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Examining the Effects of Gamified Digital Learning Tools on Mathematics Anxiety and Attitudes toward Mathematics among Primary School Students

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ABSTRACT

This study examined the effects of gamified digital learning tools on fourth-grade students' mathematics anxiety and attitudes toward mathematics. An embedded mixed-methods design was employed, combining a quasi-experimental pre-test–post-test control group design with a qualitative case study. The participants were 66 fourth-grade students (experimental = 33, control = 33). The intervention lasted eight weeks, during which Matific, Wordwall, and Kahoot! were integrated into mathematics instruction in complementary ways. Quantitative data were collected using the Mathematics Anxiety Scale for Elementary School Children and the Attitude Toward Mathematics Scale, while qualitative data were gathered through semi-structured focus group interviews. Quantitative data were analyzed using independent samples t-tests and ANCOVA by controlling for pre-test scores after testing assumptions, whereas qualitative data were analyzed through thematic analysis. The findings showed that gamified digital learning tools significantly reduced mathematics anxiety and improved attitudes toward mathematics. Qualitative findings supported these results, revealing that students perceived mathematics lessons as more enjoyable, motivating, supportive, and conducive to a stronger sense of achievement. These findings suggest that integrating well-structured gamified digital tools into mathematics instruction can support both cognitive engagement and affective development.

Keywords: Mathematics anxiety, attitudes toward mathematics, gamified digital learning tools, primary school students

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Introduction

Affective factors, along with cognitive factors, play a decisive role in learning processes. Since learning mathematics involves not only cognitive but also strong affective components, the emotional connection students form with mathematics is critical. Students' positive or negative feelings toward mathematics can affect their performance, effort, attention, academic success, and long-term educational and career choices (Uğraş, 2025). Mathematics anxiety and attitudes toward mathematics, which are key indicators of students' cognitive and emotional relationship with mathematics, are significantly related to academic success (Abín et al., 2020; Iyamuremye et al., 2023). Primary school years are particularly critical because students' relationship with mathematics is shaped, anxiety becomes more pronounced, and attitudes toward mathematics become relatively permanent (Jameson, 2013; Luo et al., 2024; Ramirez et al., 2013). Therefore, learning approaches that reduce anxiety and support positive emotional bonds with mathematics from an early age are important. The abstract nature of mathematics and the limitations of traditional classroom practices in meeting individual learning needs increase the need for more interactive and adaptable learning environments (Liu, 2023). In recent years, technology-supported learning environments have emerged as promising approaches that can improve mathematical achievement, strengthen self-confidence, and reduce mathematics anxiety (Atoyebi & Atoyebi, 2022; Chen, 2019; Elma et al., 2024). Within this framework, studies have shown that digital learning platforms can help students with mathematics anxiety reduce anxiety and develop a more positive relationship with mathematics (Mamolo & Sugano, 2024). Their interactive structure, instant feedback, and game-based features support active participation and make mathematics more accessible and engaging (Jardeloza et al., 2016), thereby increasing interest and motivation and contributing to more positive attitudes toward mathematics (Gökdeniz Tahiroğlu & Özcan, 2025; Nayıroğlu & Tutak, 2023). This potential becomes even stronger in digital environments that incorporate gamified features.

Gamification-based learning approaches have been shown to positively influence cognitive, affective, and behavioral learning outcomes at the K-12 level (Dehghanzadeh et al., 2024). In primary school mathematics education, this approach is increasingly important because of its potential to support interest, motivation, and attitudes toward mathematics, a subject often perceived as challenging (Yan, 2023). Similarly, digital game-based learning approaches have been reported to increase motivation, strengthen classroom participation, and support self-efficacy (Gil-Doménech & Berbegal-Mirabent, 2019). They can also positively improve the cognitive skills of children who struggle with mathematics (Benavides-Varela et al., 2020). In this context, gamified digital learning tools, as practical applications of gamification principles, have considerable pedagogical potential for supporting affective experiences, reducing mathematics anxiety, and fostering more positive attitudes toward mathematics. Although the literature on the educational benefits of gamified digital learning tools is expanding, research examining the combined use of Matific, Wordwall, and Kahoot! on mathematics anxiety and attitudes toward mathematics among fourth-grade primary school students remains limited. In particular, how these tools influence students' affective characteristics related to mathematics and how students' experiences explain quantitative findings remain unclear. Therefore, the main objective of this study is to examine the effect of gamified digital learning tools (Matific, Wordwall, and Kahoot!) on mathematics anxiety and attitudes toward mathematics among primary school students.

Literature Review

Mathematics Anxiety

Mathematics anxiety is defined as a multidimensional emotional response shaped by the interaction of cognitive, emotional, social, and biological factors that negatively affects learning, reasoning, and performance in mathematical contexts (Jukić Matić et al., 2026). This anxiety manifests itself in intense emotional reactions such as fear, worry, frustration, and tension toward mathematics, leading students to avoid mathematical activities (Ashcraft & Krause, 2007). From a cognitive perspective, mathematics anxiety disrupts mathematical processing by depleting limited working memory resources, thereby reducing students' levels of attention, efficiency, and accuracy (Beilock & Maloney, 2015). The increased cognitive load and emotional processes associated with anxiety further weaken students' engagement with mathematical problems and contribute to lower achievement levels (Uğraş, 2025). Therefore, researchers emphasize that mathematics anxiety must be considered when examining the relationship between children's cognitive abilities and mathematical performance (Wei et al., 2024; Westfall et al., 2021). Indeed, it has been noted that students with high mathematics anxiety make significantly more errors than their peers on complex problems, and this situation stems not from low ability but from an anxiety cycle in which worry and avoidance reinforce each other (Ramirez et al., 2018). This reciprocal interaction can reinforce the perception of failure and reduce self-efficacy, causing anxiety to become chronic over time. This creates a vicious cycle in which low mathematics achievement increases anxiety, and increased anxiety leads to avoidance of mathematics, making it even more difficult for students to improve their mathematical skills (Balt et al., 2022). Although a certain level of anxiety is considered a natural response that can motivate an individual's performance, high mathematics anxiety leads to increased avoidance of mathematical tasks and the development of negative attitudes (Ashcraft, 2002).

Teachers' encouraging, supportive, and constructive feedback can create a positive learning climate. Such a learning environment increases students' emotional engagement, contributes to a decrease in mathematics anxiety, and improves their self-confidence in their mathematical abilities (Eden et al., 2013; Zhang & Zhou, 2024). Teaching methods with high cognitive activation can reduce students' anxiety about failure by creating an interactive classroom atmosphere and contribute to alleviating mathematics phobia (Burge et al., 2015; Zuo et al., 2024). In addition, personalized learning approaches such as differentiated instruction and adaptive learning technologies can allow students to progress at their own pace and receive targeted support when needed (Zhang & Zhou, 2024). Therefore, interventions that go beyond traditional teaching approaches are needed to reduce students' mathematics anxiety.

Attitudes toward Mathematics

It can be said that students' attitudes toward a discipline are one of the important psychological factors that determine the quality of their relationship with that discipline in the learning process. Dubé and Wen (2021) define attitude as a multidimensional psychological construct generally consisting of cognitive, affective, and behavioral components. In the context of mathematics, the authors state that these components include the individual's beliefs about the value of mathematics and their own competence, their emotional responses to mathematics, and their behavioral tendencies to participate in or avoid mathematical activities. Attitude toward mathematics is considered a multidimensional construct that reflects students' general psychological tendencies regarding the mathematics learning process, including the individual's feelings and evaluations toward mathematics, their perceptions of their own competence, and their

beliefs about the usefulness of mathematics (Lijie et al., 2020; Sengül & Dereli, 2013). One of the important components of attitude toward mathematics is the enjoyment students derive from mathematics or the emotional responses they develop toward it. Depending on the quality of these components, attitude toward mathematics can develop in a positive or negative direction. A positive attitude toward mathematics can encourage students to show greater interest in mathematical problems, put more effort into mathematical tasks, and participate more effectively in problem-solving processes, while a negative attitude can lead students to distance themselves from mathematical activities and perceive mathematics as a challenging field (Mutegi et al., 2021).

The literature frequently emphasizes a significant relationship between mathematics anxiety and attitudes toward mathematics (Luo et al., 2024). Recent studies show that positive attitudes toward mathematics can play a role in reducing mathematics anxiety in primary school students and can function as a protective factor against anxiety (Zhuo et al., 2025). In this context, addressing mathematics anxiety and attitudes toward mathematics together, especially at the primary school level, and examining interventions that may affect these variables appear to be an important pedagogical goal. The teaching materials used in the classroom, the teacher's classroom management and content knowledge, and the use of examples enriched with real-life contexts can also influence students' attitudes toward mathematics (Yılmaz et al., 2010). It is emphasized that recent innovations in educational technologies facilitate the use of gamification applications and offer teachers the opportunity to design more immersive and interactive learning environments (Vrcelj et al., 2023). In this context, gamification and gamified digital learning tools are particularly noteworthy approaches with the potential to support students' emotional engagement.

Gamification and Gamified Digital Learning Tools in Education

Gamification is defined as the integration of game design principles and mechanics into non-game contexts to increase interaction and motivation (Deterding et al., 2011). By transforming passive learning environments into interactive and challenge-based experiences, gamified learning approaches increase participation and support more active, meaningful, and lasting learning (Li & Jianxing, 2025). Since this study focuses on digital learning environments, the term “digital gamification” is used throughout the text. In education, gamified digital learning tools have become prominent for creating interactive, student-centered, and personalized learning experiences that can increase motivation, engagement, and academic achievement (Kapp, 2012; Aibar-Almazán et al., 2024; Li & Jianxing, 2025; Ruiz-Navas et al., 2024; Dewi et al., 2025). These tools combine the motivational power of games with educational content, supporting exploration, problem-solving, and flexible content delivery aligned with learning objectives (Dewi et al., 2025; Kocabatmaz & Saraçoğlu, 2024). Research shows that gamified digital learning tools can improve attention, participation, retention, academic achievement, attitudes, creativity, critical thinking, and broader cognitive, affective, and behavioral outcomes by supporting motivation and engagement (Pozzi et al., 2024; Dewi et al., 2025; Kocabatmaz & Saraçoğlu, 2024; Dehghanzadeh et al., 2024; Arufe-Giráldez et al., 2022). However, their effectiveness depends strongly on design quality. Effective gamified digital learning environments should provide regular practice, immediate feedback, adjustable difficulty, manageable content, student choice, and appropriate rewards (Alt, 2023). Gamification should also balance competition, mastery, and cooperation according to students’ needs (Ratinho et al., 2026). Poorly designed systems may increase anxiety, technostress, burnout, and reduced autonomy (Kwon & Özpolat, 2020; Liu, 2023). This highlights the need to examine how gamified digital learning tools function in mathematics education and which learning outcomes they support.

Research Gaps in Gamified Digital Learning for Mathematics Education

Gamified digital learning tools are considered important resources in the literature for overcoming the limitations of traditional lecture-based mathematics instruction, supporting students' positive affective experiences, increasing active participation and social interaction, and contributing to the development of cognitive learning outcomes. By integrating game design elements into learning environments, these tools have the potential to transform mathematics instruction into a more dynamic, interactive, and student-centered process, thereby enabling students to experience mathematical concepts in more meaningful and engaging ways (Liu, 2023). Accordingly, a growing number of studies have examined gamified digital learning tools and the effects of learning activities designed around these tools in mathematics education. The existing literature indicates that these studies have predominantly focused on outcomes such as mathematics achievement, motivation, engagement, problem-solving, and self-efficacy, although some studies have also addressed affective variables such as anxiety, attitudes, flow, and emotions.

Comprehensive meta-analyses examining gamification in mathematics education have demonstrated that gamification positively affects students' motivation, active participation, mathematical problem-solving skills, and mathematics achievement (Ratinho et al., 2026; Yığ & Sezgin, 2021). More specific studies also support this overall trend. For example, Kaya and Ercag (2023) found that a gamification-based digital application enhanced high school students' academic performance and overall motivation, while Lukman et al. (2023) reported significant improvements in middle school students' problem-solving and mathematical critical-thinking skills. Similar findings have also been reported at the primary school level. Rahim et al. (2025) found that gamification-based formative assessment conducted through Kahoot! enhanced academic achievement and supported cognitive development in mathematics education, while Newpher (2025) demonstrated that gamified learning performance was a significant predictor of mathematics achievement among fifth-grade students. In addition, Ester et al. (2025) found that gamified digital learning tools effectively supported mathematical skills such as computation and problem-solving among students with intellectual disabilities.

Studies more closely related to the present research provide limited but important evidence, particularly regarding specific tools and affective variables. Kocabatmaz and Saraçoğlu (2024) found that Wordwall and Matific, when used in mathematics lessons, positively affected third-grade primary school students' mathematics achievement and attitudes toward mathematics. However, their study did not address mathematics anxiety. Similarly, using a mixed-methods approach, Gökdeniz Tahiroğlu and Özcan (2025) demonstrated that Nearpod positively affected middle school students' mathematics motivation and attitudes toward mathematics. However, their study differs from the present research in terms of both the educational level of the sample and the digital tool employed. Chen et al. (2023), in contrast, found that an online gamified learning activity positively affected high school students' mathematics achievement, motivation, flow, anxiety, and emotions. Nevertheless, their study focused on high school rather than primary school students. Although the study by Jukić Matić et al. (2026) is noteworthy for its emphasis on reducing mathematics anxiety and supporting positive emotional engagement, it did not involve an experimental intervention but instead proposed a conceptual model for developing digital educational games. Likewise, Jagušt et al. (2017) found that gamified digital learning applications positively affected the motivation of second- and third-grade primary school students. However, the present study also differs from their research in terms of its sample and the variables examined. McKevitt et al. (2025) found that gamified digital learning applications, specifically Blooket games, enhanced middle school students' mathematical resilience and reduced their mathematics

anxiety. However, their sample and the tools employed also differ from those in the present study. Taken together, although the literature provides growing evidence regarding the effects of gamified digital learning in mathematics education, studies simultaneously examining mathematics anxiety and attitudes toward mathematics through the combined use of three tools at the fourth-grade primary school level remain limited.

Although evidence regarding the effects of gamified digital learning tools in mathematics education continues to grow, several important research gaps remain. A substantial proportion of existing studies focus on a single digital tool and cognitive outcomes such as mathematics achievement, performance, and problem-solving. In contrast, studies examining the combined use of different gamified digital tools and affective variables, such as mathematics anxiety and attitudes toward mathematics, remain limited. To the best of our knowledge, no study has simultaneously examined the effects of the combined use of Matific, Wordwall, and Kahoot! on mathematics anxiety and attitudes toward mathematics among fourth-grade primary school students. Furthermore, existing research has predominantly assessed the effects of these tools using quantitative data, while mixed-methods studies examining how students experience gamified mathematics instruction and how these experiences contribute to the interpretation of quantitative findings remain scarce. Given that gamified environments may create adverse experiences related to competition, technostress, and an excessive reliance on rewards, despite their potential to promote interest, motivation, and engagement, students' views also need to be considered. Therefore, examining quantitative changes alongside qualitative data concerning students' experiences may contribute to a more comprehensive understanding of the effects of gamified digital learning tools on students' affective characteristics. Accordingly, the present study employs an embedded mixed-methods design to examine the effects of the combined use of Matific, Wordwall, and Kahoot! on fourth-grade students' mathematics anxiety and attitudes toward mathematics.

Theoretical Framework

The primary focus of the present study is the effects of gamified digital learning tools (Matific, Wordwall, and Kahoot!) on mathematics anxiety and attitudes toward mathematics among fourth-grade primary school students. The theoretical framework of this study is grounded in Flow Theory (Csikszentmihalyi, 1990). Within this theory, flow can be defined as an optimal experience in which students or individuals become fully immersed in an activity, lose track of time, derive intrinsic satisfaction from the activity, and actively engage in the learning process. According to Flow Theory, for a flow experience to occur, there must be a balance between an individual's knowledge and skill level and the tasks and responsibilities encountered in the learning environment. In other words, individuals should not be excessively challenged. Otherwise, when the demands of a task exceed an individual's skills, anxiety may emerge. Similarly, tasks that are too easy may lead to boredom and a loss of motivation. The gamified digital learning tools that constitute the focus of the present study (Matific, Wordwall, and Kahoot!) incorporate many features that support the development of flow experiences and the conditions necessary for achieving flow. These tools provide progressively challenging tasks, immediate feedback, points, badges and reward mechanisms, clear goals, and interactive structures that encourage students' active participation. Likewise, these features help students sustain their attention for longer periods, become more engaged in the learning process, and participate more actively. Consequently, through the use of gamified digital learning tools (Matific, Wordwall, and Kahoot!), students are more likely to perceive mathematics activities as more accessible, enjoyable, and achievable. One of the major causes of mathematics anxiety is that students often perceive

mathematical tasks as exceeding their own abilities. In contrast, gamified digital learning tools (Matific, Wordwall, and Kahoot!) provide activities with an appropriate level of difficulty for students' skill levels and offer continuous feedback, thereby increasing students' experiences of success and reducing anxiety. In this way, gamified digital learning tools (Matific, Wordwall, and Kahoot!) can make the learning process more enjoyable and motivating while fostering more positive attitudes toward mathematics. Therefore, Flow Theory was adopted in the present study not only to explain the findings but also as the theoretical framework underpinning the expectation that gamified digital learning tools can reduce mathematics anxiety and promote more positive attitudes toward mathematics.

The Current Study

The present study aimed to examine the effects of mathematics instruction supported by gamified digital learning tools on fourth-grade students' mathematics anxiety and attitudes toward mathematics and to explore students' experiences in order to provide a more comprehensive explanation of the quantitative findings. Accordingly, the following overarching research question and sub-questions were formulated: *How do quantitative findings on mathematics anxiety and attitudes toward mathematics, together with students' qualitative experiences, explain the effects of mathematics instruction supported by gamified digital learning tools?*

RQ1. After controlling for pre-test scores, do students receiving mathematics instruction supported by gamified digital learning tools demonstrate significantly lower mathematics anxiety than students receiving conventional mathematics instruction?

RQ2. After controlling for pre-test scores, do students receiving mathematics instruction supported by gamified digital learning tools demonstrate significantly more positive attitudes toward mathematics than students receiving conventional mathematics instruction?

RQ3. How do fourth-grade students describe their experiences of mathematics instruction supported by gamified digital learning tools?

Based on Flow Theory and the empirical evidence reviewed above, the following directional hypotheses were proposed for the quantitative component:

H1. Gamified digital learning is expected to have a negative effect on mathematics anxiety.

H2. Gamified digital learning is expected to have a positive effect on attitudes toward mathematics.

Method

Research Design

This research utilized an embedded mixed-methods design, a type of mixed-methods research design (Creswell, 2012). Quantitative data were used to examine changes in fourth-grade students' mathematics anxiety and attitudes toward mathematics following the use of gamified digital learning tools. However, since quantitative findings alone were insufficient to explain how students experienced these tools, which features they found motivating or challenging, and how students' experiences contributed to the interpretation of the observed changes, qualitative data were included to capture students' experiences during the intervention process. In an embedded mixed-methods design, one type of data forms the primary structure of the research, while the other plays a supporting role (Creswell & Plano Clark, 2018). In this study, quantitative data

constituted the primary dataset, whereas qualitative data served as a secondary dataset to explain and contextualize the quantitative findings. Accordingly, the primary design was a quasi-experimental pre-test-post-test control group design, and the secondary design was a qualitative case study.

To address H1 and H2, the quasi-experimental design was used to examine the effects of gamified digital learning tools (Matific, Kahoot!, and Wordwall) on fourth-grade students' mathematics anxiety and attitudes toward mathematics. This design was preferred because the study was conducted in a primary school setting where random assignment to experimental and control groups was not possible. Instruction in the experimental group was conducted using these tools, whereas the control group followed existing classroom practices. The lesson delivery in the control group is described in detail in the implementation phase. To address RQ3, the qualitative case study aimed to examine students' experiences with gamified digital learning tools and provide a deeper explanation of the quantitative findings by revealing which aspects of the intervention they found useful, engaging, or challenging, how these tools supported mathematical understanding, and what positive or negative experiences emerged during the intervention process. Thus, the embedded mixed-methods design enabled the study to address the research questions comprehensively by combining evidence regarding the effects of the intervention with evidence concerning how students experienced the intervention process. The embedded mixed-methods design used in the research process is presented in Figure 1.

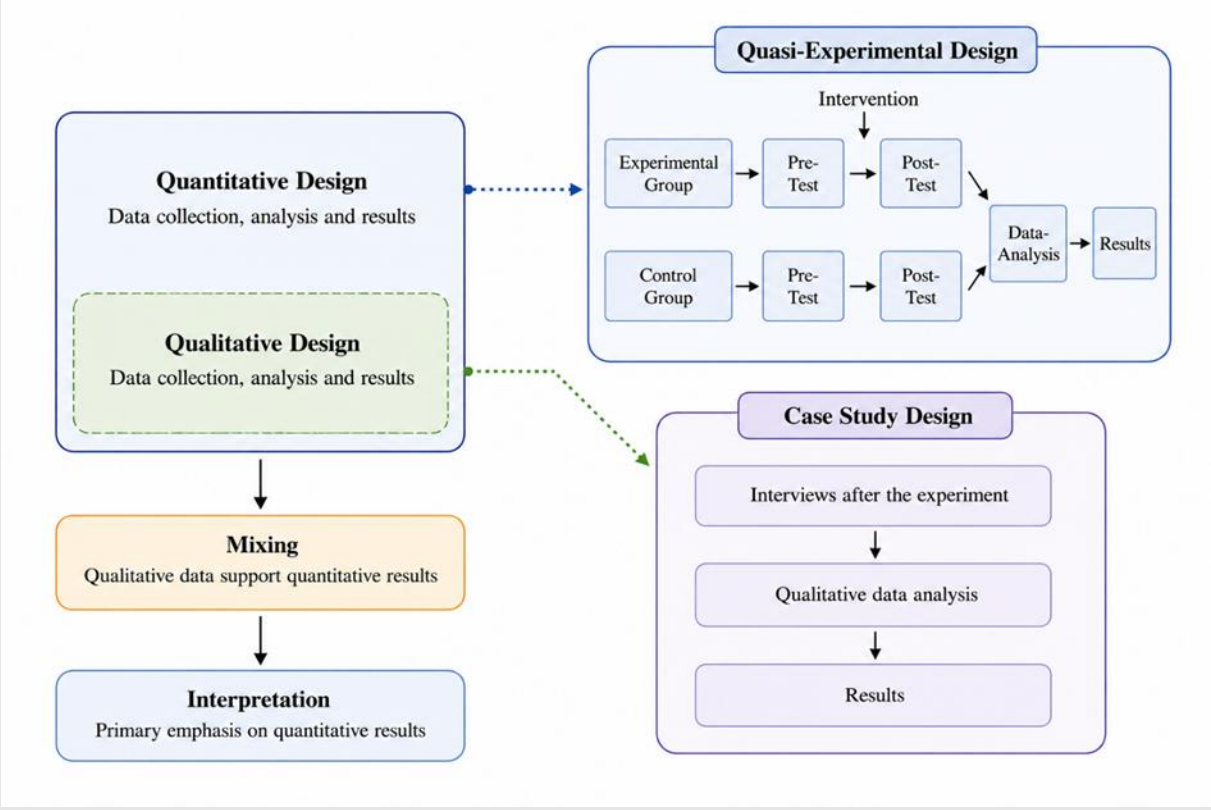

Figure 1. Embedded Mixed Design (Creswell & Plano Clark, 2018)

As shown in Figure 1, in this study, quantitative and qualitative data were analyzed separately, while the integration and interpretation of the datasets were mainly carried out in the discussion section. In this context, qualitative findings were linked to the quantitative findings in order to support, explain, and deepen the quantitative results.

Participants

This study was conducted in a public primary school in Van, Türkiye, during the 2025–2026 academic year. A total of 66 fourth-grade students, all aged 10, participated in the study. The school was randomly selected from schools meeting criteria such as having smart boards and multiple fourth-grade classes. Since the research was conducted in a natural school setting and existing classroom structures were preserved, students were not individually assigned to groups. Instead, the experimental and control groups were determined by lottery from the existing classes. Accordingly, class 4/C (20 girls, 13 boys) was assigned to the experimental group, and class 4/B (19 girls, 14 boys) was assigned to the control group. The groups were similar in terms of the number of students and gender distribution. The teacher of class 4C had 12 years of professional experience, whereas the teacher of class 4B had 11 years of experience. Both teachers had previously taught fourth grade twice. In other words, the teachers had comparable experience teaching at the fourth-grade level. Neither class had any prior experience with gamified digital learning tools, and neither teacher had previously used such tools in mathematics instruction. Finally, a post-hoc power analysis was conducted to evaluate whether the sample size of the current study provided adequate statistical power. In the analysis, the significance level was set at $\alpha = .05$ and the total sample size was 66. The post-hoc power analysis yielded a power value of $1\text{-}\beta = 0.99$ ($f = 0.592$) for the mathematics anxiety variable and $1\text{-}\beta = 0.99$ ($f = 0.667$) for the attitude toward mathematics variable. Since power values of .80 or above are generally considered acceptable (Pagano, 2012), these results indicate that the sample size was sufficient to detect the observed effects in the present study.

Data Collection Instruments

In mixed-method research, it is essential to utilize both quantitative and qualitative data collection tools in alignment with the research questions (Creswell & Plano Clark, 2018).

Quantitative Data

Mathematics Anxiety Scale for Elementary School Children*:* The Mathematics Anxiety Scale for Elementary School Children, developed by Mutlu and Söylemez (2018), measures mathematics anxiety levels of 3rd- and 4th-grade students. The scale consists of 13 items and uses a 3-point Likert format (agree, undecided, disagree). Its Cronbach's alpha reliability coefficient is .747. Five items are positive and eight are negative. Positive items are scored as 3-2-1, whereas negative items are scored as 1-2-3. Scores range from 13 to 39.

Attitude Toward Mathematics Scale: The Attitude Toward Mathematics Scale, developed by Yetgin and Yeşilyurt (2020) for elementary school students, is a 29-item, 4-point Likert-type instrument (Strongly Disagree, Disagree, Agree, Strongly Agree). The Cronbach's alpha reliability coefficient is .86. The scale consists of six factors: Avoidance, Positive Attitudes, Anxiety and Prejudice, System, Observation, and Experience. Scores range from 29 to 116.

Qualitative Data

In this study, qualitative data were collected to address the research questions and support the interpretation of quantitative findings by explaining the intervention outcomes. Qualitative data were obtained through focus group interviews. The researchers conducted focus group interviews using a semi-structured interview form to examine the experimental group students' perspectives on the use of gamified digital learning tools in mathematics teaching. Focus group interviews are a qualitative data collection technique used to gather information simultaneously from multiple participants (Onwuegbuzie et al., 2009). They are generally conducted with a small number of participants who share a common experience and enable different perspectives to emerge through group interaction (Krueger, 2000). Moreover, focus group interviews may help participants feel safe and comfortable when sharing their experiences and opinions (Vaughn et al., 1996). In the present study, this technique was preferred because the participants were young students who had shared the same experience of using gamified digital learning tools in mathematics lessons. Although individual interviews could have provided detailed accounts of students' personal experiences, the focus group format allowed students to recall, elaborate on, and compare different aspects of their shared experiences through interaction with their peers. This interaction contributed to the findings by eliciting diverse views regarding enjoyment, classroom participation, mathematics learning, anxiety, competition, and time pressure. However, participants in focus group interviews may be influenced by others' responses, and some participants may dominate the discussion. To minimize these limitations, each student was encouraged to respond individually, sufficient speaking time was provided to all participants, and different students were invited to respond first to different questions.

The semi-structured interview form was reviewed by an expert in mathematics education and revised based on feedback by removing two questions, modifying question wording, and adding one follow-up question. A pilot study was then conducted with two students from a class not included in the study, and one unclear question was revised for clarity. The interviews explored students' experiences with gamified digital learning tools, including the features they liked or disliked, difficulties encountered, classroom participation, perceived contribution to mathematics learning, and willingness to use such tools in the future.

Gamified digital learning tools

In this study, the gamified digital learning tools used were evaluated not as applications offering similar experiences on their own, but as complementary tools that meet the different pedagogical needs of mathematics teaching.

Matific is an intelligent digital learning platform that provides children with mathematics activities and game-based tasks. It was selected because it offers interactive activities that support conceptual understanding, includes real-life problems, and promotes student-centered, applied learning through multilingual access and teacher guides with pedagogical support. In addition, Matific enhances the gamified learning experience through features such as process-based assessment, instant feedback, adaptive learning, avatar personalization, achievements, and rewards. Figure 2 presents an example of a division activity in Matific. (https://www.matific.com).

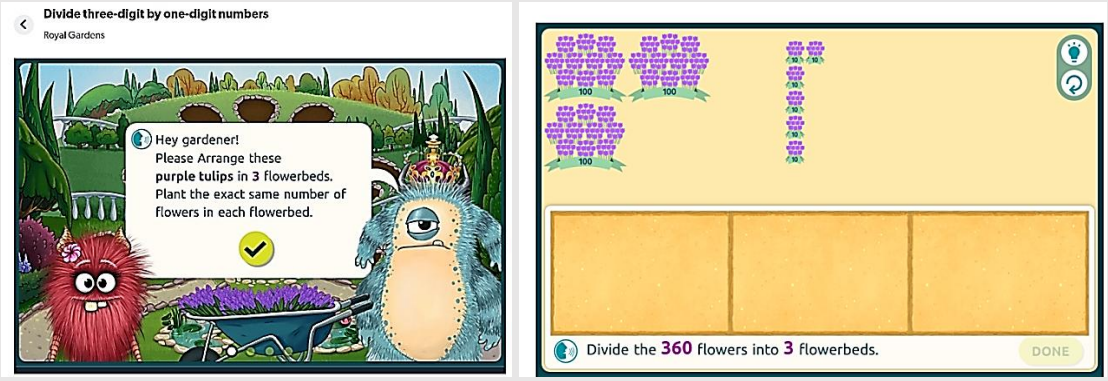

Figure 2. A game-based mathematics activity offered on the Matific platform

Wordwall is a versatile digital learning platform that enables the creation of both interactive and printable activities. It was included in this study because it allows teachers to transform lesson content into various formats, such as quizzes, matching, unboxing, and drag-and-drop tasks, while supporting fast, interactive practice and flexible adaptation to grade level. Its usability both inside and outside the classroom also supports practice, repetition, and reinforcement. Additionally, Wordwall offers gamified features such as leaderboards, time limits, and instant feedback, creating a learning environment that can enhance student participation and interest. Figure 3 presents a sample activity from Wordwall. (https://wordwall.net).

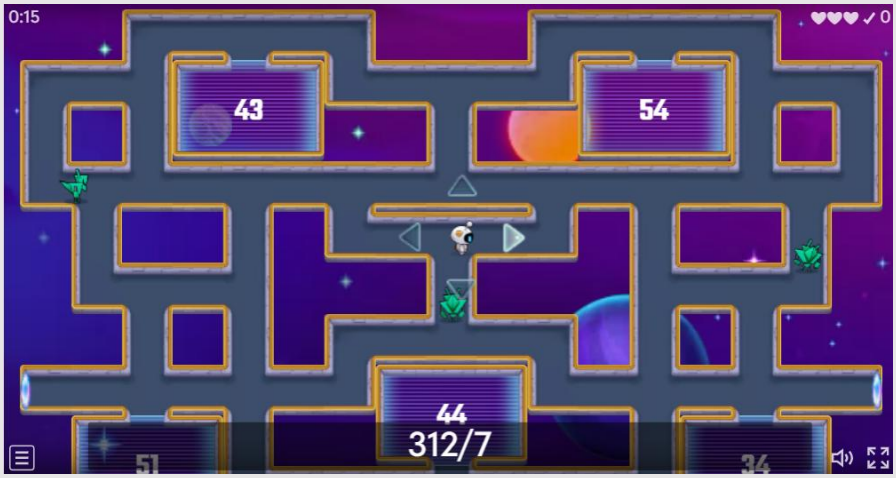

Figure 3. A game-based mathematics activity offered on the Wordwall platform

Kahoot! is a game-based digital learning platform in which students respond to questions simultaneously and which offers gamified features such as scoring, time limits, ranking, and instant feedback. The reasons for selecting this platform include its ability to create an interactive assessment environment in the classroom, support students' active participation in the lesson, and facilitate the review and reinforcement of learned content. In addition, its ability to enable teachers to quickly turn content into review and assessment activities makes Kahoot! a particularly functional tool in learning processes that require attention, speed, and immediate feedback. Figure 4 presents a sample activity from the Kahoot! platform (https://kahoot.it).



Figure 4. A game-based mathematics activity offered on the Kahoot! platform

The three tools used in this research are structured to complement each other pedagogically: Matific supports conceptual exploration and deeper learning, Wordwall provides individual reinforcement, repetition, and fluency practice, and Kahoot! facilitates group interaction and enjoyable assessment processes. This diversity aims to contribute to reducing mathematics anxiety and fostering more positive attitudes toward the subject by addressing students' different learning preferences. From the perspective of Flow Theory, the three tools were used to support different components of the flow experience within the learning environment. In Matific, progressively structured and adaptive activities that allowed students to advance according to their skill levels and individual learning pace helped maintain a balance between task difficulty and students' skills. Immediate feedback, hints, and opportunities to retry supported students in recognizing and correcting their mistakes while maintaining a sense of control over the learning process. In Wordwall, short and focused activities with clear goals enabled students to concentrate on specific mathematical tasks. Immediate corrective feedback and opportunities to retry also helped students monitor their responses and gradually improve their skills. Kahoot! was used for whole-class review and formative assessment activities. Clearly structured questions, immediate feedback, scoring, and visible progress supported students' active engagement in the activities. Thus, the fundamental components of Flow Theory, including challenge–skill balance, clear goals, immediate feedback, sense of control, concentration, and a sense of progress, were reflected in the mathematics learning environment through the different and complementary features of the three tools.

Data Collection and Implementation Process

The experimental process lasted eight weeks, while the total implementation period was 14 weeks, including the introduction, information gathering, permissions, teacher training, introduction of the gamified digital learning tools to students, administration of the pre- and post-tests, and interviews. The researchers informed students in the pre-selected classes about the purpose of the study, its voluntary nature, and their right to withdraw at any time, and obtained their consent. Permission forms were also collected from parents.

The first week involved an information session. In the second week, pre-tests were administered to both the experimental and control groups, and the procedure for completing the scales was explained separately to each group. Administration of the scales took approximately one class hour (40 minutes). In the third and fourth weeks, the experimental group teacher received eight hours of training on the classroom use of Matific, Kahoot!, and WordWall. The training covered registration, interface use, activity creation or adaptation, sending activities to students, and using the tools via the interactive whiteboard. In the experimental group, the classroom teacher also provided basic guidance to help students complete the assigned tasks individually on computers. The teacher and students in the control group did not receive similar training. The

researchers then collaborated with the teacher to prepare lesson plans for the eight-week intervention, covering two class hours per week for a total of sixteen hours. Weekly lesson plans were prepared according to the targeted learning outcomes, and games appropriate to these outcomes were included. To ensure implementation consistency, all lessons followed the pre-prepared plans, reducing potential teacher-related variation within the natural classroom setting. The use, sequence, and duration of Matific, Kahoot!, and Wordwall were determined in advance according to the targeted learning outcomes, instructional flow, and pedagogical purposes, including conceptual exploration, practice, reinforcement, and formative assessment. All students in the experimental group participated in the same core implementation process.

The intervention was integrated into the regular fourth-grade mathematics curriculum. The learning outcomes scheduled for the implementation period focused on division with natural numbers and mathematical equality, including performing division procedures, mental division, estimating division results, recognizing the relationship between multiplication and division, solving problems involving division, determining missing values, and establishing equality between mathematical expressions. Matific was used to explore mathematical concepts, recognize relationships, and engage in progressively structured problem-solving. Wordwall was used to apply and reinforce acquired knowledge and strategies and develop computational fluency, whereas Kahoot! was used to assess learning, discuss students' responses as a class, and identify errors. For example, in teaching mental division by 10, 100, and 1,000, students first explored the pattern between the dividend and quotient. Matific activities were then used to support conceptual understanding and strategy development, while Wordwall activities allowed students to apply and reinforce these strategies with different numbers. Progressively sequenced tasks, immediate feedback, hints, and opportunities to retry enabled students to correct their errors during the learning process and perceive mathematical tasks as achievable. Making progress visible through points, achievement indicators, and completed tasks was intended to increase participation, reduce mathematics anxiety, and foster more positive attitudes toward mathematics.

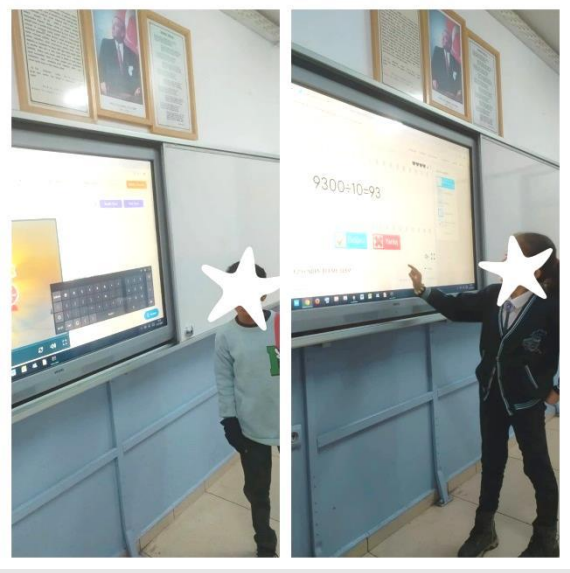

Figure 5. Implementation with Experimental Group Students

Figure 5 was taken in the classroom as an example of the experimental process. During the experimental process, care was taken to ensure that lessons were conducted according to the lesson plans jointly prepared by the teacher and the researchers during teacher training and that all students participated in the process. There were no significant problems with student absenteeism, and students generally attended school regularly on intervention days. To support implementation within the planned framework, the researchers maintained regular communication with the teacher throughout the intervention. The implementation of the weekly lesson plans, the use of digital tools for the intended mathematical purposes, student participation, and any technical or instructional needs were reviewed through regular discussions with the teacher. The difficulties reported by the teacher mainly concerned temporary internet connection problems, access to some activities, and differences in students' task-completion pace. When difficulties were reported, the researchers provided guidance on tool use and suggested alternative tasks aligned with the same learning outcomes. These adjustments did not alter the duration, targeted learning outcomes, or basic structure of the intervention. Figure 6 presents the timeline of the experimental intervention process.

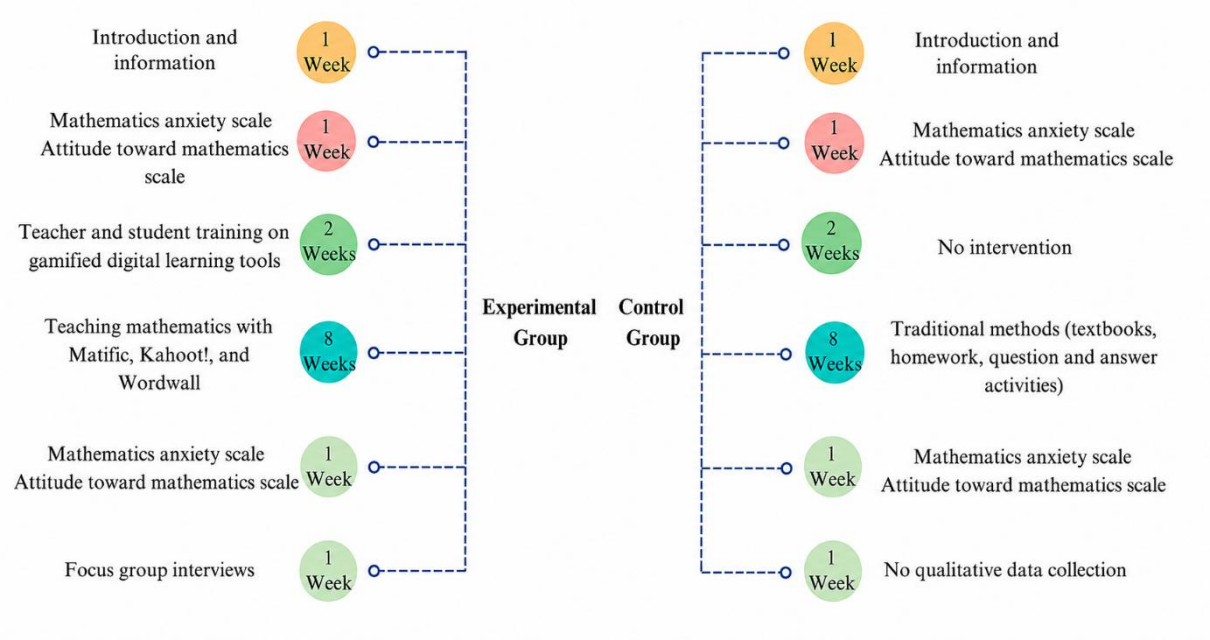

Figure 6. Implementation Process

As shown in Figure 6, existing teaching practices continued in the control group throughout the implementation process, and no digital tools were used. Mathematics lessons were conducted by the teacher based on the textbook and in line with the curriculum learning outcomes. The same learning outcomes addressed in the experimental group were covered in similar weeks and within the same lesson duration. Apart from teacher explanations, question-and-answer activities, and routine homework assignments, no additional interventions or supplementary materials were used. Thus, mathematics lessons in the control group mainly involved direct instruction and passive learning experiences, reflecting the usual classroom procedures followed before the research. In this respect, the main difference between the groups was that instruction in the experimental group was supported by gamified digital learning tools. After the eight-week intervention, the Mathematics Anxiety Scale for Elementary School Children and the Attitude Toward Mathematics

Scale were re-administered to students in both groups, and the data obtained constituted the post-test scores. Following the post-tests, focus group interviews were conducted only with students in the experimental group. The class was divided into three focus groups of eleven students, and separate interviews were conducted with each group in the school library. Due to the participants' age, each interview lasted one class hour (40 minutes). Audio recordings of the interviews constituted the primary qualitative data source. The researchers ensured that each student responded individually and was given sufficient time before moving to the next question, preventing any single participant from dominating the discussion and allowing different students to respond first to different questions.

Data Analysis

Quantitative Data Analyses

The quantitative data were analysed using SPSS. To examine whether the mathematics anxiety and attitude toward mathematics scores approximated a normal distribution, Shapiro-Wilk test results as well as skewness and kurtosis values were examined. Although the Shapiro-Wilk test yielded significant results, skewness and kurtosis values were within acceptable limits. Considering these values together with the sample size, parametric tests were considered appropriate**.**

Table 1. Shapiro-Wilk Test Results, Skewness, and Kurtosis Values for Mathematics Anxiety and Attitude toward Mathematics Scores

Scale	Test	Statistics	N	Skewness	Kurtosis	p
Math Anxiety	Pre-Test	.947	66	-.069	-.373	.007*
	Post-Test	.900	66	-.607	-.849	< .001*
Attitude toward	Pre-Test	.963	66	.817	1.115	.047*
Mathematics	Post-Test	.923	66	-.068	-.806	.001*

** p <.05*

According to Table 1, the Shapiro-Wilk test results for the mathematics anxiety pre-test (p = .007) and post-test (p < .001) scores were significant, indicating deviations from normality. The skewness and kurtosis values of the mathematics anxiety pre-test and post-test scores were examined. However, the skewness (-.069 and -.607) and kurtosis (-.373 and -.849) values were within the acceptable range of -1.5 to +1.5 (Tabachnick & Fidell, 2013). Therefore, the distribution was considered sufficiently close to normal for the use of parametric tests. Similarly, the Shapiro-Wilk test results for the attitude toward mathematics pre-test (p = .047) and post-test (p = .001) scores were significant, also indicating deviations from normality. The skewness and kurtosis values of the mathematics attitude pre-test and post-test scores were examined. The skewness (.817 and -.068) and kurtosis (1.115 and -.806) values were also within the acceptable range of -1.5 to +1.5. Therefore, despite the significant Shapiro-Wilk results, the attitude toward mathematics scores were considered sufficiently close to normal distribution for parametric analyses.

An Independent Sample T-Test was used to determine whether there was a significant difference between the groups. In addition, analysis of covariance (ANCOVA) was conducted to compare the post-test scores of the groups while controlling for their pre-test scores. Separate ANCOVA models were used for mathematics anxiety and attitude toward mathematics. Before conducting the ANCOVA, its assumptions were examined (Çokluk et al., 2010) including

normality, homogeneity of variances, homogeneity of regression slopes, and the linear relationship between the covariate and the dependent variable.

Before conducting the ANCOVA, the Levene's Test was used to test the homogeneity of the groups. The Levene's test indicated that the assumption of homogeneity of variances was satisfied for both attitude toward mathematics, $F(1, 64) = .528$, $p > .05$, and mathematics anxiety, $F(1, 64) = 1.136$, $p > .05$. The homogeneity of regression slopes assumption was also tested. The interaction between group and pre-test scores was not statistically significant for mathematics anxiety, $F(1, 62) = 1.287$, $p = .26$, or for attitude toward mathematics, $F(1, 62) = .002$, $p = .96$. Therefore, the assumption of homogeneity of regression slopes was satisfied. In addition, a linear relationship was found between the dependent variable and the covariate for each group.

Qualitative Data Analyses

In focus group interviews, units of analysis may include individual data, group data, and/or group interaction data (Onwuegbuzie et al., 2009). Since the researchers did not aim to compare the focus groups, this study focused on individual data. Qualitative data were analyzed using the thematic analysis approach based on Creswell and Creswell's (2018) qualitative data analysis cycle. Audio recordings from the focus group interviews were transcribed and prepared for analysis. The dataset was read repeatedly to ensure familiarity, and significant sections in participants' statements were identified and coded inductively. During coding, two researchers independently examined the dataset and generated initial codes. These codes were then compared in terms of similarities and differences to develop candidate themes. The researchers discussed the codes and themes, resolved differences through consensus, and refined the thematic structure by merging overlapping themes and eliminating insufficiently supported ones. The findings are presented in line with the final themes and supported by direct participant statements.

Findings

Quantitative Findings

Findings Related to Mathematics Anxiety

Table 2 presents the comparison of the mathematics anxiety pre-test scores of the experimental and control groups.

Table 2. T-Test Results for Mathematics Anxiety Pre-Test Scores by Group

Group	*N*	$\bar{X}$	S	df	*t*	*p*
Experimental	33	26.33	1.96	64	.132	.895
Control	33	26.27	1.75			

** p <.05*

According to Table 2, there was no statistically significant difference between the mathematics anxiety pre-test scores of the experimental and control groups, $t(64) = 0.132$, $p = .895$. The mean scores of the experimental group ($\bar{X} = 26.33$) and the control group ($\bar{X} = 26.27$) were very close to each other. These findings indicate that the groups were comparable in terms of mathematics anxiety before the experimental procedure. The results of the ANCOVA for the adjusted mathematics anxiety post-test scores based on the pre-test scores are presented in Table 3.

Table 3. ANCOVA Results for Adjusted Mathematics Anxiety Post-Test Scores by Group

Source	Sum of Squares	df	Mean Square	*F*	*p*	η^2
Pre-test	28.692	1	28.692	5.567	.021*	.081
Group	113.912	1	113.912	22.102	< .001*	.260
Error	324.702	63	5.154			
Total	42016.000	66				
Adjusted (Estimated Marginal) Means						
Group			Adjusted Mean	SE	95% CI	
Experimental			23.777	0.395	22.987–24.567	
Control			26.405	0.395	25.615–27.195	

* $p < .05$

Table 3 presents the ANCOVA results for the adjusted mathematics anxiety post-test scores. After controlling for pre-test scores, there was a statistically significant difference between the experimental and control groups in terms of mathematics anxiety post-test scores, $F(1, 63) = 22.102$, $p < .001$, $\eta^2 = .260$. The post-test mean of the experimental group ($\bar{X} = 23.78$) was lower than that of the control group ($\bar{X} = 26.39$). Similarly, the adjusted (estimated marginal) mean of the experimental group ($M = 23.777$, $SE = 0.395$) was lower than that of the control group ($M = 26.405$, $SE = 0.395$). These adjusted means indicate that the difference between the groups remained statistically meaningful after controlling for pre-test mathematics anxiety scores. The effect size of the experimental procedure on mathematics anxiety is $\eta^2 = .260$, which is high. An eta-square value of $\eta^2 = 0.14$ or higher indicates a large effect size (Cohen, 1988). This finding indicates that 26% of the variance in post-test mathematics anxiety scores was associated with group membership after controlling for pre-test scores. In other words, the use of gamified digital learning tools had a significant effect on reducing mathematics anxiety.

Findings Related to Attitudes Towards Mathematics

Table 4 presents the comparison of the pre-test scores for attitudes towards mathematics in the experimental and control groups.

Table 4. T-Test Results for Pre-Test Scores for Attitudes Towards Mathematics by Group

Group	N	$\bar{X}$	S	df	*t*	*p*
Experimental	33	57.66	6.14	64	.492	.624
Control	33	56.60	10.7			

* $p < .05$

According to Table 4, there was no statistically significant difference between the experimental and control groups in terms of their pre-test scores for attitudes towards mathematics, $t(64) = 0.492$, $p = .624$. The mean scores of the experimental group ($\bar{X} = 57.66$) and the control group ($\bar{X} = 56.60$) were close to each other. These findings indicate that the groups were comparable in terms of attitudes towards mathematics before the experimental procedure. The results of the ANCOVA for the adjusted post-test scores for attitudes towards mathematics based on the pre-test scores are presented in Table 5.

Table 5. ANCOVA Results for Adjusted Attitudes Towards Mathematics Post-Test Scores by Group

Source	Sum of Squares	df	Mean Square	*F*	*p*	η^2
Pre-test	189.956	1	189.956	4.147	.046*	.062
Group	1286.023	1	1286.023	28.093	< .001*	.308
Error	2883.962	63	45.777			
Total	207601.000	66				

Adjusted (Estimated Marginal) Means			
Group	Adjusted Mean	SE	95% CI
Experimental	59.923	1.179	57.567–62.278
Control	51.077	1.179	48.722–53.433

** $p < .05$*

Table 5 presents the ANCOVA results for the adjusted post-test scores for attitudes towards mathematics. After controlling for pre-test scores, there was a statistically significant difference between the experimental and control groups in terms of post-test scores for attitudes towards mathematics, $F(1, 63) = 28.093$, $p < .001$, $\eta^2 = .308$. The post-test mean scores for mathematical attitude in the experimental group ($\bar{X}$ = 59.81) are higher than those in the control group ($\bar{X}$ = 51.18). Similarly, the adjusted (estimated marginal) mean of the experimental group (M = 59.923, SE = 1.179) was higher than that of the control group (M = 51.077, SE = 1.179). These adjusted means indicate that the difference between the groups remained statistically meaningful after controlling for pre-test attitudes toward mathematics scores. The effect size was large ($\eta^2 = .308$). This finding indicates that approximately 30% of the variance in post-test scores for attitudes towards mathematics was associated with group membership after controlling for pre-test scores. In other words, the use of gamified digital learning tools had a significant effect on improving students' attitudes towards mathematics.

Qualitative Findings

Students' Experiences with Gamified Digital Learning Tools

The quantitative findings of the study revealed that gamified digital learning tools had a significant effect on reducing mathematics anxiety and improving positive attitudes toward mathematics among primary school students. Students' views on their experience of mathematics instruction using gamified digital learning tools shed light on the reasons for this effect of the experimental intervention. The experiences of primary school students in the experimental group regarding mathematics instruction with gamified digital learning tools are presented in Figure 7.

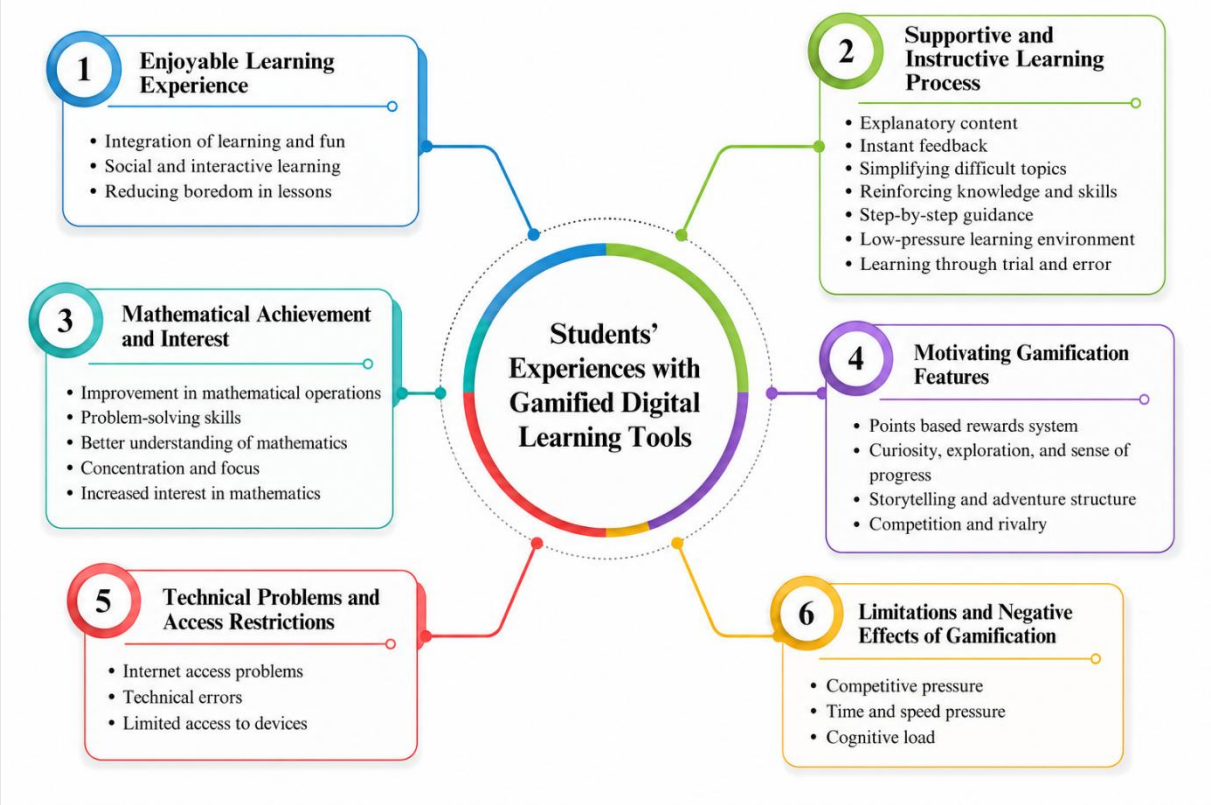

Figure 7. *Thematic map of students' experiences with gamified digital learning tools*

As shown in Figure 7, the positive effects of gamified digital learning tools on primary school students were associated with enjoyable learning experience, supportive and instructive learning process, mathematical achievement and interest, and motivating gamification features. These positive aspects also indicate that students developed a willingness to use these tools regularly in mathematics lessons. However, student views also revealed technical problems and access restrictions, as well as limitations and negative effects of gamification. Within the theme of enjoyable learning experience, students stated that these tools combined integration of learning and fun, social and interactive learning, and reducing boredom in lessons. Playing with friends, active participation, and enjoyable learning were particularly prominent. For example, Participant 3 emphasized both social and interactive learning and the more enjoyable nature of the lesson by stating, *"We had a lot of fun, and the lesson was not boring. Playing together with our friends made it more enjoyable."* These experiences of enjoyment, reduced boredom, and active participation represent affective and behavioral indicators of a more positive attitude toward mathematics.

Within supportive and instructive learning process, students emphasized that these tools supported mathematics learning through explanatory content, instant feedback, simplifying difficult topics, reinforcing knowledge and skills, step-by-step guidance, low-pressure learning environment, and learning through trial and error. Some students stated that being able to try again without pressure made learning more comfortable. For example, Participant 6 emphasized both instant feedback and the opportunity to try again without pressure by stating, *"When I make a mistake, it does not get angry; it gives a hint or I lose points. Then I understand where I made a*

mistake." Participant 15, on the other hand, drew attention to both step-by-step guidance and the reinforcement of knowledge and skills by stating, *"I really liked the way it solved the questions by explaining them. We learned some difficult questions and practiced them."* Receiving immediate feedback and being able to retry without negative reactions reflected a less threatening learning experience and helped explain the quantitative reduction in mathematics anxiety.

Within mathematical achievement and interest, students reported improvements in mathematical operations, problem-solving skills, better understanding of mathematics, concentration and focus, and increased interest in mathematics. Students felt not only more engaged but also more capable in mathematics. For example, Participant 8 drew attention to improvement in mathematical operations and increased speed by stating, *"It makes us solve the questions quickly. I used to be unable to do division, and I was slow. Now, after playing these, I have started to do mathematics more quickly."* Participant 21, on the other hand, reflected increased attention, a sense of achievement, and greater interest together by stating, *"Thanks to these, I became better at mathematics, I started to like mathematics more... I liked the problems."* Students' increased interest, enjoyment of mathematical problems, and perceived competence reflected a more positive attitude toward mathematics.

Within motivating gamification features, students highlighted the points based rewards system, curiosity, exploration, and sense of progress, storytelling and adventure structure, and competition and rivalry. These gamification elements increased students' willingness to engage with mathematics. For example, Participant 1 reflected both the points and reward system and the competition dimension by stating, *"Finding treasure and earning gold was very enjoyable. We were competing, and we were coming first. Thanks to these games, I started to like mathematics more."* Similarly, Participant 12 emphasized ranking and competition with the statement, *"I felt very happy when my name appeared at the top of the board, and competing was very exciting."* Participant 30, on the other hand, reflected the desire for progress and collecting rewards by stating, *"When I answered the question correctly, my monsters improved. I think collecting those points makes you want to solve more questions."*

Within technical problems and access restrictions, student views were mainly centered on internet access problems, technical errors, and limited access to devices. For example, Participant 9 drew attention to both technical errors and internet access problems by stating, *"Some pictures would not open. Also, sometimes we could not access the site, and we had problems when there was no internet."* Some students also stated that they could not always access the necessary devices at home. Within limitations and negative effects of gamification, some students reported competitive pressure, time and speed pressure, and cognitive load. For example, Participant 14 reflected both time pressure and the feeling of inadequacy created by this pressure by stating, "*I am just finishing reading the question, and right when I am about to click, it says time is up. Then I feel bad, as if I cannot do it."* Similarly, Participant 27 showed that time and speed pressure could increase cognitive load by stating, *"Sometimes I get stressed while playing the game because my score might go down."* These statements indicate that time pressure and competitive scoring were associated with stress and feelings of inadequacy among some students, despite the overall reduction in mathematics anxiety.

Taken together, the qualitative findings help explain the significant reduction in mathematics anxiety and improvement in attitudes toward mathematics identified in the quantitative analyses. Enjoyment, active participation, perceived mathematical competence, immediate feedback, and opportunities to retry were consistent with more positive attitudes and a less threatening mathematics learning experience. However, time pressure, competitive stress, and technical difficulties showed that the intervention was not experienced positively by all students. Thus, the qualitative findings both supported and qualified the quantitative results.

Discussion and Conclusion

This study found that the teacher-mediated integration of Matific, Kahoot!, and Wordwall into fourth-grade mathematics instruction was associated with significantly lower mathematics anxiety and more positive attitudes toward mathematics after controlling for pre-test scores, thereby supporting both H1 and H2. The embedded qualitative findings extend these quantitative results by revealing the student experiences through which these changes may have occurred. Students' accounts suggest that enjoyment, active participation, instant feedback, opportunities to retry, step-by-step guidance, and a visible sense of progress made mathematical tasks appear more manageable and strengthened their interest and sense of competence. From the perspective of Flow Theory (Csikszentmihalyi, 1990), clear goals, immediate feedback, engaging activities, and opportunities to observe progress may have encouraged students to participate more willingly and experience mathematics more positively. At the same time, reports of time pressure, competitive stress, and cognitive load indicate that these benefits were not experienced uniformly and depended on how particular gamification features interacted with students' needs. Accordingly, the findings should not be interpreted as evidence of the isolated effects of the digital tools themselves, but as outcomes of a teacher-guided instructional process shaped by pedagogical integration, tool design, and individual student experiences. The possible effects of novelty, increased attention, and interest in technology should also be considered, and the findings should be evaluated within the limitations of the study.

Mathematics Anxiety and Gamified Digital Learning Tools

According to the findings of the current study, gamified digital learning tools were associated with a decrease in mathematics anxiety among primary school students in the experimental group. This suggests that interactive and gamified digital learning environments may support students' emotional experiences related to mathematics. This finding is consistent with studies showing that technology-supported mathematics instruction may reduce mathematics anxiety at the primary school level (Atoyebi & Atoyebi, 2022; Elma et al., 2024), as well as research indicating that gamified digital learning tools can reduce mathematics anxiety and support positive emotional engagement (McKevitt et al., 2025; Jukić Matić et al., 2026). However, the current study differs by examining multiple gamified digital learning tools together and explaining quantitative findings through embedded qualitative data.

The literature emphasizes a strong relationship between mathematics anxiety and mathematics achievement, suggesting that increased anxiety may lead students to avoid mathematics and hinder skill development (Balt et al., 2022). In the present study, reduced mathematics anxiety appears to be associated with both a more supportive learning environment and students' growing sense of mathematical competence. Students reported improvements in mathematical operations, problem-solving, and confidence in mathematics, suggesting that the intervention may have disrupted the negative cycle in which avoidance leads to lower performance

and increased anxiety (Ramirez et al., 2018). Although mathematical performance was not directly measured, these perceptions align with studies showing that gamified digital learning tools can support mathematical skills (Ester et al., 2025; Kocabatmaz & Saraçoğlu, 2024; Rahim et al., 2025). Compared with the control group, students in the experimental group showed a greater decrease in mathematics anxiety, suggesting that traditional classroom practices may be less effective in reducing anxiety (Cengiz, 2017; Elma et al., 2024). Qualitative findings further support this interpretation, as students emphasized learning through fun, active participation, instant feedback, retry opportunities, and social interaction, all of which may create a less stressful and more supportive learning environment (Camacho-Sánchez et al., 2022; Rahim et al., 2025; Li & Jianxing, 2025). More specifically, immediate feedback and step-by-step guidance may have reduced uncertainty by helping students identify and correct their mistakes during the learning process. Opportunities to retry without pressure may also have encouraged students to view mistakes as part of learning rather than as evidence of mathematical failure. In this sense, the intervention may have reduced mathematics anxiety by enabling students to experience greater support and control when encountering difficult mathematical tasks.

However, qualitative findings also showed that gamified digital learning tools did not affect all students in the same way. Competitive pressure, time and speed pressure, and cognitive load negatively affected some students. The coexistence of an overall reduction in mathematics anxiety with these negative experiences suggests that different gamification features may have operated in opposite directions. While immediate feedback, retry opportunities, and a visible sense of progress may have reduced anxiety for many students, time limits, rankings, and competitive scoring appear to have created stress for some. Thus, the affective consequences of gamification may depend less on the mere presence of game elements than on the particular elements employed and their compatibility with individual students' needs. Previous studies similarly indicate that poorly designed gamified systems, especially those overly dependent on external rewards or excessive competition, may increase anxiety, stress, burnout, and reduced autonomy (Gini et al., 2025; Kwon & Özpolat, 2020; Liu, 2023; Ratinho et al., 2026). The qualitative findings also showed that internet connectivity problems, technical errors, and limited access to devices disrupted some students' experiences. This suggests that the anxiety-reducing potential of gamified digital learning tools depends not only on pedagogical design but also on reliable technical infrastructure and equitable access to technology. Therefore, the anxiety-reducing potential of gamified digital learning tools depends on careful pedagogical design and balanced competition. From the perspective of Flow Theory (Csikszentmihalyi, 1990), clear goals, immediate feedback, and opportunities to observe progress may have made mathematical tasks more manageable and supported students' willingness to participate. Conversely, students' reports of time pressure and cognitive load suggest that this experience may have been disrupted when task demands exceeded their perceived competence or when they lacked sufficient time to respond. Accordingly, reducing mathematics anxiety through gamified learning requires an appropriate balance among task difficulty, students' competence, and the conditions under which they participate.

Attitudes toward Mathematics and Gamified Digital Learning Tools

According to the findings of the current study, gamified digital learning tools (Matific, Kahoot!, and Wordwall) were associated with improved attitudes toward mathematics among ten-year-old fourth-grade primary school students in the experimental group. This suggests that technology-supported applications may contribute to more positive attitudes toward mathematics by increasing students' interest in learning. This finding is consistent with previous research showing that technology-supported mathematics instruction may improve attitudes toward

mathematics at the primary school level (Gökdeniz Tahiroğlu & Özcan, 2025). However, the current study differs from related studies by examining multiple gamified digital learning tools together and explaining quantitative findings through embedded qualitative data.

This result is also consistent with studies showing that gamified digital learning tools positively influence attitudes toward mathematics. Kocabatmaz and Saraçoğlu (2024) found that Wordwall and Matific improved mathematics achievement and attitudes among third-grade students, while Yıldız et al. (2024) reported that digital gamification-supported mathematics instruction improved attitudes, increased lesson enjoyment, and reduced prejudice toward mathematics among gifted seventh-grade students. Taken together, these findings suggest that gamification can positively influence participation, learning outcomes, and attitudes toward mathematics. Embedded qualitative findings in the present study similarly showed that students experienced mathematics lessons as more enjoyable, engaging, and participatory. These experiences help explain the quantitative improvement in attitudes by indicating that the intervention may have changed not only how students participated in mathematics lessons but also how they perceived and emotionally experienced mathematics. In particular, students' descriptions of mathematics as more enjoyable and interesting suggest an increased willingness to participate in mathematical activities. From the multidimensional perspective of attitude, students' enjoyment, reduced boredom, and increased willingness to participate represent affective and behavioral indicators of a more positive attitude toward mathematics (Dubé & Wen, 2021).

Student views indicated that not only lesson content but also motivating gamification features contributed to positive attitudes toward mathematics. Curiosity, discovery, sense of progress, and story-based task structures increased students' willingness to engage in mathematical activities. Points, rewards, levels, and other indicators of progress may have made students' improvement more visible and provided concrete experiences of achievement. Experiencing progress in this way may have strengthened their perceived mathematical competence, while curiosity and story-based tasks may have sustained their interest and willingness to participate. Although motivation was not directly examined, qualitative findings suggest that motivational factors played an important role in attitude development. Students reported becoming faster in mathematical operations, understanding difficult topics more easily, solving problems better, and becoming more interested in mathematics. These perceptions of academic growth and increased interest may have contributed to more positive attitudes toward mathematics. Accordingly, the improvement in attitudes may reflect the combined influence of enjoyment, increased interest, active participation, and perceived mathematical competence rather than enjoyment alone. This interpretation is consistent with studies showing that gamified learning tools support learning behaviors, academic achievement, and motivation (Kocabatmaz & Saraçoğlu, 2024; Li & Jianxing, 2025; Ratinho et al., 2026).

Another important finding was that students in the control group did not show the same level of improvement in attitudes toward mathematics as those in the experimental group. Traditional methods based mainly on textbooks and homework may provide more limited support for developing positive attitudes. This is consistent with studies showing that digital games have more positive effects on attitudes toward mathematics than traditional problem-solving methods and that traditional methods are often insufficient in this respect (Mavridis et al., 2017; Gökdeniz Tahiroğlu & Özcan, 2025). When considered together with the qualitative findings, this difference suggests that the improvement in attitudes may be associated with the opportunities for active participation, exploration, immediate feedback, and visible progress provided by the teacher-guided use of digital tools. These opportunities were less prominent in the textbook- and

homework-based instruction implemented in the control group. Therefore, the difference between the groups should be interpreted as an outcome of the broader instructional experiences created around the tools rather than as the isolated effect of the digital applications.

The findings can also be interpreted through Flow Theory (Csikszentmihalyi, 1990). The curiosity-evoking structure of the activities, clear goals, immediate feedback, and opportunities to observe progress may have helped students sustain their engagement and experience mathematical activities more positively. Students' accounts of enjoyment, active participation, achievement, and willingness to continue using the tools provide empirical support for this interpretation. From this perspective, improved attitudes toward mathematics may have emerged as students became more deeply involved in mathematical activities, experienced visible progress, and perceived themselves as more capable of completing mathematical tasks.

Recommendations

The results of this research suggest that gamified digital learning tools may contribute to lower mathematics anxiety and more positive attitudes toward mathematics among primary school students. Accordingly, these tools can be integrated into mathematics teaching, particularly to support students' affective characteristics related to mathematics. However, the findings should be interpreted in light of several limitations. Because the study was conducted with fourth-grade students within a specific educational context and over an eight-week intervention period, its findings may not be generalizable to other age groups, educational levels, or longer-term implementations. Future studies could examine the sustainability of these effects using longer interventions and follow-up measurements with students from different educational and socioeconomic contexts. In addition, different teachers taught the experimental and control groups. Although the teachers had similar levels of professional experience, differences in their instructional styles, classroom interactions, and technology-use competencies may have contributed to the observed outcomes. Future studies could control teacher-related effects more closely and examine how teachers' pedagogical integration of gamified digital tools shapes students' mathematics anxiety and attitudes.

Since time pressure created by such tools may increase cognitive load and cause pressure, anxiety, or distraction for some students, comprehensive in-service training should be provided for teachers to ensure effective use. These programs should help teachers use technology not only as instructional material but also as a tool to increase participation and reduce mathematics anxiety, while providing concrete examples of adaptation for different student profiles. In addition, financial support may be provided to enable teachers to access various tools free of charge, and free online platforms and resources compatible with these tools could be developed. Strengthening digital infrastructure, including smart boards and reliable internet access, is also critical, and teachers should be encouraged to actively use these resources.

Ethics

The ethics application for the study was made on 23/01/2025, and the research was carried out with the approval of the Van Yuzuncu Yil University Social and Humanities Research Ethics Committee dated 23/01/2025 and numbered 2025/02-37

CRediT authorship contribution statement

Each author's contribution must be detailed according to the CRediT taxonomy and will be transparently displayed in the published article.

Declaration of Generative AI and AI-assisted Technologies Usage

Authors must disclose whether generative AI or AI-assisted technologies were used at any stage of the research process, including but not limited to conceptualization, data analysis, visualization, or writing. If used, the nature and extent of the AI assistance must be clearly described. Authors are fully responsible for the accuracy, originality, and integrity of the submitted work.

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