fraction 8/12 to its lowest terms.	Simplify the fraction 9/15 to its lowest terms.	Simplify fractions and understand the concept of equivalent fractions.

Table 4. Continued

No	Pre-Test Exercises	Post-Test Exercises	Learning Objective
7	Determine if 2/5 and 4/10 are equivalent.	Determine if 3/6 and 1/2 are equivalent.	Check for equivalence between fractions.
8	If you have 1/2 a pizza and eat 1/3 of what is left, how much pizza do you have left?	If you have 3/4 of a cake and eat 2/5 of what is left, how much cake do you have left?	Apply fractions to real-life situations involving addition and subtraction.
9	If a recipe requires 3/4 cup of sugar, and you want to make half the recipe, how much sugar do you need?	If a recipe requires 2/3 cup of flour, and you want to make one-third of the recipe, how much flour do you need?	Apply fractions to real-life situations involving multiplication and division.
10	You have 12 roses, 8 tulips, and 10 violets. You use 2/3 of the roses, half of the tulips, and 1/5 of the violets to make a bouquet. How many flowers are left?	You have 15 apples, 10 oranges, and 5 bananas. You use 3/5 of the apples, 2/5 of the oranges, and 4/5 of the bananas to make a fruit salad. How many fruits are left?	Apply fractions to real-world problems involving multiple steps.

Data Analysis

SPSS 21 software was used to code and analyze the quantitative data (including ANOVA), with Microsoft Excel 2010 assisting in preliminary data management. The student responses from the pre- and post-test exercises were evaluated using a standardized scoring rubric that assigned numeric codes for correct, partially correct, and incorrect answers. Two trained raters, working independently, applied these codes to each response. The raters were unaware of whether the response belonged to the pre-test or the post-test (i.e., the data were coded blindly), helping to reduce potential bias.

To ensure consistency, the raters measured inter-rater reliability using Cohen's kappa, achieving an acceptable level of agreement. In cases where they disagreed, the raters discussed their assessments and reached a consensus. This protocol was pilot-tested on a small sample of student responses before large-scale implementation, allowing for fine-tuning of the rubric and improving clarity in scoring criteria.

Once coded, the data were entered into SPSS for statistical analysis, which included ANOVA to compare student performance across the three groups. A power analysis was conducted to estimate the required sample size for detecting a medium effect (Cohen's $d = 0.5$) at a 0.05 significance level and 0.80 power, indicating that each group should comprise approximately 64 participants for a total of around 192 students. As 252 students ultimately participated, the study exceeded this requirement, ensuring sufficient power for the analysis.

Results

In this study involving 252 students, the effectiveness of three teaching methodologies—Educational Software, Video, and a combination of both (Software & Video)—on solving fraction-related exercises was examined. Here is a detailed analysis of the findings for each exercise.

1. Which Teaching Method is Most Effective in Improving Fraction Comprehension?

The effectiveness of the teaching methods (Educational Software, Video Tutorials, and Educational Software & Video) was evaluated based on improvements in solving fraction-related exercises. The Educational Software & Video method consistently showed the highest improvements, with differences of up to 26% observed in some cases. In comparison, Educational Software showed improvements between 9% to 20%, and Video Tutorials showed comparatively smaller increases, ranging from 7% to 16% (Table 5).

Table 5. Detailed Results of Exercise Improvement

No	Educational Software	Video Tutorials	Educational Software & Video
1	20%	13%	26%
2	20%	15%	23%
3	18%	16%	24%
4	16%	14%	21%
5	15%	15%	21%
6	14%	14%	22%
7	15%	13%	20%
8	11%	10%	20%
9	11%	11%	18%
10	9%	7%	16%

The results of the Between-Subjects ANOVA indicated a significant effect of the teaching methods on fraction comprehension ($F(2, 249) = 15.20$, $p = .000$, $\eta^2 = 0.110$), confirming that the method used impacts student performance (Table 6). Post-hoc comparisons using Tukey's HSD (Table 7) revealed that the combined Software & Video method significantly outperforms both Educational Software ($p = .039$) and Video Tutorials ($p = .001$). However, there is no statistically significant difference between Educational Software and Video Tutorials ($p = .089$). These findings underscore the superior efficacy of the integrated approach in enhancing students' understanding and application of fractions.

Table 6. Between-Subjects ANOVA Results

Source	*df*	*F*	*p*	η^2
Teaching Method	2	15.20	0.000	0.110
Error	249	-	-	-

Next, Table 7 presents the pairwise comparison results from the Tukey's HSD post-hoc test, which was conducted to further investigate the differences in fraction comprehension scores among the three teaching methods. The table reports the mean differences and corresponding p-values, highlighting which specific methods significantly outperformed others in enhancing students' fraction.

Table 7. Post-hoc Pairwise Comparisons (Tukey's HSD)

Comparison	Mean Difference	*p*
Educational Software vs Video Tutorials	0.278	0.089
Educational Software vs Software & Video	-0.200	0.039
Video Tutorials vs Software & Video	-0.478	0.001

2. What is the impact of each teaching method on enhancing the ability to solve real-world fraction problems?

Table 8 shows that the repeated measures ANOVA revealed a significant improvement in students' ability to solve real-world fraction problems from pre-test to post-test ($F(1,249) = 104.75$, $p < .001$, $\eta^2 = 0.296$), indicating that the intervention had an overall positive effect. In addition, a significant main effect of teaching method ($F(2,249) = 25.90$, $p < 0.001$, $\eta^2 = 0.173$) demonstrated that the instructional approaches varied in their effectiveness. Importantly, the significant interaction between test time and method ($F(2,249) = 18.45$, $p < .001$, $\eta^2 = 0.129$) suggests that the degree of improvement differed depending on the method used, with the combined use of Educational Software and Video Tutorials yielding the highest gains—particularly in exercises targeting real-world problem solving (Exercises 8, 9, and 10). These findings underscore the potential advantage of an integrated instructional approach in enhancing students' practical application of fraction concepts.

Table 8. Repeated Measures ANOVA Results

Measure	MSE	*df*	*F*	*p*	η^2
Test time point (Pre vs. Post)	38.41	1	104.75	0.000	0.296
Method	9.498	2	25.90	0.000	0.173
Test Time Point × Method	6.317	2	18.45	0.000	0.129
Error	0.367	249	-	-	-

3. How do students' performances differ between the pre-test and post-test across the three teaching methods?

The repeated measures ANOVA results (Table 9) indicated significant differences in performance between the pre-test and post-test across all three groups, as shown by a significant main effect of test time ($F(1,249) = 104.75$, $p < 0.001$, $\eta^2 = 0.296$). Additionally, there was a significant main effect of method ($F(2,249) = 25.90$, $p < 0.001$, $\eta^2 = 0.173$) and a significant interaction between test time and method ($F(2,249) = 18.45$, $p < 0.001$, $\eta^2 = 0.129$), indicating that the magnitude of improvement varied by teaching method. Notably, the combined Educational Software and Video approach produced the largest effect, with the greatest increase in performance from pre-test to post-test. These results underscore the potential benefits of an integrated instructional approach in enhancing students' ability to solve real-world fraction problems.

Table 9. Repeated Measures ANOVA Results

Measure	MSE	*df*	*F*	*p*	η^2
Test time point (Pre vs. Post)	38.41	1	104.75	0.000	0.296
Method	9.498	2	25.90	0.000	0.173
Test Time Point × Method	6.317	2	18.45	0.000	0.129
Error	0.367	249	-	-	-

4. What are the specific benefits of integrating multiple teaching tools (software and video) compared to using them individually?

Table 10 summarizes the pre-test and post-test mean scores (M (SD)) for each teaching method. The analysis revealed that integrating educational software and video tutorials significantly improved students' fraction comprehension. Specifically, the combined Educational Software & Video group increased from a pre-test score of 0.25 (SD = 0.10) to a post-test score of 0.83 (SD = 0.20), with $t(83) = 8.39$ ($p = 0.000$) and a very large effect size (Cohen's $d = 3.03$). In comparison, the Educational Software group improved from 0.27 (SD = 0.10) to 0.60 (SD = 0.15) ($t(83) = 5.50$, $p = 0.015$, Cohen's $d = 2.52$), while the Video Tutorials group showed only a modest change from 0.13 (SD = 0.05) to 0.20 (SD = 0.07) ($t(83) = 1.01$, $p = 0.987$, Cohen's $d = 0.14$). These results, in conjunction with the Repeated Measures ANOVA findings, underscore that an integrated instructional approach leveraging both educational software and video tutorials is the most effective method for enhancing students' ability to solve real-world fraction problems.

Table 10. Pre-Test and Post-Test Performance for Each Teaching Method

Teaching Method	Pre-Test *M(SD)*	Post-Test *M(SD)*	*t*(83)	*p*	Cohen's *d*
Educational Software	0.27(0.10)	0.60(0.15)	5.50	0.015	2.52
Video Tutorials	0.13(0.05)	0.20(0.07)	1.01	0.987	0.14
Educational Software & Video	0.25(0.10)	0.83(0.20)	8.39	0.000	3.03

Next, for results visualization the bar graph (Fgure1) illustrates mean student scores before (Pre-Test) and after (Post-Test) the intervention across three teaching methods: Educational Software, Video Tutorials, and the Combined Method (Educational Software & Video). The Combined Method demonstrated the greatest improvement from pre-test to post-test, indicating its superior effectiveness for enhancing fraction comprehension.

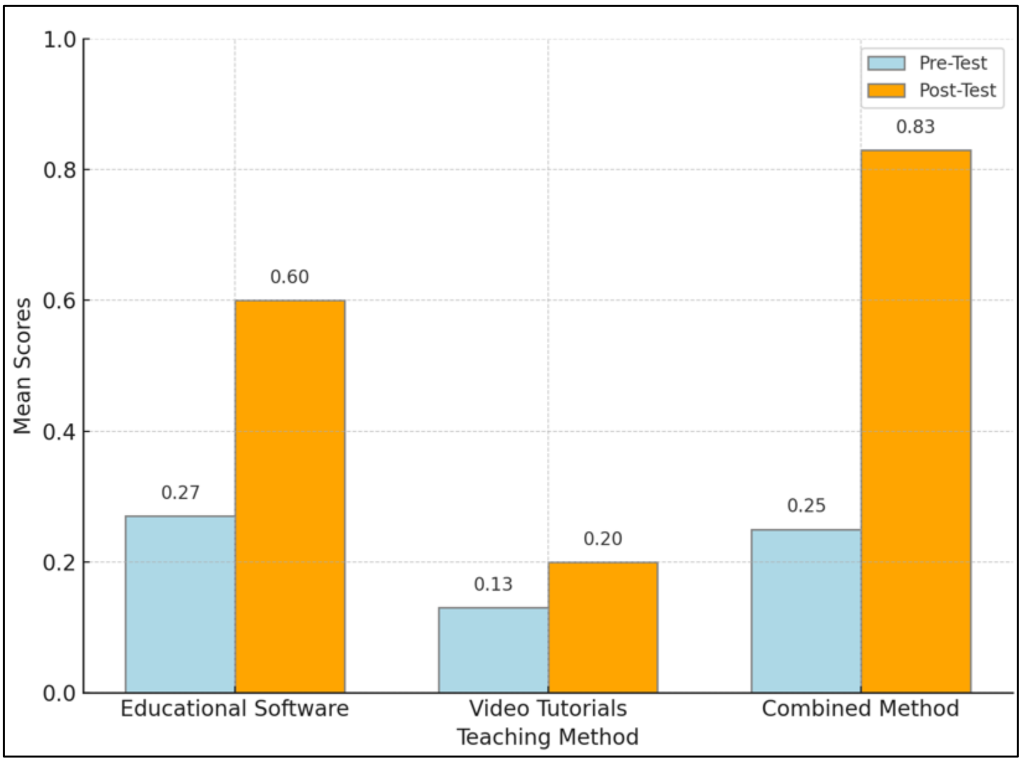

Figure 1. Comparison of Pre-Test and Post-Test Mean Scores by Teaching Method

In summary, the results showed that all three instructional methods enhanced students' fraction comprehension, with the combined use of Educational Software and Video Tutorials proving most effective. While Educational Software alone demonstrated moderate gains, Video Tutorials alone had limited effectiveness. These findings highlight the advantage of integrated technological approaches, particularly for students with learning difficulties.

Discussion

This study examined the impact of three teaching approaches—Educational Software, Video Tutorials, and a combined method—on improving fraction comprehension among elementary students with learning difficulties. In contrast to many existing interventions that focus on a single digital tool, this study integrated two distinct types of technology to explore whether their complementary strengths could yield superior learning outcomes. Rather than presenting statistical results in detail, the following discussion interprets these findings and situates them within the broader literature.

Students engaged in interactive fraction tasks, ranging from identifying and comparing fractions to applying them in real-world contexts (Pappa et al., 2024; Rodríguez-Jiménez et al., 2023). The teaching process leveraged adaptive, feedback-rich educational software and structured, visually guided video tutorials. Students received immediate feedback on their progress through the software, which allowed them to correct misconceptions early (Foster, 2024; Rezat, 2021). Meanwhile, the video tutorials offered clear demonstrations of mathematical concepts, enabling students to observe step-by-step solutions (Reimers et al., 2020; Sharma, 2018). This dual modality of instruction appears to have influenced learners by combining self-paced exploration with visual reinforcement of key fraction skills (McLaren et al., 2017; Mensah & Ampadu, 2024).

Several factors likely contributed to the effectiveness of the combined method in this study. One key element is the immediate, personalized feedback afforded by the educational software, which provides real-time alerts to errors or misconceptions (Ran et al., 2022). This targeted feedback fosters meta-cognitive awareness and has been shown to accelerate conceptual understanding in mathematics (Bedin et al., 2023; Casler-Failing, 2021). Another significant aspect is the structured, visually guided instruction delivered through video tutorials, which present a linear sequence of steps that students can pause, rewind, or re-watch, accommodating different learning paces and styles (Lalian, 2019). This format is particularly beneficial for students with learning difficulties, as they often require additional scaffolding and repeated exposure to challenging concepts (Hawkins et al., 2017; Wang et al., 2018).

The integrated approach that combines adaptive software and video tutorials also appears to foster greater depth in learning. This finding is consistent with research suggesting that multi-modal interventions can enhance mathematics learning in fraction-related topics (Mensah & Ampadu, 2024; Reinhold et al., 2020), ultimately improving performance on both basic fraction operations and real-world problem-solving tasks. Furthermore, the real-world application and contextual learning aspect—embedding fractions in authentic scenarios like measuring ingredients or dividing objects—

has been identified as critical for enabling the transfer of knowledge to everyday settings (Abidin et al., 2017; Kong & Liu, 2023). By allowing students to interact with meaningful examples, digital tools can make fraction concepts more tangible and engaging, thereby deepening comprehension and retention.

Unlike many studies that evaluate software or video tutorials in isolation (e.g., Adelabu & Alex, 2022; Cheung & Slavin, 2013), this research highlights how a multifaceted, technology-enhanced approach can produce significantly more significant improvements in fraction comprehension. These findings align with those of McLaren et al. (2017) and Reinhold et al. (2020), who emphasize the value of combining adaptive tools with instructional scaffolding to address diverse learner needs. Additionally, the study extends previous work by focusing on students with learning difficulties, underscoring that carefully chosen digital interventions can be particularly supportive for this demographic (Pappa et al., 2024; Rodríguez-Jiménez et al., 2023). Several contextual elements may have influenced these results. Teachers' familiarity with digital tools, as well as their training in delivering the integrated intervention, could have shaped the consistency and quality of implementation (Hamutoğlu & Basarmak, 2020; Meda et al., 2023). Students' baseline engagement with technology and their attitudes toward mathematics might also have played a role, given the motivational impact of personalized and visually engaging instruction (Fabia, 2024; Tarquini & McDorman, 2019). Finally, school resources and infrastructure, such as the availability of dedicated computer labs, likely contributed to the feasibility and success of the intervention (Bedin et al., 2023).
In summary, the teaching strategies employed in this study—particularly the combined use of educational software and video tutorials—demonstrated substantial promise in improving fraction comprehension among elementary students with learning difficulties. By providing personalized feedback, visual demonstrations, and authentic learning contexts, this dual-modality approach addresses known challenges in fraction education and aligns with broader research on the importance of integrating multiple digital tools for deeper conceptual learning. Future studies may further refine these interventions by examining long-term retention, exploring additional technological tools, and investigating best practices for teacher training and support.

Conclusion

This study addressed a critical gap in existing research by systematically comparing the effectiveness of educational software, video tutorials, and their integrated use in enhancing fraction comprehension among elementary students with learning difficulties. Previous studies often examined these technologies individually, offering limited insight into potential synergies from combining multiple digital tools. By demonstrating that an integrated approach resulted in significantly higher improvements than individual methods, especially in real-world applications, this research provides new knowledge on how complementary digital methods, adaptive, feedback-oriented software paired with structured, visually guided tutorials, can maximize educational outcomes. These findings extend existing literature by highlighting the importance of multimodal instructional strategies to support diverse learning needs, specifically among students facing challenges in mathematics. Consequently, scholars can utilize these insights to investigate further integrated technology-based methodologies that effectively enhance conceptual understanding and practical skills in mathematics education.

The integration of technology not only enhances students' academic performance but also aligns with contemporary educational goals of fostering critical thinking, engagement, and problem-solving abilities. However, the study also reveals the necessity for proper teacher training and infrastructure to maximize the benefits of these methodologies.

Educational policymakers should actively promote the integration of educational software and video tutorials in mathematics instruction to address students' diverse learning needs. Specifically, policymakers can support curricula and guidelines that encourage teachers to use both adaptive, interactive software and structured visual tutorials. Similarly, educators are encouraged to regularly incorporate these combined digital methods—leveraging the immediate feedback provided by educational software along with the explicit instructional scaffolding of video tutorials—to effectively enhance fraction comprehension, particularly among students with learning difficulties.

In conclusion, the combined use of technology-based tools offers a promising pathway to address challenges in mathematics education, particularly for students with learning difficulties. Moving forward, educational policymakers, practitioners, and researchers should continue to explore and refine these strategies to promote equitable and effective learning opportunities in increasingly technology-driven classrooms.

Recommendations

Based on the findings of this study, several recommendations can be made for future research and educational practice:

- Further Exploration of Integrated Tools: Given the effectiveness of combining educational software and video tutorials, future research should explore different combinations of digital tools and their impact on other mathematical concepts beyond fractions. Investigating various content areas could help identify the most effective tool combinations for different topics and learner profiles.

- Longitudinal Studies: This study utilized a pre- and post-test design, but future studies should consider longitudinal approaches to assess the long-term effects of technology on students' mathematical proficiency. Examining how students retain and apply knowledge over time could provide deeper insights into the sustainability of digital tool interventions.
- Personalization and Adaptation: Research could explore how personalized digital learning environments, which adapt to individual students' needs, may enhance learning outcomes. Customizing content delivery based on learning pace and style could help further optimize the effectiveness of educational software and video tutorials, particularly for students with learning difficulties.
- Inclusion of Diverse Student Populations: This study focused on 5th-grade students with learning difficulties in mathematics. Future studies could include a more diverse range of students, such as those from different socio-economic backgrounds, ethnicities, and educational contexts, to evaluate the generalizability of the findings.
- Expanding the Use of Collaborative Tools: Incorporating collaborative, interactive elements in educational software could further enhance engagement and learning outcomes. Future research could explore how students' collaboration through digital platforms influences their understanding of mathematical concepts, particularly for those with learning difficulties.

Limitations

This study involved 252 students from 8 state-funded schools, which may not be representative of all students with learning difficulties in mathematics. Additionally, the study measured results immediately after the intervention but did not assess long-term retention of knowledge, which is crucial for understanding whether the improvements in fraction comprehension are sustainable over time. Finally, the study did not account for varying levels of access to technology or differences in how teachers implemented the digital tools. Disparities in students' technological familiarity and teacher effectiveness could have influenced the outcomes, highlighting the need for further research controlling for these variables.

Ethics Statements

The study involving human participants, including minors, was reviewed and approved by the University of Crete Ethics Committee. Informed consent was obtained from the parents or legal guardians of the students, who were made fully aware of the study's purpose, procedures, and any potential risks.

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Conflict of Interest

The authors declare no conflicts of interest related to this study.

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Generative AI Statement

As the authors of this work, we used the AI tool ChatGPT for the purpose of refining and editing the English language content. After using this AI tool, we reviewed and verified the final version of our work. We, as the authors, take full responsibility for the content of our published work.

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