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Research Article

Design and Implementation of an Audio-Guided Digital Game to Support Addition Skills in Preschool Mathematics Education

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Abstract

This design-based implementation study examined an audio-guided digital game developed to support preschool children's addition skills through object-supported tasks. The study was conducted with 15 children aged 4 to 5 years in one public preschool classroom in Ankara, Türkiye. Participants were selected through criterion sampling from an intact classroom; the criteria were being enrolled in preschool, being in the 4- to 5-year-old age range, not yet having conventional reading and writing skills, having written parental consent, and voluntarily participating in the activity. The game was designed according to Keller's Attention, Relevance, Confidence, and Satisfaction (ARCS) Motivation Model and Mayer's Cognitive Theory of Multimedia Learning. Because the target group had not yet developed conventional literacy skills, written task instructions were used only as teacher-orientation cues and were functionally replaced with Turkish audio guidance, concrete object representations, color-based signals, and immediate feedback. Data were collected through a five-point object-supported addition pre-test and post-test, a three-item smiley-face usability form for children, and an expert evaluation form completed by three specialists. Expert feedback informed concrete prototype revisions, including refinements to audio timing and non-punitive feedback cues. Descriptive findings indicated that the class mean increased from 4.07 to 4.87 out of 5 after the implementation, while the total performance percentage increased from 81.33% to 97.33%. Thirteen of the 15 children reached full performance in the post-test. Children evaluated the game as easy to use, visually attractive, and worth replaying. Expert ratings were also positive, particularly for pedagogical appropriateness and usability. The findings should be interpreted as preliminary because the study used a single-group pre-test-post-test design, involved a small sample, and did not include a comparison group or delayed retention measure.

Keywords: Digital game-based learning, preschool mathematics education, audio-guided digital game, object-supported addition, ARCS motivation model, multimedia learning.

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INTRODUCTION

Preschool mathematics education is a foundational context for the development of mathematical awareness, numerical reasoning, language, self-regulation, and socio-emotional dispositions toward learning (Clements & Sarama, 2009, 2011; Duncan et al., 2007; Ministry of National Education, 2024). In this study, mathematical awareness is used operationally to refer to children's ability to notice quantities, compare sets, construct one-to-one correspondence, detect patterns, reason about part-whole relations, and connect mathematical ideas to concrete objects and everyday situations. Object-supported addition is used operationally to refer to combining two visible object sets, counting the resulting total, and selecting the corresponding number. This emphasis is consistent with preschool mathematics work that treats early numerical learning as situated, embodied, and developmentally appropriate rather than as early formal instruction (Clements & Sarama, 2009; Karakuş, 2020).

The importance of early mathematics has been repeatedly emphasized in developmental and educational research. Longitudinal evidence indicates that mathematics skills at school entry are among the strongest predictors of later academic achievement (Duncan et al., 2007). Clements and Sarama (2009, 2011) similarly argue that early mathematical experiences shape children's later competence because they support learning trajectories from informal quantitative reasoning to more formal mathematical thinking. These findings are especially relevant for preschool classrooms, where children's first systematic encounters with number, operation, pattern, and spatial concepts occur through play, conversation, manipulation of objects, and guided activities.

Digital game-based learning has become a significant instructional approach in preschool mathematics because it can combine concrete representations, feedback, repetition, challenge, and engagement in a single environment. When designed with pedagogical constraints in mind, digital games can reduce the affective cost of error, provide immediate feedback, and allow children to progress at an individually manageable pace (Al-Hassan et al., 2025; Papadakis et al., 2021). In mathematics education, digital game-based learning has attracted increasing scholarly attention, with bibliometric and thematic reviews pointing to its potential for supporting achievement, motivation, and attitudes (Poçan, 2023; Yıldız et al., 2024). In preschool contexts, this potential is particularly strong when mathematical tasks are based on concrete objects, oral prompts, and multimodal cues rather than written symbolic explanations (Flores et al., 2022).

Recent literature further supports this rationale while also indicating the need for careful design and evaluation. A systematic review and meta-analysis reported that game-based learning in early childhood education can support cognitive development, motivation, and engagement when games are aligned with developmental needs (Alotaibi, 2024). A recent systematic review focused specifically on early mathematics concluded that math games may support young children's learning, but that outcomes depend on game design features, dosage, content focus, and the context of use (DePascale & Ramani, 2025). In Türkiye, review and empirical studies have similarly emphasized the increasing use of digital games in mathematics education while noting that many studies focus on older learners or use ready-made games rather than preschool-specific instructional prototypes (Aydın & Ata, 2024; Karabekmez & Yıldız, 2017; Kendüzler, 2023; Poçan, 2023; Yıldız et al., 2024).

Despite this potential, preschool digital game design raises substantial pedagogical and ethical challenges. Young children have limited attention spans, emergent executive functions, and little or no ability to process written instructions independently (Clements & Sarama, 2009; Mayer, 2001). Therefore, digital materials designed for this group cannot simply reproduce worksheets on a screen. They must provide developmentally appropriate interaction, short task segments, familiar objects, audio instructions, clear navigation, non-punitive feedback, and visual signals that support attention without overloading working memory. In the context of the addition operation, children need to see, count, and coordinate concrete sets before they are expected to reason symbolically about equations.

Accordingly, the present study responds to a specific gap: the need for a purpose-built, audio-guided, object-supported addition game for children who are not yet independent readers. In this study, an audio-guided digital game means a browser-based game in which the primary instructional prompts are delivered orally in Turkish and can be replayed by the child. Rather than treating the digital game as a generic motivational add-on, the study examines how audio prompts, concrete objects, segmented tasks, and supportive feedback can be combined into a preschool-appropriate mathematics reinforcement environment.

The present study addresses this design need by developing and applying a Turkish audio-guided digital game for 4- to 5-year-old preschool children. The game, titled “Küçük Dahi” in the prototype interface, was designed to support object-supported addition as a component of early mathematical skills. It uses familiar objects such as apples, stars, balloons, and butterflies; structures tasks across progressive levels; and integrates immediate verbal and visual feedback. The design was informed by Keller's Attention, Relevance, Confidence, and Satisfaction (ARCS) Motivation Model (Keller, 1987, 2010) and Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2001).

The main aim of this study was to design, implement, and preliminarily evaluate an audio-guided digital game developed to support preschool children's addition skills through object-supported tasks. The study was framed as a classroom-based design and implementation inquiry rather than a controlled efficacy trial. Within this aim, the following sub-problems guided the study:

1. How did children's object-supported addition performance change after the digital game implementation?

2. How did children evaluate the usability, visual appeal, and replay value of the game?

3. How did experts evaluate the game in terms of pedagogical appropriateness, visual design, navigation, and classroom usability?

4. How were ARCS motivation components and multimedia learning principles translated into concrete design decisions for preschool children?

5. What preliminary error patterns were observed during children's interaction with object-supported addition tasks?

THEORETICAL FRAMEWORK

The theoretical design of the digital game was based on two complementary perspectives: Keller's Attention, Relevance, Confidence, and Satisfaction (ARCS) Motivation Model and Mayer's Cognitive Theory of Multimedia Learning. ARCS was used to structure motivational affordances, whereas multimedia learning principles were used to regulate the cognitive presentation of information. The combination was selected because preschool digital mathematics environments must simultaneously maintain children's engagement and reduce unnecessary cognitive load.

The ARCS model conceptualizes motivation through four dimensions: attention, relevance, confidence, and satisfaction (Keller, 1987, 2010). Attention refers to capturing and sustaining the learner's curiosity through perceptual arousal, inquiry, and variation. In the game, attention was supported through colorful object visuals, a simple progress bar, level indicators, and short animated feedback. Relevance refers to the perceived connection between the learning task and the learner's needs, experiences, or interests. For preschool children, relevance is strengthened when tasks are embedded in familiar objects and everyday situations. Therefore, addition tasks were represented through concrete objects that children could recognize and count.

Confidence concerns the learner's belief that success is possible and controllable. In the game, confidence was supported through a progressive level structure from beginner to master, a limited number of answer choices, repeated listening options, and non-punitive feedback for incorrect responses. Children were encouraged to try again instead of receiving failure messages. Satisfaction refers to the positive affect and reinforcement that follow successful learning. The game used immediate verbal praise such as “Great! [Harika!]” and “Well done! [Aferin sana!]”, visual confirmation marks, and the accumulation of stars to reinforce success. These design features were intended to support persistence and reduce anxiety around mathematical errors.

Mayer's Cognitive Theory of Multimedia Learning argues that meaningful learning occurs when learners select, organize, and integrate information through visual and verbal channels (Mayer, 2001). In preschool contexts, this theory is useful because children often process mathematical meaning more effectively through images, speech, gestures, and concrete representations than through written text. The game operationalized the multimedia principle by pairing audio instructions with visual object sets. It operationalized the modality principle by replacing written instructions with spoken guidance, which was essential because the participating children were not conventional readers.

The contiguity principle was reflected by presenting spoken instructions at the same time as the relevant visual objects appeared on the screen. The coherence principle guided the removal of decorative elements that did not support the task. Although the interface remained colorful, the central task screen was intentionally sparse: children saw the relevant objects, the answer options, and the feedback cue. The signaling principle was applied through color changes, check marks, and animation that directed attention to correct and incorrect answers. Finally, the segmentation principle was applied by dividing content into 17 short questions across four levels and five task types: counting, pattern recognition, identifying the odd item, relational reasoning, and addition.

The theoretical framework is therefore not treated as a post-hoc justification but as a design grammar. Each pedagogical feature of the prototype was linked to a motivational or cognitive principle. This is important because digital game-based learning is not automatically educational; its effectiveness depends on how game mechanics, content, feedback, representation, and learner characteristics are aligned.

The alignment shown in Table 1 clarifies how the two theoretical frameworks were translated into concrete game features. The table is included to make the relationship among motivational principles, multimedia learning principles, and preschool mathematics design decisions explicit.

Table 1.

Alignment between theoretical principles and game design decisions

Theoretical component	Design decision	Purpose in preschool mathematics learning
ARCS - Attention	Colorful objects, short animations, progress bar, audio prompts	Sustains attention without requiring reading
ARCS - Relevance	Familiar objects such as apples, stars, balloons, and butterflies	Connects addition tasks to everyday concrete experiences
ARCS - Confidence	Four progressive levels and non-punitive retry feedback	Supports perceived competence and willingness to continue
ARCS - Satisfaction	Immediate praise, visual confirmation, and star accumulation	Reinforces success and task completion
Multimedia and modality	Audio guidance paired with visual object sets	Supports children who cannot yet read written instructions
Coherence and signaling	Simple task screen, green/red answer feedback, check marks	Reduces extraneous load and directs attention to key information
Segmentation	Seventeen short tasks in levels and task types	Divides learning into manageable steps

Note. The table summarizes the design logic used to translate motivational and cognitive principles into classroom-ready game features.

DESIGN AND IMPLEMENTATION OF THE ACTIVITY

The design process followed a systematic educational design approach and consisted of six stages: target group and needs analysis, theoretical framing, question bank and level design, visual interface design, audio integration and accessibility, and testing with expert feedback. At each

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stage, design decisions were filtered through developmental appropriateness, the curricular relevance of early mathematical skills, and the usability needs of children who were not yet readers.

The design logic was cyclical at the prototype level. After the initial interface and question bank were prepared, three experts reviewed the materials before classroom implementation. Their feedback was used to revise selected interface, audio, and feedback components before the final classroom use. This process is consistent with design-based inquiry in which theoretical principles, prototype construction, expert review, and classroom feasibility are examined together.

In the needs analysis stage, the target group was defined as 4- to 5-year-old preschool children. The central constraints were short attention span, limited symbolic processing, the absence of conventional reading skills, and the need for frequent success experiences. Accordingly, the game avoided written instructions as the primary instructional channel and relied on speech, object visuals, and intuitive color feedback. The intended learning outcome was for children to combine two visually presented object groups and identify the total number, thereby practicing object-supported addition.

The game's task structure was organized into 17 questions distributed across four levels: Beginner, Intermediate, Advanced, and Master. The levels included five task types. Counting tasks asked children to identify the number of objects in a set. Pattern tasks asked them to continue simple visual sequences. Odd-item tasks asked them to identify a different object in a set. Relational tasks involved size or visual association. Addition tasks asked children to combine two object sets, count the total, and select the correct numerical response. Each item included one correct answer and three plausible distractors.

To clarify how the five task types were presented, the counting item asked, for example, “How many apples are there?”; the pattern item asked the child to continue a short object sequence; the odd-item item asked the child to identify the object that was different from the others; the relational item asked the child to compare or associate objects by a visible attribute such as size; and the addition item asked the child to combine two visible object groups and identify the total. In all task types, the oral prompt was the primary instruction, while any text visible on the screen functioned as a secondary orientation cue for the teacher or researcher.

The game interface was implemented through HTML, CSS, and JavaScript. The screen used a pastel background, a white task card, large answer buttons, and a progress indicator. The interface intentionally minimized text, but some short labels remained visible in the prototype screen for teacher orientation. The instructional logic, however, did not depend on reading. Each question triggered automatic audio guidance after a short delay, and children could replay the prompt by pressing a listening button. Turkish text-to-speech was implemented using the Web Speech API, with speech rate and pitch adjusted to approximate a child-friendly pace. For addition items, the audio prompt directed children to count the first object group, count the second object group, and then count both groups together before selecting the answer.

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Two expert-informed revisions illustrate how the design cycle affected the final interface. First, the initial audio prompt started immediately after the task appeared. Experts suggested that some children might need a brief visual orientation period before listening to the instruction. Therefore, a short delay and a replay-listening button were emphasized in the final version. Second, the first prototype used only color change for incorrect responses. Following expert feedback, the incorrect-response cue was strengthened with a brief shaking animation and a supportive audio prompt so that error correction remained perceptually clear but emotionally non-punitive.

Feedback was designed as an interactive instructional mechanism. Correct responses turned green, displayed a confirmation mark, and triggered positive verbal feedback. Incorrect responses turned red, used a brief shaking animation, and provided supportive guidance such as “Let's look again; you can do it! [Bir daha bak bakalım, yapabilirsin!]” rather than corrective failure language. This feedback design reflected the assumption that preschool learners benefit from immediate, emotionally safe correction. The purpose was to keep children in the task cycle and make the correct option perceptually salient.

The implementation followed a three-phase sequence. First, children completed an object-supported addition pre-test. Second, they played the digital game individually in the classroom context with teacher supervision available only for procedural support. Third, children completed the post-test and the smiley-face usability form. Expert evaluation was obtained after reviewing the prototype and implementation materials. Photos of identifiable children were not included in the article version because of the ethical sensitivity of visual data involving minors; only interface screenshots are presented.

The activity was designed as a short classroom practice episode rather than a long stand-alone intervention. In a typical classroom use scenario, the teacher first introduces the task goal with concrete manipulatives, then allows children to work through the digital game individually or in pairs, and finally closes the activity with a brief discussion about how the total number was found. This sequence is important because the digital game is most appropriate as a reinforcement environment that extends hands-on mathematical experience; it is not intended to replace teacher-guided mathematical talk or physical manipulation of objects.

The required materials are minimal: one computer or tablet with a browser, audio output, and access to the locally hosted or web-hosted game file. The prototype does not require external accounts, child logins, or collection of identifiable digital traces. From a classroom management perspective, the audio replay button and large response areas were included to reduce teacher dependence during task navigation. This design choice may support inclusive use with children who need repeated instructions, slower pacing, or additional perceptual cues.

The representative addition-operation screen shown in Figure 1 clarifies how the child encountered two visible object sets before selecting the total. The child did not need to read the written expression on the screen; the spoken instruction guided the child to count three stars, then two

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stars, and then count all stars together. The numeric answer choices were used after the object-supported counting action, not as a substitute for coordinating the visible sets.

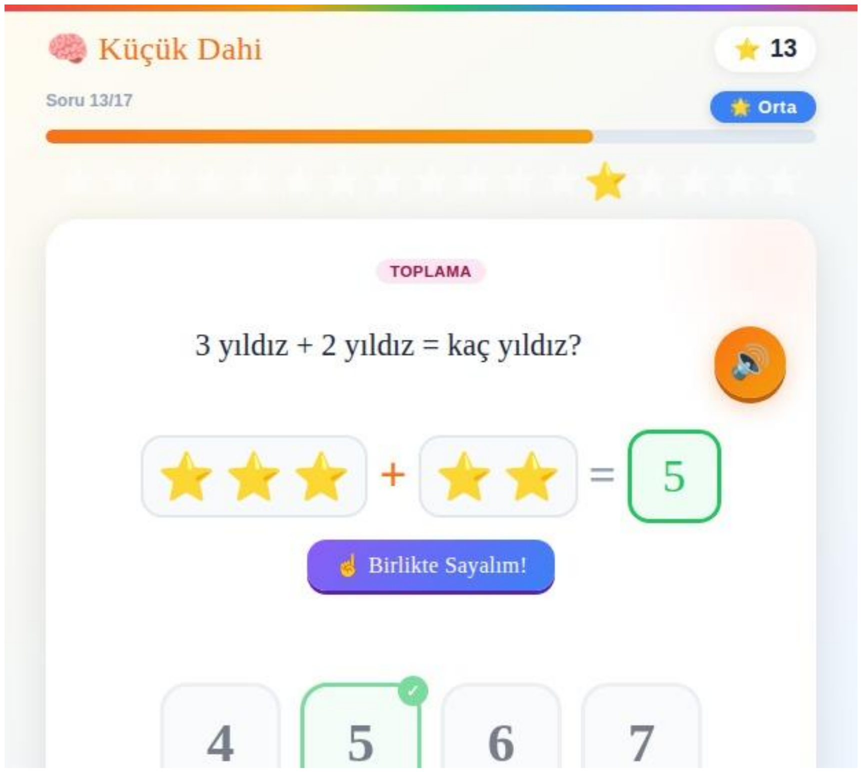

Figure 1. *Example of an object-supported addition task in the digital game*

Note. The screen shows two star sets combined visually before the child selects the total. The written expression remained on the prototype screen as a teacher-orientation cue, while the child-facing instruction was delivered orally. The screenshot is from the original prototype interface.

Figure 2 illustrates the immediate-feedback logic used after a response. The green cue, confirmation mark, and praise message were intended to signal correctness without adding unnecessary verbal or visual complexity.

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Figure 2. *Example of immediate visual feedback after a counting task*

Note. The green response cue and positive message illustrate the game's signaling and feedback mechanisms.

Participants And Context

The study was conducted with 15 preschool children aged 4 to 5 years in one public preschool classroom in the Keçiören district of Ankara, Türkiye. Participants were selected through criterion sampling from an intact classroom because the study targeted children whose developmental profile matched the design problem. The inclusion criteria were as follows: being enrolled in preschool education, being in the 4- to 5-year-old age range, not yet having conventional reading and writing skills, having written parental consent, and expressing willingness to participate in the activity. Children who did not meet the age criterion, did not have parental consent, or did not wish to participate were not included.

The classroom teacher and researcher identified eligible children according to these criteria, and all participating children were coded as C1, C2, and so forth in the data set. No child names were used in analysis or reporting. Because the sample consisted of one intact classroom and was not randomly selected, the findings are context-bound and should not be generalized to all preschool

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children. The sampling strategy was appropriate for documenting design feasibility, but it limits claims about effectiveness.

The setting was a natural classroom environment rather than a laboratory. This context was important because the study aimed to examine a teacher-led digital mathematics activity that could be integrated into routine preschool practice. The digital game was used as a reinforcement and practice tool for mathematical awareness activities conducted in class. The small sample size reflects the classroom-based nature of the study and limits generalizability. The findings should therefore be read as preliminary evidence about design feasibility and potential learning support rather than as population-level evidence of effectiveness.

The study aligns with the number and operation emphasis in the 2024 Preschool Education Program in Türkiye. The program structures preschool mathematics around areas such as number and operation, patterns, spatial relations, and measurement rather than through narrowly stated school-type achievement outcomes (Ministry of National Education, 2024). The present implementation focused specifically on number and operation through object-supported addition while also including related tasks such as counting and pattern recognition.

Data Collection and Analysis

Three data collection tools were used. The first tool was an object-supported addition pre-test and post-test scored out of five points. The pre-test was administered before the digital game implementation to identify children's existing performance in combining concrete object sets. The post-test was administered after the game-based activity to describe performance change in the same skill domain. The test required children to count visible objects, combine two groups, and choose the total quantity.

The pre-test and post-test were administered individually in the classroom setting using visible object sets. The researcher administered the tasks orally, ensured that each child understood the response format, and recorded the score immediately after the response; the classroom teacher remained available for routine classroom supervision and procedural support. The same skill domain was assessed before and after implementation, but items were treated as descriptive indicators rather than as a standardized achievement test. The purpose was to document short-term performance change in the targeted object-supported addition skill.

The second tool was a three-item smiley-face usability form adapted for preschool children. Instead of using abstract Likert-type statements, the form asked children to indicate whether the game was easy to play, whether they liked the pictures, and whether they wanted to play the game again. The exact child-facing questions were: (1) Was the game easy to play? (2) Did you like the pictures in the game? and (3) Would you like to play this game again? For each question, children selected a smiling, neutral, or sad face. This format was selected because preschool children can respond more reliably to concrete affective symbols than to verbalized scale anchors. The tool should not be interpreted as a standardized usability scale; it is a developmentally simplified user-response instrument.

The third tool was an expert evaluation form completed by three specialists from the areas of preschool education, educational technology, and game-supported learning. Experts rated the prototype on four criteria: pedagogical appropriateness for preschool mathematics learning, visual design and interface clarity, navigation and ease of use for children, and general usability and classroom applicability. Each criterion was rated using a five-point format. Open-ended expert comments were also reviewed. These comments were used to refine audio timing, make the replay option more salient, and strengthen the incorrect-response animation and supportive feedback message.

The data were analyzed descriptively. For the pre-test and post-test, total score, mean score, performance percentage, and individual score change were calculated. Because the study used a single-group pre-test-post-test design, involved a small classroom sample, and did not include a control group, inferential statistics were not emphasized. This analytic decision was made to avoid overclaiming causality. Smiley-face responses were reported as frequencies, and expert evaluation scores were summarized as criterion means.

FINDINGS

The findings are presented in three parts. First, Table 2 and Figure 3 report children's pre-test and post-test performance in object-supported addition. Second, Table 3 reports children's smiley-face usability responses. Third, Table 4 reports the expert evaluation results. A brief informal error analysis is included after the performance findings because it provides design-relevant information about the kinds of difficulties children experienced.

As shown in Table 2, the pre-test and post-test findings indicated positive change in children's object-supported addition performance after the digital game implementation. The total class score increased from 61 to 73 out of a possible 75. The mean increased from 4.07 to 4.87 out of 5, corresponding to an average score increase of 0.80 points. The total performance percentage increased from 81.33% to 97.33%, a 16 percentage-point increase. Thirteen of the 15 children reached full performance in the post-test.

At the individual level, 10 children improved their scores and five children maintained full performance from pre-test to post-test. This pattern indicates a ceiling effect for some participants: one-third of the class already scored at the maximum level before the implementation. Nevertheless, children who had lower initial scores showed improvement. The largest score changes were observed for C1 and C3, who each increased by two points. These findings suggest that the digital game was particularly useful as reinforcement for children who had not yet fully mastered object-supported addition.

A limited informal error analysis provided additional pedagogical information. The few incorrect responses observed before or during gameplay tended to occur when children shifted from

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counting a single set to coordinating two sets as one total. In these cases, children sometimes counted only the first group, skipped an item while moving from the first group to the second, or selected a response close to one of the addends rather than the combined total. This pattern suggests that the main difficulty was not navigation of the interface but the mathematical coordination of one-to-one counting, part-whole reasoning, and total-set formation. Because these observations were not collected through a formal observation protocol, they are reported only as descriptive design feedback.

Table 2.
Children's pre-test and post-test scores for object-supported addition

Child code	Pre-test	Post-test	Change
C1	3	5	+2
C2	3	4	+1
C3	2	4	+2
C4	4	5	+1
C5	4	5	+1
C6	4	5	+1
C7	4	5	+1
C8	4	5	+1
C9	4	5	+1
C10	4	5	+1
C11	5	5	0
C12	5	5	0
C13	5	5	0
C14	5	5	0
C15	5	5	0
Total / mean	61 / 4.07	73 / 4.87	+12 total / +0.80 mean

Note. Scores are out of five points.

Figure 3 complements Table 2 by presenting the mean pre-test and post-test scores visually. This figure is intended to make the magnitude of the descriptive performance change more accessible to readers.

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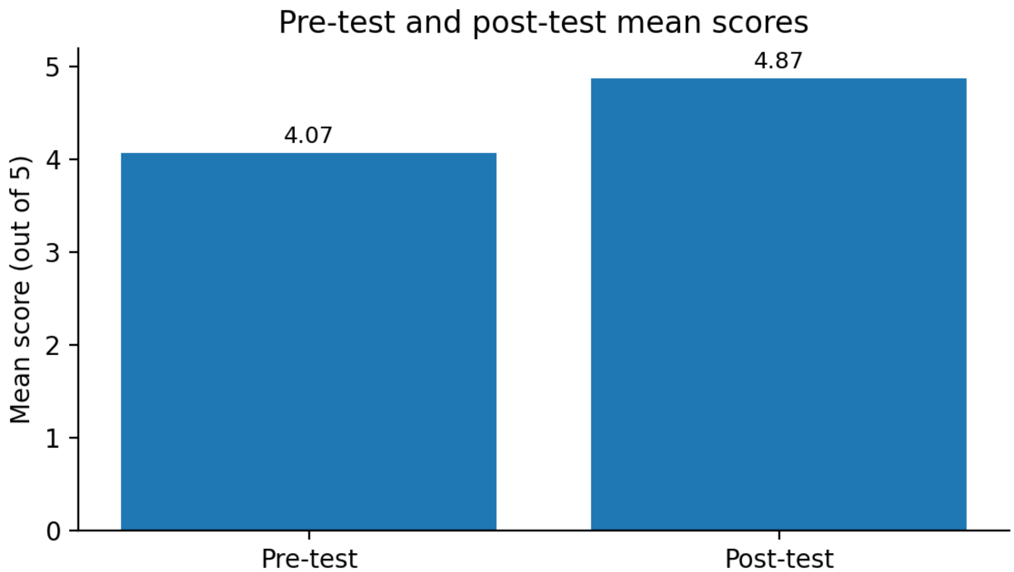

Figure 3. *Pre-test and post-test mean scores for object-supported addition*

Note. Mean scores are displayed out of five points. The graph is intended to complement Table 2 by making the pre-test/post-test change visually accessible.

Table 3 presents children's responses to the three smiley-face usability questions. The usability responses were strongly positive: fourteen children indicated that the game was easy to play, while one child selected the neutral option. All 15 children indicated that they liked the visual design and wanted to play the game again. These results are consistent with the ARCS design goal of creating a motivating, low-friction learning environment. However, the findings should be interpreted carefully because preschool children's self-reports can be influenced by novelty, teacher presence, and social desirability.

Table 3.
Smiley-face usability responses

Question	Smiling face	Neutral face	Sad face
Was the game easy to play?	14	1	0
Did you like the pictures in the game?	15	0	0
Would you like to play this game again?	15	0	0

Note. The smiley-face format was used to match the developmental level of preschool children.

Table 4 presents the expert evaluation results across the four criteria. Expert ratings were favorable: pedagogical appropriateness received a mean score of 4.80 out of 5, visual design and interface received 4.50, navigation and ease of use received 4.70, and the overall mean was 4.66. Experts emphasized that audio guidance was a strong accessibility feature for children who could not yet read. They also evaluated the game's use of object-supported representations and immediate feedback as developmentally appropriate. The relatively lower score for visual design suggests that the interface, while suitable, could still be refined for clarity, icon consistency, or layout balance.

Table 4.
Expert evaluation results

Evaluation criterion	Mean score (1-5)
Pedagogical appropriateness	4.80
Visual design and interface	4.50
Navigation and ease of use	4.70
Overall mean	4.66

Note. Three experts evaluated the game prototype using a five-point format.

DISCUSSION

The findings are theoretically coherent with the design framework. The increase in post-test scores may be related to the combination of concrete object representation, audio instruction, segmented task presentation, and immediate feedback. In Mayer's terms, children received coordinated verbal and visual information rather than literacy-dependent written instruction; in ARCS terms, they encountered a task environment intended to support attention, relevance, confidence, and satisfaction. The object-supported addition task in Figure 1, for example, translates the abstract operation "3 + 2" into two visible sets that can be counted and combined. This type of representation aligns with early mathematics learning trajectories, where children move from perceptual and counting-based strategies toward more abstract numerical reasoning (Clements & Sarama, 2009, 2011; Piaget, 1962).

The results also align with recent game-based learning literature. Alotaibi's (2024) synthesis suggests that game-based learning can support cognitive and motivational outcomes in early childhood when implementation is developmentally appropriate. DePascale and Ramani (2025) further emphasize that math games are most useful when their design features, mathematical content, and dosage are explicitly considered. International studies on mobile and app-based mathematics learning similarly indicate that digital tools are most defensible when they are connected to concrete mathematical actions and teacher-supported classroom practice (Flores et al., 2022; Papadakis et al., 2021). The present prototype reflects this logic by restricting the mathematical target to object-supported addition, using short task segments, and embedding feedback within the learning action rather than adding unrelated entertainment features.

The study also contributes to the national literature. Turkish reviews and empirical studies have reported increasing interest in digital games in mathematics education, but they also point to a need for curriculum-aligned, developmentally appropriate, and purpose-built materials, especially for younger learners (Aydın & Ata, 2024; Karabekmez & Yıldız, 2017; Kendüzler, 2023; Poçan, 2023; Ünal & Erbil Kaya, 2024; Yıldız et al., 2024). The present study addresses this need by documenting not only the outcome scores but also the design rationale, audio-guidance solution, feedback structure, and expert-informed revisions of a preschool mathematics game.

The results also support the argument that preschool digital games should be designed around developmental constraints rather than general entertainment principles. The most important design choice in this study was not simply making the activity game-like; it was replacing literacy-dependent instructions with audio guidance and visual feedback. This choice allowed children to interact with mathematical content more independently. Such independence is important in preschool classrooms because teacher attention is distributed across many children, and digital tools are more valuable when they support self-paced engagement without excluding emergent readers (Mayer, 2001; Ministry of National Education, 2024).

The positive usability responses suggest that the game was accessible and appealing to the target group. However, high enjoyment does not automatically imply learning. The learning interpretation rests primarily on the pre-test-post-test change, the alignment between tasks and measured skills, and the expert evaluation of pedagogical fit. The informal error analysis suggests that future versions should include prompts that explicitly support transition from two separate sets to one combined total, such as highlighting each object during counting or requiring children to tap objects one by one before selecting the answer.

Several limitations should be acknowledged. First, the study used a single-group design without a control group. Therefore, the findings cannot establish that the game alone caused the observed score changes. Second, the sample size was small and limited to one preschool context. Third, the pre-test scores were already high, producing a ceiling effect that constrained possible improvement for several children. Fourth, the usability form was intentionally simplified for preschool children and should not be interpreted as a psychometrically validated usability scale. Fifth, the error analysis was informal and should be examined with a structured observation form in future studies. Finally, the expert evaluation involved only three specialists. These limitations do not invalidate the design contribution, but they require cautious interpretation.

Overall, the study contributes to practice by providing a documented example of how early mathematics content can be transformed into a multimodal, audio-guided digital game for children who cannot yet read. It also contributes to design knowledge by showing how ARCS and multimedia learning principles can be jointly operationalized in preschool mathematics education. The most transferable design principle is the integration of concrete object sets, spoken instructions, manageable task segments, supportive feedback, and teacher-guided follow-up discussion.

CONCLUSION AND RECOMMENDATIONS

This study designed and implemented an audio-guided digital game to support preschool children's addition skills through object-supported tasks. The game was grounded in the ARCS

Motivation Model and Mayer's Cognitive Theory of Multimedia Learning. It used concrete visual objects, Turkish audio guidance, progressive levels, and immediate supportive feedback to create a developmentally appropriate environment for 4- to 5-year-old children.

Descriptive results indicated that children's object-supported addition performance improved after the implementation. The class mean increased from 4.07 to 4.87 out of 5, and the performance percentage increased from 81.33% to 97.33%. Children's usability responses and expert evaluations were also positive. These results suggest that the game has potential as a classroom reinforcement tool for early addition and mathematical awareness. Nevertheless, because of the small single-group design, the results should be interpreted as preliminary evidence of feasibility and promise rather than as conclusive evidence of effectiveness.

For classroom practice, preschool teachers may use similar digital activities as short reinforcement tasks after concrete manipulative work. The game should not replace hands-on counting materials, teacher-child mathematical dialogue, or play-based exploration. Instead, it can serve as an additional practice environment where children receive individualized prompts and immediate feedback. Teachers should observe children's strategies during gameplay, especially whether they count objects accurately, use one-to-one correspondence, or guess from answer choices.

For future design, the game can be expanded to include other mathematical awareness components such as subtraction with objects, pattern extension, spatial relations, measurement comparisons, and number decomposition. Parent dashboards or teacher analytics may also be developed, provided that data privacy and child protection standards are met. For future research, the design should be tested with larger and more diverse samples, a comparison group, a delayed retention test, and richer qualitative data such as structured observation notes, think-aloud protocols adapted for young children, screen interaction logs that do not identify children, or teacher interviews. Such studies would clarify not only whether the game works, but also how children use its visual and auditory supports while constructing mathematical meaning.

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Ethics Statement

This study was conducted in accordance with the ethical principles of educational research involving young children. Prior to the implementation, the school administration was informed about the purpose, scope, procedure, and duration of the study. Parents/legal guardians of all participating children were provided with clear information about the study, including the voluntary nature of participation, the digital game-based activity, the data to be collected, and the intended use of the findings for academic purposes. Written parental consent was obtained before the children participated in the implementation process. In addition, the children were informed verbally in an age-appropriate manner about the activity, and their willingness to participate was respected throughout the process.

Participation in the study was entirely voluntary, and children were allowed to withdraw from the activity at any stage without any negative consequence. No personally identifiable information was reported in the study. The participating children were coded as C1, C2, C3, and so forth in the data analysis and reporting process. All data were anonymized before analysis, and the findings were presented only in aggregate form. Any visual materials used in the manuscript were selected and processed in a way that did not disclose the identities of the children.

The data obtained from the pre-test, post-test, smiley-face usability form, and expert evaluation forms were stored securely by the researcher. Digital data were kept in password-protected files, and any printed documents were stored in a locked environment accessible only to the researcher. The data will be retained only for the period necessary for academic verification and reporting purposes and will not be shared with third parties. At the end of the retention period, all identifiable or raw data will be securely destroyed. The study did not involve any physical, psychological, or social risk beyond ordinary classroom-based educational activities.

Author Contributions

Author: conceptualization, instructional design, digital game development coordination, implementation, data collection, analysis, and manuscript preparation.

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Conflict of Interest

The author declares no conflict of interest.

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Declaration of AI-Assisted Tool Use

AI-assisted tools were used during the design process to support idea generation, question-bank structuring, interface-code drafting, and adaptation of evaluation forms to the developmental level of preschool children. The researcher remained responsible for all pedagogical decisions, implementation, data collection, interpretation, and final scholarly judgment.