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The Impact of Technology-Supported Teaching on Primary School Students' Attitudes Towards Mathematics

Teknoloji Destekli Öğretimin İlkokul Öğrencilerinin Matematiğe Yönelik Tutumlarına Etkisi

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Abstract: Student attitudes towards mathematics, often formed during the early primary grades, are of critical importance for future academic success and engagement. This study, grounded in the Technology-Enhanced Learning (TEL) framework, investigated the effect of a technology-supported teaching intervention on the attitudes of fourth-grade students towards mathematics. A quasi-experimental pre-test/post-test control group design was employed with 43 students in Turkey. The experimental group (n=21) participated in a six-lesson intervention that integrated various interactive digital tools, while the control group (n=22) followed the conventional curriculum. The 'Attitudes Towards Mathematics Scale' was administered to both groups before and after the intervention. The findings revealed a statistically significant and large positive impact on the attitudes of the experimental group, with a particularly notable increase observed in the self-confidence sub-dimension. In contrast, no significant attitudinal change was detected in the control group. The study concludes that a pedagogically sound intervention using interactive digital tools is a highly effective strategy for fostering positive mathematics attitudes in primary school students. The results reveal that the key to this positive outcome is the active, exploratory, and learner-centered learning environment created through technology.

Keywords: Mathematics attitudes, technology-enhanced learning, primary education, educational technology

Öz: Genellikle ilkokulun erken kademelerinde oluşan matematiğe yönelik öğrenci tutumları, gelecekteki akademik başarı ve katılım için kritik bir öneme sahiptir. Bu çalışma, Teknoloji Destekli Öğrenme kuramsal çerçevesine dayanan teknoloji destekli bir öğretim müdahalesinin, dördüncü sınıf öğrencilerinin matematiğe yönelik tutumları üzerindeki etkisini incelemiştir. Türkiye'de 43 öğrencinin katılımıyla ön test-son test kontrol gruplu yarı-deneysel desen kullanılmıştır. Deney grubu (n=21), çeşitli etkileşimli dijital araçların entegre edildiği altı derslik bir müdahaleye katılırken kontrol grubu (n=22) mevcut öğretim programını takip etmiştir. "Matematiğe Yönelik Tutum Ölçeği", müdahaleden önce ve sonra her iki gruba da uygulanmıştır. Bulgular, deney grubunun tutumları üzerinde istatistiksel olarak anlamlı ve geniş düzeyde pozitif bir etki olduğunu ortaya koymuştur; özellikle özgüven alt boyutunda dikkat çekici bir artış gözlemlenmiştir. Buna karşılık, kontrol grubunda anlamlı bir tutum değişikliği saptanmamıştır. Çalışma, etkileşimli dijital araçlar kullanan pedagojik olarak etkili bir müdahalenin, ilkokul öğrencilerinde olumlu matematik tutumları geliştirmek için oldukça başarılı bir strateji olduğu sonucuna varmıştır. Sonuçlar, bu olumlu sonucun anahtarının, teknoloji aracılığıyla oluşturulan aktif, keşfe dayalı ve öğrenci merkezli bir öğrenme ortamı olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Matematik tutumları, teknoloji destekli öğrenme, ilköğretim, eğitim teknolojisi

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Introduction

The primary school years are often considered a critical period for shaping students' attitudes towards mathematics, with foundational experiences potentially having a long-term influence on their academic trajectory. Fostering a positive disposition towards the subject in these early grades is therefore a key concern for mathematics education. The integration of technology in education has ushered in profound shifts in the dynamics of teaching and learning, particularly in subjects like mathematics, which present unique cognitive challenges due to their abstract nature. Contemporary research underscores the capacity of technological tools to enhance students' engagement and comprehension in mathematics, promoting more positive attitudes toward the subject (Hillmayr et al., 2020; National Council of Teachers of Mathematics, 2014). Rather than serving as mere substitutes for traditional resources, digital tools in mathematics instruction are instrumental in deepening students' conceptual understanding, facilitating the development of higher-order thinking and problem-solving skills, and promoting active, participatory learning environments (Pierce & Ball, 2009).

The motivational effects of technology in educational settings have also been widely acknowledged. Interactive digital platforms, computer-assisted learning, and game-based instructional methods have the potential to heighten student engagement, making mathematics more accessible and enjoyable, particularly for those who may struggle with the subject (Higgins et al., 2017). Additionally, the adaptive capabilities of these technologies allow for individualized learning pathways, enabling students to progress at their own pace and tailor the learning experience to their specific needs, thus enhancing the efficacy of the educational process (Taylor et al., 2021).

To build upon these insights, it is essential to situate the present study within the existing body of scholarly work. A review of the current literature on the integration of technology in mathematics education reveals that various studies emphasize the significant benefits that digital tools offer in terms of enhancing student learning outcomes, motivation, and attitudes toward mathematics. The synthesis of these studies underscores the necessity of embedding technology within a robust pedagogical framework to maximize its potential impact on student achievement and engagement.

A prominent focus within the literature is the impact of digital tools on higher-order thinking skills, such as critical thinking and problem-solving. Viberg and Mavroudi (2018) argue that when technology is combined with well-designed pedagogical strategies, it facilitates the development of these cognitive skills. This notion is supported by Young (2017), whose research highlights how the effective use of digital tools can positively influence student achievement in mathematics. Likewise, Hillmayr et al. (2020), in their meta-analysis, found that while the overall effect of digital technologies on mathematics achievement is moderate, their proper integration can lead to significant improvements in learning outcomes.

In terms of student attitudes, several studies point to the role of technology in fostering a more engaging and motivating learning environment. Higgins et al. (2017) explored how technology-supported teaching enhances student motivation and interest in mathematics, particularly through the use of interactive and gamified learning tools. These tools, by creating a more dynamic learning environment, contribute to higher levels of student engagement and participation. Similarly, Pierce and Ball (2009) found that technology can individualize learning experiences, allowing students to progress at their own pace, which enhances both the effectiveness of learning and students' attitudes toward the subject.

The success of technology integration, however, is contingent on several critical factors. Drijvers (2015) identified the design of technological tools, the teacher's role, and the broader educational context as key determinants of whether technology can significantly enhance mathematics learning. This aligns with findings from Clark-Wilson et al. (2020), who emphasized the importance of teacher professional development and the careful design of digital tasks to maximize the benefits of technology in educational settings. Teachers' ability to effectively integrate technology into their instruction is crucial, as they mediate the interaction between students and digital tools, guiding and facilitating the learning process.

The literature also points to the effectiveness of specific digital tools in enhancing mathematical understanding. For instance, Pittalis and Drijvers (2023) demonstrate that visualization tools and dynamic geometry software are particularly beneficial in helping students grasp abstract mathematical concepts by rendering them more tangible and accessible. These findings are supported by Reed et al. (2010), who emphasize the role of technological tools in fostering collaborative learning and promoting mathematical discussions, thus enabling deeper conceptual understanding.

Despite the overall positive effects of technology integration in mathematics education, challenges remain, particularly regarding the design and implementation of these tools. Drijvers (2015) notes that poorly designed technological interventions or insufficient teacher training can undermine the potential benefits of technology in the classroom. However, when these challenges are addressed, the impact can be profound. Hidayat and Firmanti (2024), for example, found that technology-enhanced instruction not only improves student achievement but also promotes a more positive attitude toward mathematics.

In conclusion, the literature consistently demonstrates that the integration of technology into mathematics education has the potential to significantly enhance both learning outcomes and student attitudes, provided that the tools are well-designed and the implementation is supported by effective teacher training. These findings highlight the importance of adopting a holistic approach to technology integration, one that considers the interplay between technological tools, pedagogical strategies, and the educational context. However, it is noteworthy that much of this research has primarily focused on secondary and higher education, with a recognized need for more studies at the primary school level, a gap also identified in other core subjects such as science (Kaya & İzci, 2024).

Theoretical Framework: Technology Enhanced Learning

Technology Enhanced Learning (TEL) refers to the intentional integration of digital technologies within educational practices to significantly improve the quality of teaching and learning processes by promoting more meaningful engagement and facilitating deeper cognitive development (Law et al., 2015). At its core, TEL emphasizes the transformation of the learner's experience by enabling access to knowledge through innovative digital mediums, reshaping how learners approach understanding, thinking, and interacting with the world around them (Downes, 2014).

Since its inception in the early 2000s, TEL has become a pivotal focus in educational research, particularly in evaluating how the incorporation of technology influences learning outcomes (Kirkwood & Price, 2013). The framework provides a critical lens through which to examine how digital tools contribute to enhancing learning environments, focusing particularly on the shift towards learner-centered approaches that allow for more personalized, interactive, and autonomous educational experiences (Bourdeau & Balacheff, 2014; Goodyear & Retalis, 2010).

TEL is grounded in both cognitive and constructivist learning theories. Cognitive learning theory posits that learning occurs through mental processes and information processing, while constructivist theory suggests that learners actively construct knowledge through interactions and experiences within their environment (Vygotsky, 1978). TEL bridges these theoretical perspectives, positing that digital tools can facilitate and enhance learning by supporting these cognitive processes and enabling learners to actively engage with and personalize their learning experiences (Higgins et al., 2017).

A central tenet of TEL is the facilitation of learner autonomy through digital technologies. The theory advocates that digital tools empower students to take control of their learning, tailor their learning pace to individual needs, and engage in more personalized, reflective learning experiences (Peng et al., 2019). In the context of mathematics education, TEL is particularly relevant as it facilitates the representation of abstract mathematical concepts in more tangible and comprehensible ways, thereby promoting students' mathematical reasoning and problem-solving skills (Sen & Leong, 2020).

TEL's wide recognition and application in the academic literature highlight its significant contribution to the field of educational technology (OECD, 2020). Notably, Goodyear and Retalis (2010) suggest that TEL offers a robust framework for understanding the role of digital technologies in education, while Kirkwood and Price (2013) argue that TEL is an effective guide for integrating technology into subject-specific instruction, particularly in mathematics.

This study adopts TEL as its theoretical foundation to explore how technological tools influence students' attitudes toward mathematics. By focusing on the student-centered learning principles inherent in TEL, this study investigates the potential of these technologies to positively impact students' engagement and attitudes toward mathematics. Drawing from the interactive and customizable nature of digital learning environments, this research hypothesizes that the integration of technology can significantly enhance students' mathematical experiences, fostering more positive attitudes and deeper engagement with the subject matter. The interactive capabilities and flexibility of these technologies, as suggested by TEL theory, offer a promising avenue for transforming traditional approaches to mathematics education and contributing to students' cognitive and affective development.

Method

Research Design

This study employed a quasi-experimental pre-test/post-test control group design to investigate the impact of a technology-supported teaching intervention on students' attitudes towards mathematics. Quasi-experimental designs are robust research methods used to test cause-and-effect relationships in situations where full random assignment of participants to groups is not feasible (Büyüköztürk, 2018).

Within this design, the 'Attitudes Towards Mathematics Scale' was administered as a pre-test to both the experimental and control groups. Subsequently, the experimental group received the technology-supported teaching intervention, while the control group followed the conventional curriculum. At the conclusion of the intervention, the same scale was re-administered as a post-test to both groups to assess any changes in their attitude scores.

Participants

The study was conducted with 43 fourth-grade students from a public school in Turkey, divided into an experimental group ($n = 21$) and a control group ($n = 22$). The experimental group included 10 female and 11 male students, while the control group consisted of 9 female and 13 male students. The groups were formed through random assignment to ensure comparability. To examine baseline equivalence, an independent-samples *t*-test was conducted on the pre-test scores. The analysis revealed no statistically significant difference between the experimental and control groups, $t(29.57) = -0.033$, $p = .974$, indicating that the groups were comparable at baseline, which supports the internal validity of the study.

Data Collection Instrument

Attitudes Towards Mathematics Scale: To assess students' attitudes toward mathematics, the Attitudes Towards Mathematics Scale was used. This validated scale measures general attitudes toward mathematics across three factors: values, self-confidence, and enjoyment/motivation. The scale, originally developed by Lim and Chapman (2013), was adapted for the Turkish context by Hacıömeroğlu (2017) following rigorous psychometric testing, including Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and reliability analysis. The final adapted version retained a three-factor structure with an overall Cronbach's alpha reliability coefficient of .84. The sub-scales demonstrated strong internal consistency with $\alpha = .91$ for values, $\alpha = .86$ for self-confidence, and $\alpha = .82$ for enjoyment and motivation (Hacıömeroğlu, 2017).

For the present study, a reliability analysis was conducted on the data collected from the 43 participants. The internal consistency for the current sample was also found to be strong, with a Cronbach's alpha coefficient of $\alpha = .81$.

Intervention Procedure

In this study, technology-supported educational materials were used to ensure that students acquire the skills of determining the area of shapes as the number of unit squares covering that area, and recognizing and modeling simple, compound, and mixed fractions. The application process was enriched with digital tools and interactive simulations, with the aim of enhancing the effectiveness and sustainability of the learning process. With the input of experts, the researcher designed six hours of technology-supported activities related to the learning outcomes outlined in the Mathematics Teaching Program. The final version of this intervention procedure was determined after receiving expert review from three faculty members (one from Mathematics Education, one from Curriculum and Instruction, and one from Elementary Education) as well as from one mathematics teacher.

Instructional Materials and Digital Tools

Educational Informatics Network (EIN): The EIN is an integrated digital learning platform developed by the Turkish Ministry of National Education. It offers a wide variety of instructional materials, including video lessons, e-books, and interactive exercises, catering to different levels of education. EIN is designed to support both teachers and students by providing a structured, resource-rich environment that promotes personalized learning. Additionally, the platform facilitates remote learning and offers tools to track student progress, making it a valuable resource in blended and distance education settings.

PhET Interactive Simulations: PhET is a suite of free, interactive simulations primarily designed for science and mathematics education. Developed by the University of Colorado Boulder, PhET simulations visually demonstrate abstract concepts, allowing students to manipulate variables and observe real-time effects. This hands-on approach aids in deepening conceptual understanding, particularly in areas like physics, chemistry, and mathematics.

LearningApp: LearningApp is an online tool designed to create interactive learning modules in a variety of subjects. It offers customizable templates that educators can use to create quizzes, matching games, and other engaging activities. The platform supports differentiated instruction, making it adaptable to various educational needs and enhancing the learning experience through interactivity.

Math Playground: Math Playground is an educational website that provides students with a variety of math games, logic puzzles, and instructional videos. It focuses on building essential math skills through interactive and game-based learning, covering topics like basic arithmetic, geometry, and algebra. The platform is aimed at elementary and middle school students, supporting both individual and collaborative learning experiences.

Tarsia Maker: Tarsia Maker is a digital tool used to create jigsaw puzzles and dominoes that aid in reinforcing educational concepts, particularly in mathematics. It allows educators to design activities that require students to match questions with answers or related concepts, fostering critical thinking and engagement through problem-solving tasks.

Implementation of the Lessons

The six-lesson intervention was structured as follows:

Calculating the Areas of Shapes

- Lesson 1: Students watched an instructional video lesson on how to calculate the areas of shapes using square units via the Education Information Network (EIN) platform. This video was selected in line with the basic learning outcomes of the lesson to ensure that students understood the topic. Following the video, students were given related exercises via EIN to reinforce what they had learned (Figure 1). Students then applied this knowledge through the "Area Creator" activity using the smart board and PhET interactive simulation tool (Figure 2). This activity was designed to foster active participation through interactive simulations and help students internalize the learning outcomes more effectively.
- Lesson 2: Digital stories were presented to students to deepen their understanding of the concept of area. Through this story-based learning approach, students were encouraged to relate the concept of area to everyday life and develop solutions related to the topic. The learning outcomes for calculating area with unit squares were reinforced with a puzzle activity created on the LearningApps and PhET platforms (Figure 3). These activities enabled students to apply what they had learned through a technology-supported, game-based approach, concluding the lesson in an engaging manner.
- Lesson 3: The focus was on evaluating and applying the knowledge gained in the previous lessons. Students were asked to create new stories similar to the ones presented previously, and these stories were presented in class. After the presentations, the best story was selected, developed into a digital story, and shared with the whole class. This process was planned to develop students' creative thinking and problem-solving skills.

Recognizing and Modeling Fractions

- Lesson 4: Students were introduced to foundational concepts by watching videos on fractions via the EIN platform (Figure 4). The content of the videos focused on explaining simple, compound, and mixed fractions with examples from everyday life. Students participated in fraction modeling activities using the PhET interactive simulation tool to reinforce the concepts presented in the videos. These activities helped students bridge theoretical knowledge with practical application.
- Lesson 5: Students engaged in exercises using the PhET interactive simulation tool and Math Playground platform to demonstrate fractions using different modeling methods (Figure 5). The activities emphasized the correct representation of fractions on a number line. Through these activities, students deepened their understanding of how fractions are formed and expressed.
- Lesson 6: The learning outcomes from previous lessons were evaluated. Students collaborated in groups to solve puzzles created with the Tarsia Maker application on the topic of fractions (Figure 6). This activity was designed to develop students' problem-solving and collaboration skills. Figures 1-6 provide visual examples of the classroom implementation, illustrating some of the applications and activities used during the intervention.

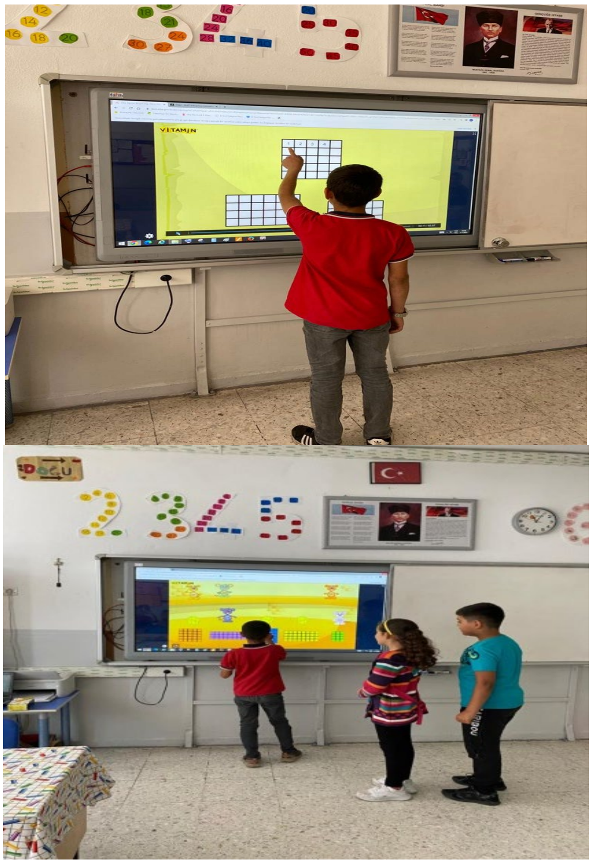

Figure 1: Students completing the "Let's Calculate Area Using Unit Squares" exercise via EIN on the interactive whiteboard during the lesson

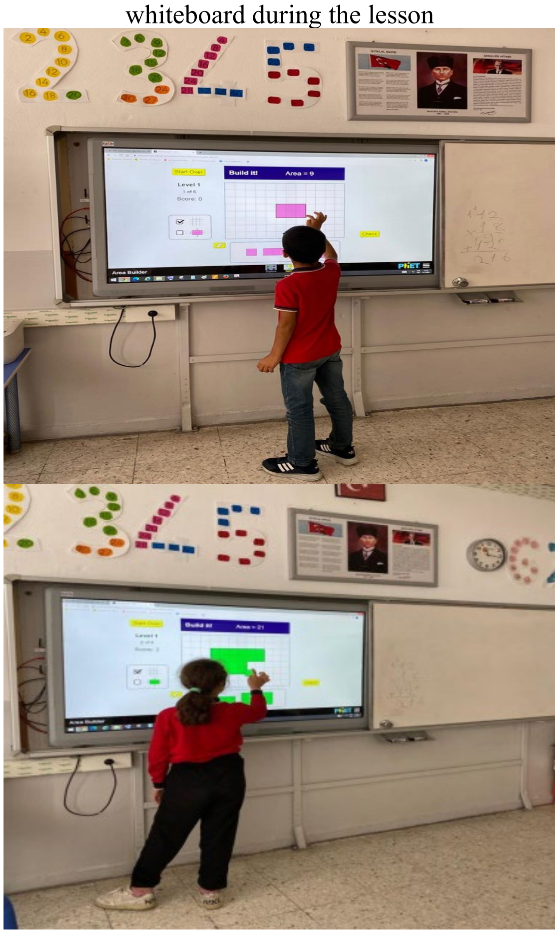

Figure 2: Students engaging in the "Area Builder" activity on the interactive whiteboard using the PhET interactive simulation

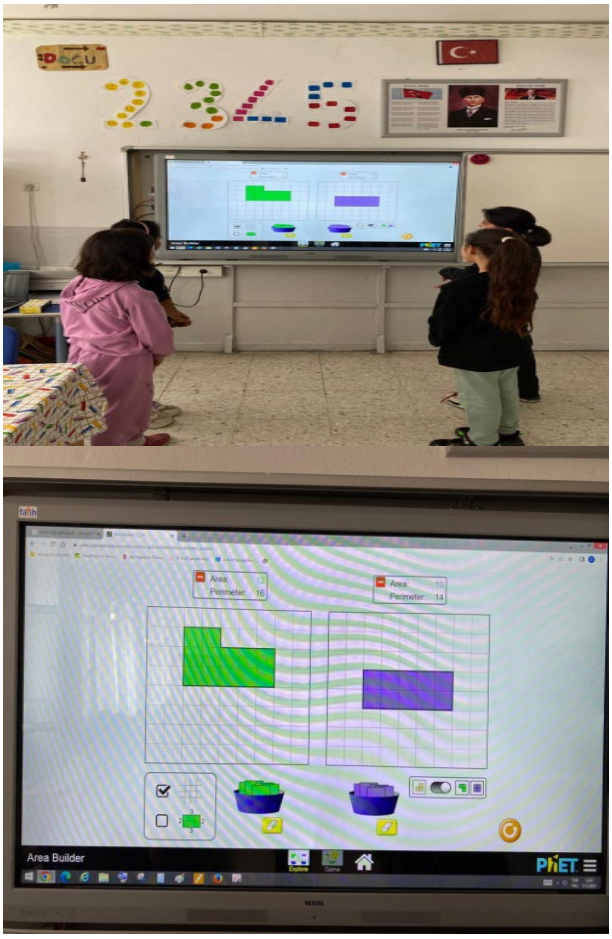

Figure 3: Student groups collaborating to design the areas for their fields on the interactive whiteboard using the PhET simulation

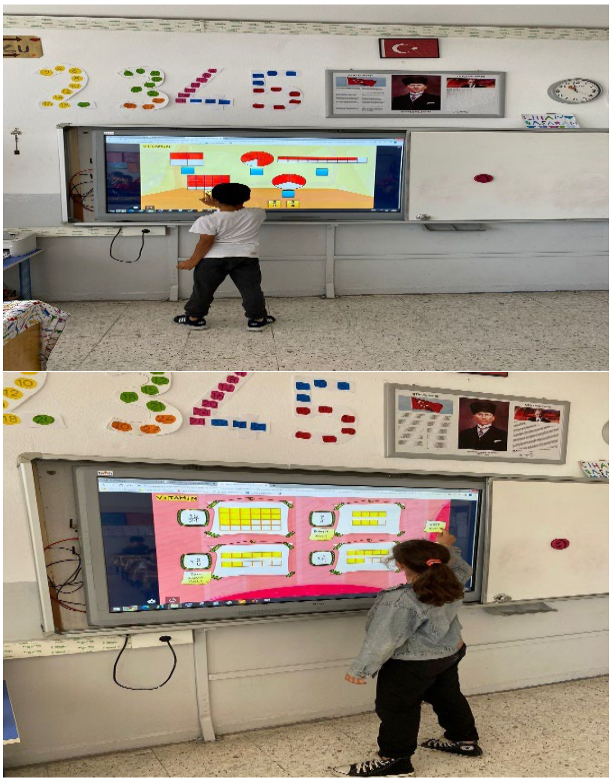

Figure 4: Students completing exercises on fractions using the EIN platform

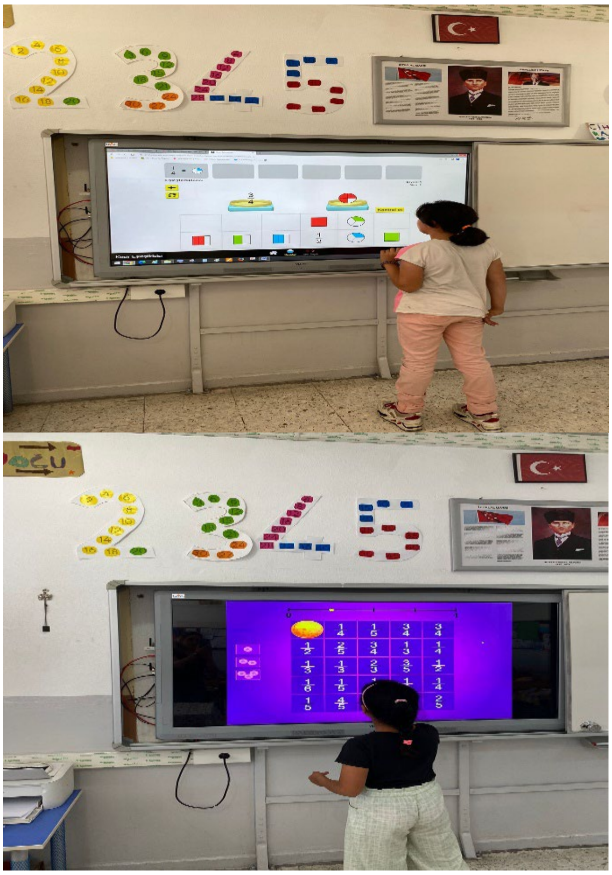

Figure 5: Students practicing with fractions using the Math Playground and PhET applications

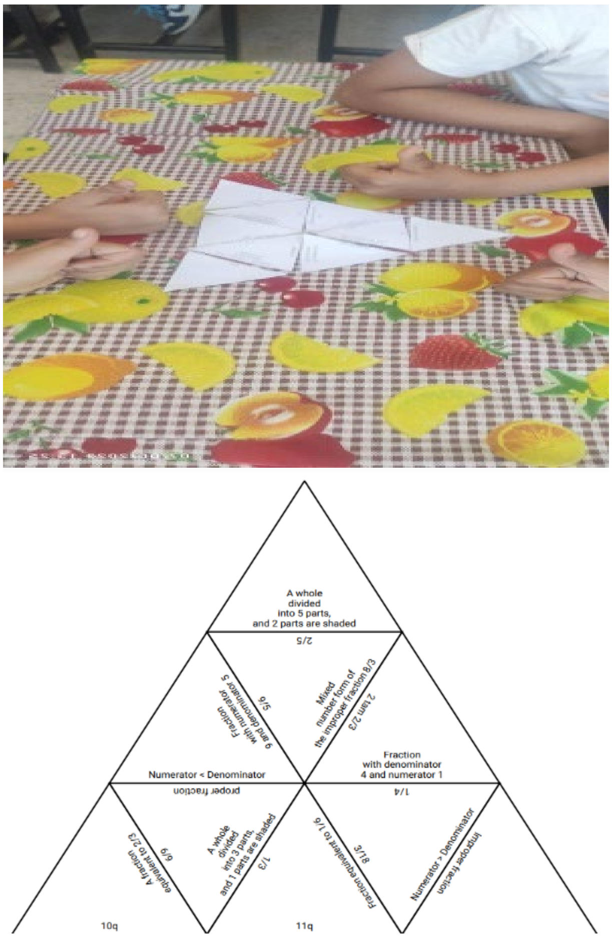

Figure 6: Students working on a puzzle activity created with Tarsia Maker

Data Analysis

Quantitative data were analyzed using SPSS software. First, normality tests were conducted to determine the suitability of parametric analyses. For within-group comparisons (pre-test vs. post-test), paired-samples *t*-tests were used. For between-group comparisons (experimental vs. control), independent-samples *t*-tests were employed.

Ethical Considerations

All procedures in this study were conducted in strict adherence to established ethical standards. Ethical approval was granted by the Ethics Committee of Kilis 7 Aralık University, (Meeting No: [2025/8], Date: [21.05.2025]).
Prior to the commencement of the research, informed consent was obtained from the parents or legal guardians of all participants. Furthermore, verbal assent was secured from the students themselves after they were informed about the study's objectives and activities in age-appropriate language. Participation was fully voluntary, and participants were assured that they or their parents could withdraw from the study at any time without consequence. All collected data were anonymized to ensure participant confidentiality and maintain the integrity of the data collection process.

Results

Prior to conducting statistical analyses on the quantitative data, normality assessments were executed to ensure the appropriateness of the analytical methods employed. Specifically, normality tests were carried out for both the pre-test and post-test data of the *Attitudes Towards Mathematics Scale* for the experimental group, as well as for the corresponding pre-test and post-test data for the control group. The results of these normality tests confirmed that the data for both groups were normally distributed, as assessed by the Shapiro-Wilk test (Table 1). Given this normality, parametric statistical methods were deemed appropriate for the subsequent analyses.

A paired-samples *t*-test was conducted to evaluate the impact of the technology-supported teaching intervention by comparing the pre-test and post-test scores for both groups. The descriptive statistics and *t*-test results are presented in Table 2 and Table 3, respectively.

The results for the experimental group showed a statistically significant improvement in attitudes towards mathematics following the intervention. The group's overall mean score on the attitude scale increased from a pre-test score (M = 3.35, SD = 0.53) to a post-test score (M = 3.79, SD = 0.42). This difference was statistically significant, $t(20) = -5.46$, $p < .001$, $d = 0.92$. An examination of the sub-dimensions reveals that this positive shift was evident across all factors, with a particularly notable increase in the *Self-confidence* factor (from M = 2.58 to M = 3.44). The intervention's effect size indicates a large impact on the experimental group's attitudes, underscoring the practical efficacy of the technology-supported teaching method.

In contrast, the control group, which followed the traditional curriculum, showed no statistically significant change in their attitudes towards mathematics over the same period. The group's overall mean score moved from a pre-test score (M = 3.35, SD = 0.27) to a post-test score (M = 3.46, SD = 0.31). This change was not statistically significant, $t(21) = -1.56$, $p = .134$.

Table 1. Normality Test Results for Pre-Test and Post-Test Applications of the Scale in the Experimental and Control Groups

		Shapiro-Wilk						
		Statistic	df	p	Skewness	SE Skewness	Kurtosis	SE Kurtosis
Experiment Group	Pre-Test	.933	21	.156	.391	.501	-.998	.972
	Post-Test	.913	21	.063	-.922	.501	.532	.972
Control Group	Pre-Test	.977	22	.863	.388	.491	-.306	.953
	Post-Test	.985	22	.972	.109	.491	.807	.953

Note. *df* = degrees of freedom; SE = standard error.

Table 2. Pre-Test and Post-Test Total Scores and Standard Deviations of the Sub-Dimensions of the Scale for the Experimental and Control Groups

	Experiment Group				Control Group			
	pre-test		post-test		pre-test		post-test	
Factors	M	SD	M	SD	M	SD	M	SD
1. Enjoyment and Motivation	3.66	.48	3.90	.52	3.60	.36	3.78	.48
2. Self-confidence	2.58	.87	3.44	.47	2.23	.95	2.37	.84
3. Value	3.59	.69	3.96	.66	4.01	.57	3.99	.54
Overall Factor Score	3.36	.53	3.79	.42	3.35	.27	3.46	.31

Note. M = mean; SD = standard deviation.

Table 3. Difference Between Pre-Test and Post-Test Total Scores in the Experimental Group and Control Group

		N	M	SD	df	t	p	d
Experiment Group	pre-test	21	3.35	.53	20	-5.456	.000	.92
	post-test	21	3.79	.42				
Control Group	pre-test	22	3.35	.27	21	-1.559	.134	
	post-test	22	3.46	.31				

Note. M = mean; SD = standard deviation; *df* = degrees of freedom; *d* = Cohen's d.

Table 4. Independent Samples T-Test Results for Post-Test Scores of the Experimental and Control Groups

Group	N	M	SD	df	t	p
Control Group	22	3.46	.31	41	-2.93	.006
Experiment Group	21	3.79	.42			

Not. M = mean; SD = standard deviation; *df* = degrees of freedom; *p* = significance value.

These findings collectively demonstrate that while the technology-supported intervention led to a significant and large positive shift in students' attitudes towards mathematics, no such improvement was observed in the group receiving conventional instruction.

According to the independent samples t-test results in Table 4, the post-test scores of the experimental group (M = 3.79, SD = 0.42), which received technology-supported instruction, were statistically significantly higher than the post-test scores of the control group (M = 3.46, SD = 0.31), which received conventional instruction [t(41) = -2.93, p = .006]. This finding indicates that the applied intervention had a positive and significant effect on students' attitudes towards mathematics compared to conventional instruction.

Conclusion and Discussion

This study investigated the effect of a technology-supported teaching intervention on fourth-grade students' attitudes towards mathematics. The findings revealed a significant and large positive impact for the experimental group, while the control group, which received conventional instruction, exhibited no significant change.

The primary finding that a well-designed, technology-supported intervention can substantially improve student attitudes towards mathematics is consistent with the principles of the Technology-Enhanced Learning (TEL) framework that guided this study. The TEL framework posits that digital tools, when integrated with sound pedagogy, can transform the learning experience by making it more active, individualized, and engaging (Law et al., 2015). The intervention in this research appears to have actualized these principles in two key ways. First, the use of interactive tools such as PhET simulations and LearningApps allowed students to move beyond passive reception of information and actively construct their understanding of abstract concepts like area and fractions. This hands-on, exploratory process may have contributed to reducing maths anxiety and enhancing self-confidence, a key factor in improving attitudes, as evidenced by the significant gains in the "self-confidence" subfactor of the attitude scale.

Second, the active participation fostered by these digital platforms is a cornerstone of the TEL approach. Rather than a uniform instructional approach, students were able to engage with the material at their own pace and receive instant feedback from the simulations. This personalized experience likely made the learning process more efficient, meaningful, and enjoyable, thereby improving their motivation and perceived value of mathematics, as also reflected in the attitude subscales.

Synthesizing these observations, the findings suggest that a key factor in this positive outcome is not only the digital tools themselves but also the pedagogical approach to how these tools were used—specifically, to foster active student participation, exploration, and interaction. This pedagogical emphasis on active engagement is well-supported by existing research. Indeed, studies in different learning contexts have also shown that active engagement and interaction within the learning process can positively influence mathematics attitudes (Hourigan et al., 2016). This principle extends to other forms of technology, such as educational robotics, which have been shown to increase student motivation and participation by allowing them to learn through engaging, game-based learning activities (Bento Miguens et al., 2024).

Furthermore, the findings of this study align with a substantial body of literature indicating that technology integration fosters positive student attitudes and engagement in mathematics (Higgins et al., 2017; Hillmayr et al., 2020). This is particularly relevant within the Turkish educational context, where students have been shown to hold generally positive perceptions of technology use in mathematics. For example, Aytekin and Isiksal-Bostan (2018) reported that Turkish middle school students demonstrated 'moderately high' attitudes toward technology integration. The present study extends these findings by showing that such positive predispositions can be further strengthened and consolidated through structured pedagogical interventions, such as the one implemented here. The observed improvement in attitudes thus provides additional empirical support for the affective benefits of digital tools in mathematics education.

The positive shift in student attitudes is further reinforced by research into other technology-mediated pedagogical models, such as the flipped classroom. For instance, a study by Kavaz and Kocak (2024) on an online flipped learning model also reported a positive shift in student attitudes towards mathematics, suggesting that the move towards a more learner-centered approach is a key factor in improving affective engagement. Moreover, while this study focused on the affective domain, its findings complement other research that demonstrates the cognitive benefits of technology in early mathematics. For instance, a study by Weiss et al. (2006) with kindergarten children revealed that students who learned with multimedia significantly outperformed their peers in mathematical achievement. Taken together, these findings suggest that technology-supported interventions may establish a positive feedback loop: by improving attitudes, as shown in this research, they may also pave the way for the enhanced academic performance reported by Weiss et al. (2006).

Beyond comparing these results with the literature, a closer look at the study's own statistical findings offers further insights. Notably, the effect size (d = 0.92) observed in this study is a significant finding. This finding should be interpreted in light of the study's limited scale. As recent literature suggests, larger effect sizes are often observed in smaller, more controlled studies compared to large-scale implementations (Drijvers & Sinclair, 2024). This may indicate that while digital tools can have a profound impact in a well-controlled pedagogical environment like the one in this study, achieving the same magnitude of effect on a larger scale presents challenges and requires careful planning regarding teacher training and resource allocation.

For educators, a key implication is that incorporating interactive digital resources like PhET and EIN can be a powerful strategy to enhance the meaningfulness, accessibility, and perceived enjoyment of mathematics learning. For policymakers, this study underscores the importance of investing in both digital infrastructure and, critically, the professional development of teachers to effectively implement TEL principles. This aligns with recent research highlighting that the success of technology integration is not guaranteed by the tools alone but depends on a complex interplay of factors, including teachers' pedagogical beliefs, school environment, and professional development opportunities. Therefore, creating a supportive ecosystem that fosters what Li et al. (2025) term 'Technological Pedagogical Readiness' is essential for replicating the positive outcomes found in this study on a wider scale. This transformation can help turn mathematics from a subject of anxiety into an engaging field of exploration for all students.

Limitations and Future Research

Despite the promising results, this study has several limitations that must be acknowledged. First, the relatively small sample size, drawn from a single school, limits the generalizability of the findings to wider populations. Second, the intervention was conducted over a limited period (six lessons). While the short-term impact was substantial, a longer implementation period would be necessary to determine if the positive attitudes are sustained over time and lead to deeper conceptual mastery.

Based on these limitations, several avenues for future research emerge. Replicating this study with larger and more diverse samples would be a crucial step to validate the findings. Longitudinal studies are needed to explore the long-term effects of such interventions. Furthermore, future studies could investigate the effectiveness of these technology-supported activities across different age groups and subjects to broaden the scope of applicability. Additionally, qualitative studies, such as classroom observations or in-depth interviews with students, could provide richer insights into the specific mechanisms of this attitudinal change, for example, by exploring precisely how the interactive simulations contributed to the notable increase in self-confidence.

Author Contributions

The author is the sole contributor to this work and confirms responsibility for the study's conception and design, data collection and analysis, and the drafting and final approval of the manuscript for publication.

Ethical Declaration

This study was conducted following the approval granted by the Ethics Committee of Kilis 7 Aralık University, Türkiye (Meeting No: 2025/8; Date: 21 May 2025).

Conflict of Interest

The author declares that there is no conflict of interest.

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