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An ADDIE-Based Educational Arithmetic Game for Children with Mild Intellectual Disabilities

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Abstract. This study presents the design and evaluation of BRILIAN, an educational arithmetic game developed to support children with mild intellectual disabilities using the ADDIE instructional design framework. The study addresses persistent challenges in numeracy learning-particularly addition and subtraction-where conventional instructional approaches often fail to sustain learner engagement and instructional effectiveness. A mixed-methods approach was employed across the ADDIE phases, incorporating teacher interviews, functional testing, standardized usability and user experience instruments (System Usability Scale, User Experience Questionnaire-Short, and Game User Experience Satisfaction Scale), classroom observations, and pre-test/post-test performance assessments. The findings indicate high usability and user satisfaction, with a mean SUS score of 75.20 and an overall GUESS score of 87.74%. Teacher observations further revealed strong learner engagement (90.26%). Learning effectiveness improved significantly, as reflected by an increase in mean test scores from 62.73 to 82.27, accompanied by reduced task completion time. By integrating structured instructional design, multimodal feedback, adaptive gameplay, and cognitive accessibility features, this study provides empirical evidence that ADDIE-based educational games can function as practical and effective instructional tools for arithmetic learning in special education classroom contexts.

Keywords: Educational game; Arithmetic learning; Mild intellectual disability; ADDIE instructional design; Usability and learning effectiveness

1. INTRODUCTION

Children with mild intellectual disabilities (MID) frequently encounter enduring challenges in mastering abstract mathematical concepts, particularly foundational arithmetic operations such as addition and subtraction[1], [2], [3]. Despite curricular expectations that these competencies be achieved by the upper elementary level, classroom-based evidence indicates that many learners with MID experience persistent difficulty when dealing with numerical operations beyond basic values [2], [4]. Insights from special education teachers further highlight the need for repetitive practice, concrete visual representations, and interactive instructional scaffolding to sustain attention and facilitate procedural understanding [5], [6], [7], [8].

In response to these learning challenges, prior research has increasingly explored the application of digital and game-based learning technologies within special education environments [9], [10], [11]. Mobile arithmetic applications incorporating multimedia elements have shown potential for enhancing engagement; however, many remain limited in numerical scope or focus on isolated arithmetic skills [12], [13]. Earlier learning systems developed using Flash technology supported basic number and object recognition but are no longer well aligned with current mobile ecosystems. Similarly, game-based interventions, such as mobile snake-and-ladders arithmetic games, have demonstrated motivational benefits [12], yet often lack comprehensive instructional feedback, consistent interface design, or sufficient coverage of arithmetic content [13], [14].

More recent studies adopting Unity-based development environments and user-centered design approaches have reported favorable usability outcomes, underscoring the importance of intuitive interfaces and accessibility-oriented interaction design [15], [16]. Nevertheless, a substantial proportion of these studies concentrate on number recognition rather than operational arithmetic, or emphasize usability and engagement without rigorously examining learning effectiveness through empirical pre-test and post-test comparisons [10], [11], [13], [14], [16]. Consequently, the interplay between usability, user experience, and demonstrable learning gains in arithmetic instruction for children with MID remains underexplored.

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Although existing research confirms the potential of educational games in special education, most prior work addresses usability, motivation, or limited arithmetic skills independently. There remains a lack of integrated studies that combine structured instructional design, cognitively accessible interfaces, expanded arithmetic content, and comprehensive evaluation of usability, user experience, and learning performance within a single game-based system for learners with mild intellectual disabilities [10], [11], [13], [14], [15], [16]. Accordingly, this study aims to design and evaluate an ADDIE-based educational arithmetic game that addresses these limitations. The objectives are twofold: (1) to develop an instructional arithmetic game grounded in the ADDIE framework, and (2) to empirically assess its usability, user experience, and learning effectiveness in authentic special education classroom contexts.

To achieve these objectives, this study presents BRILIAN, an educational arithmetic game developed using the ADDIE instructional design model. The proposed system integrates instructional videos, multimodal feedback, cognitively accessible interface features, and expanded arithmetic coverage, specifically addition up to 60 and subtraction up to 20, to support learner engagement, instructional efficiency, and arithmetic proficiency. The game is implemented and evaluated through functional testing, standardized usability and user experience instruments, teacher observations, and pre-test/post-test analyses involving children with MID.

This study makes three primary contributions. First, it introduces an ADDIE-based educational arithmetic game that integrates cognitive accessibility principles, multimodal instructional feedback, and progressive arithmetic tasks tailored for learners with mild intellectual disabilities. Second, it provides empirical evidence demonstrating how usability, user experience, and learning effectiveness can be jointly addressed within a single game-based instructional system. Third, it offers classroom-based validation through a comprehensive evaluation framework that combines standardized usability measures, teacher observations, and pre-test/post-test performance analysis, thereby extending prior research that has largely examined design, usability, or learning outcomes in isolation.

2. METHODS

This study employed the ADDIE instructional design model-Analysis, Design, Development, Implementation, and Evaluation- as a systematic framework for developing and evaluating the BRILIAN educational game. The ADDIE model was selected due to its structured and iterative characteristics, which facilitate alignment between learner needs, instructional design decisions, development processes, and evaluation outcomes, and has been widely adopted in recent educational technology research, including special education contexts [18], [19]. Figure 1 is the process of this study.

Figure 1. Research Flow

During the **analysis phase**, user requirements were identified through semi-structured interviews with three special education teachers from two special education schools, complemented by classroom observations and a focused literature review addressing arithmetic learning strategies and the cognitive characteristics of children with mild intellectual disabilities (MID) [3], [4], [6]. This phase resulted in the formulation of instructional objectives, usability criteria, and functional requirements aligned with classroom practices.

In the **design phase**, the game structure, interface layout, gameplay mechanics, and instructional content were systematically planned. Design principles prioritised cognitive accessibility, including high visual contrast, enlarged interactive elements, simplified navigation, minimal textual load, auditory guidance, and short instructional sequences. These principles are consistent with contemporary inclusive and accessibility-oriented design guidelines for learners with cognitive disabilities [15], [16], [20]. Arithmetic content was structured progressively to support addition (up to 60) and subtraction (up to 20), enabling gradual skill development.

The **development phase** involved implementing game assets, animations, instructional videos, and interactive feedback mechanisms using the Unity engine with C# scripting.

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The application was developed for the Android platform and tested on devices running Android 8.0 or higher with at least 3 GB of RAM, reflecting typical classroom hardware conditions. Unity-based development environments have been widely adopted in recent educational game research due to their flexibility and cross-platform support [21].

During the **implementation phase**, the developed prototype was piloted with students from both participating schools under continuous teacher supervision. Classroom observations focused on usability, clarity of instructions, learner interaction behaviour, and engagement during gameplay, following established practices for classroom-based evaluation of educational technologies in special education settings [15], [22].

The **evaluation phase** assessed system functionality, usability, user experience, and learning effectiveness. Functional validation was conducted using Black Box Testing to verify the reliability of all system modules. Usability and user experience were measured using the System Usability Scale (SUS) [23], the User Experience Questionnaire–Short (UEQ-S) [24], and the Game User Experience Satisfaction Scale (GUESS) [25]. Teacher observations were used to assess learner engagement and behavioural responses during gameplay.

Learning effectiveness was examined through pre-test and post-test comparisons of arithmetic performance and task completion time. Statistical analysis was conducted using paired-samples t-tests to determine the significance of learning gains, with Cohen's d effect sizes calculated to assess the magnitude of the observed improvements. A significance level of 0.05 was applied, consistent with established practices in educational intervention research [26]. he overall ADDIE-based research flow is shown in Figure 1, while the phase-specific activities and outputs are summarized in Table 1.

Table 1. ADDIE Phases and Research Outputs

ADDIE Phase	Main Activities	Key Outputs
Analysis	Teacher interviews, classroom observations, literature review	Learning objectives, usability requirements, functional specifications

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ADDIE Phase	Main Activities	Key Outputs
Design	Interface design, gameplay planning, storyboard development	UI mock-ups, instructional flow, content structure
Development	Asset creation, programming, integration	Android-based educational game prototype
Implementation	Classroom pilot testing	Usability observations, preliminary feedback
Evaluation	Functional testing, UX/usability assessment, learning analysis	SUS, UEQ-S, GUESS scores; pre-test/post-test results

The study adhered to ethical standards for research involving children with special educational needs. Participating schools approved the protocol, parents or legal guardians provided informed consent, and teachers supervised all learning activities.

3. RESULTS AND DISCUSSION

3.1. System Development and Functional Performance

The redesigned BRILIAN application was successfully implemented as an arithmetic learning tool targeting addition and subtraction for children with mild intellectual disabilities. The development process resulted in a learning system that integrates multimodal instructional elements, adaptive feedback mechanisms, and cognitively accessible interface structures. Design decisions were systematically derived from user requirements identified through teacher interviews and preliminary system evaluations, ensuring close alignment between instructional needs and technical implementation [15], [16].

Key accessibility-oriented features include high-contrast visual elements, enlarged numeric typography, simplified navigation pathways, and character-based instructional guidance. These features were intentionally incorporated to reduce perceptual overload and to accommodate learners with limited working memory and attentional capacity. In addition, multimedia components, such as narrated instructions, background audio cues, and animated instructional videos, were embedded to support comprehension through

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multiple sensory channels, which is particularly beneficial for learners who experience difficulty processing abstract numerical concepts [8].

Functional validation was conducted using Black-Box Testing across 28 execution scenarios that encompassed all system modules, including learning menus, gameplay components, difficulty level selection, scoring logic, and interactive responses. All scenarios returned valid outcomes, indicating that the system operated reliably without functional errors. Both gameplay modules, snake-and-ladders for addition and coin racing for subtraction, performed consistently across all difficulty levels, ensuring stable interaction during classroom implementation.

Beyond technical correctness, functional reliability plays a critical pedagogical role. For learners with mild intellectual disabilities, system interruptions or unpredictable responses can disrupt attention and diminish learning effectiveness [6]. The absence of functional errors therefore provided a stable foundation for subsequent evaluations of usability, engagement, and learning effectiveness.

The BRILIAN system achieved complete functional reliability, establishing a stable technical foundation for evaluating usability, engagement, and instructional effectiveness.

3.2. Interface Design Outcomes and Comparative Improvement

The BRILIAN application interface was designed to support four core instructional components: the addition learning module, the subtraction learning module, the snake-and-ladders game, and the coin-racing game. Across all modules, the interface design emphasised cognitive accessibility through consistent interaction patterns, simplified navigation, and multimodal instructional support. Significant interactive elements, minimal text, and single-tap responses were applied to reduce mental and motor demands. At the same time, audio guidance and immediate feedback were integrated to assist learners with limited reading ability and reinforce correct responses [8], [21]. The BRILIAN Game Menu and Gameplay Modes as shown in Figure 2.

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Figure 2. BRILIAN Game Menu and Gameplay Modes

The addition learning interface presents structured arithmetic exercises supported by instructional videos and narrated guidance. Enlarged numerical representations, high-contrast colour schemes, and simplified menu structures reduce visual load and support independent task completion. Immediate feedback, delivered through both audio and visual cues, clarifies errors and reinforces correct problem-solving strategies, contributing to sustained learner engagement. The Instructional videos and narrated guidance as shown in Figure 3

Figure 3. Instructional videos and narrated guidance

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The snake-and-ladders game interface integrates arithmetic tasks within a familiar board-game structure, where character tokens advance based on correct responses. Three difficulty levels (easy, medium, and hard) enable differentiated learning, with arithmetic ranges increasing progressively to support skill development. The combination of game mechanics and instructional content encourages repetition and persistence without compromising conceptual accuracy. The snake-and-ladders game interface as shown in Figure 4.

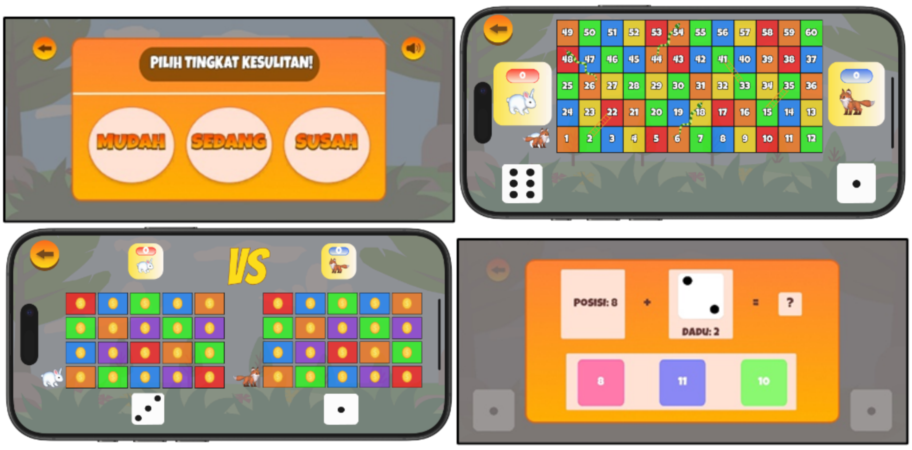

Figure 4. The snake-and-ladders game interface

In addition to the game-based modules, the subtraction learning interface was designed to maintain interaction continuity while supporting efficiency and motivation. Arithmetic problems are displayed sequentially using enlarged numerical elements, and learners respond through a single-tap mechanism to minimise navigation complexity. Motivational cues, including celebratory sounds and visual rewards, are embedded to sustain attention and reinforce task completion. The subtraction learning interface as shown in Figure 5.

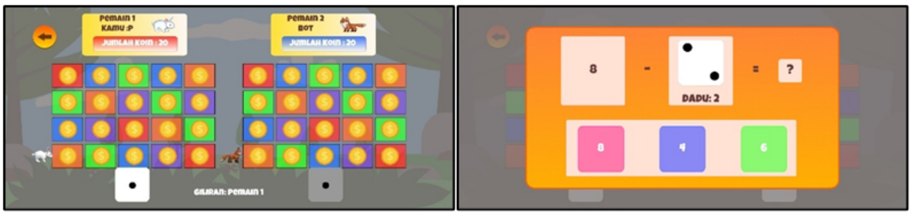

Figure 5. The subtraction learning interface

The coin-racing interface further extends subtraction practice by embedding arithmetic challenges within a dynamic, goal-oriented environment. Visual motion, time-based

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progression, and immediate response feedback increase motivation and encourage faster recall, while embedded audio instructions reduce reliance on teacher intervention. The Visual clarity as shown in Figure 6.

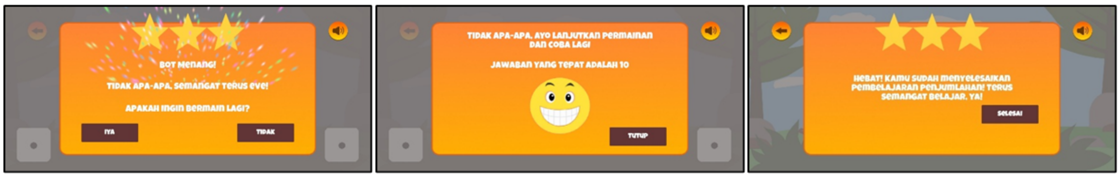

Figure 6. Visual clarity

Collectively, these interfaces form an integrated learning environment characterised by visual clarity, intuitive navigation, consistent multimodal support, and motivational reinforcement. Rather than functioning as isolated modules, the interfaces were designed to provide a coherent interaction experience that enables learners to focus on arithmetic reasoning while minimising extraneous cognitive demands.

Compared with the earlier snake-and-ladders arithmetic game reported by Novayani[8], the redesigned interface demonstrates several substantive improvements, including clearer and more consistent audio guidance, a more coherent visual hierarchy across modules, expanded arithmetic coverage, and fully integrated feedback mechanisms. Unlike prior designs that primarily emphasised visual engagement, the current interface prioritises instructional clarity and interaction predictability, enabling learners to allocate cognitive resources to problem-solving rather than navigation mechanics [30].

The redesigned interface advances prior implementations by integrating accessibility-oriented design with instructional consistency, thereby reducing cognitive load and supporting independent arithmetic practice.

3.3. Usability, User Experience, and Engagement

Building on the interface design outcomes described in Section 3.2, the evaluation phase examined whether the accessibility-oriented and instructionally consistent interface translated into measurable usability, user experience, and learner engagement outcomes. To ensure robust triangulation, the assessment involved students as primary users and

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teachers as instructional facilitators, employing multiple complementary instruments commonly used in educational technology evaluation [15], [27].

User experience was assessed using the User Experience Questionnaire–Short Version (UEQ-S), administered to 28 teachers. The results yielded mean scores of 2.16 for pragmatic quality and 2.17 for hedonic quality, with an overall score of 2.17. These values indicate highly positive perceptions of system efficiency, clarity, and enjoyment, suggesting that consistent interaction patterns and multimodal feedback effectively supported both functional usability and affective engagement. Such outcomes align with prior findings that emphasise the role of coherent interface design and sensory reinforcement in sustaining engagement among learners with cognitive disabilities [8], [16].

Usability performance was further evaluated using the System Usability Scale (SUS). Mean SUS scores reached 75.20 among 25 student users and 75.48 among 31 teachers, exceeding the widely accepted usability benchmark of 68. Complementary usability testing reinforced these findings, with task completion and interaction clarity rates of 86.47% for students and 88.60% for teachers. These results indicate that the interface supported efficient navigation and independent task execution within authentic classroom contexts, an essential requirement for technology adoption in special education settings [21], [23]. The Descriptive and Inferential Statistics of Pre-test and Post-test Scores as shown in Table 2.

Table 2. Descriptive and Inferential Statistics of Pre-test and Post-test Scores

Statistic	Value
Mean Pre-test Score	62.73
Mean Post-test Score	82.27
Mean Gain Score	19.55
Paired t-value	5.65
p-value	< 0.001
Effect Size (Cohen's d)	0.98

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User satisfaction and engagement were examined using the Game User Experience Satisfaction Scale (GUESS), completed by 31 teachers. The evaluation produced an overall mean score of 87.74%, reflecting strong satisfaction across dimensions of enjoyment, engagement, and motivational appeal. These results were corroborated by structured classroom observations, which yielded a mean engagement rating of 90.26%, indicating sustained attention, emotional positivity, and reduced reliance on teacher intervention during gameplay. This convergence of subjective and observational data suggests that reward-based progression, immediate feedback, and multimodal cues effectively supported learner motivation and persistence [25], [28].

Beyond experiential measures, learning performance outcomes further validated the usability and engagement findings. As shown in Table 1, paired-samples t-test results revealed a statistically significant improvement in arithmetic performance following the intervention, with mean scores increasing from 62.73 (pre-test) to 82.27 (post-test). The substantial gain (19.55 points; $t = 5.65$, $p < 0.001$; Cohen's $d = 0.98$) indicates that positive usability and engagement outcomes were accompanied by meaningful instructional benefits rather than superficial interaction effects.

The convergence of usability, user experience, engagement, and learning performance results demonstrates that the interface design principles outlined in Section 3.2 successfully translated into practical instructional effectiveness. By reducing interaction barriers and cognitive load, the system enabled learners to focus on arithmetic reasoning rather than interface navigation, thereby supporting both independent use and effective classroom facilitation [6], [21].

3.4. Learning Effectiveness and Efficiency Analysis

The positive usability, user experience, and engagement outcomes reported in Section 3.3 provide a basis for examining whether these interaction qualities translated into measurable learning gains. To this end, instructional effectiveness was evaluated through pre-test and post-test comparisons involving 33 students with mild intellectual disabilities. The results indicate a substantial improvement in arithmetic performance following the use of the BRILIAN game. Mean test scores increased from 62.73 in the pre-test to 82.27 in the post-test, yielding an average gain of 19.55 points. Paired-samples t-test analysis confirmed that this improvement was statistically significant ($p < 0.001$) with

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a large effect size (Cohen's d = 0.98), indicating a strong short-term instructional impact. These findings suggest that the structured progression of arithmetic tasks, combined with immediate multimodal feedback and consistent interaction patterns, supported conceptual understanding and facilitated error correction during arithmetic practice, in line with prior findings on game-based learning for learners with special educational needs [10], [29]. The Mean task completion time before and after the BRILIAN intervention as shown in Table 3.

Table 3. Mean task completion time before and after the BRILIAN intervention

Statistic	Value
Mean Pre-test Time	34.47 minutes
Mean Post-test Time	28.72 minutes
Mean Time Reduction	5.75 minutes
t-value	3.17
p-value	0.003
Cohen's *d*	0.55 (moderate effect)

In addition to improvements in accuracy, learning efficiency also increased. Task completion time decreased significantly from a mean of 34.47 minutes to 28.72 minutes, representing an average reduction of 5.75 minutes ($p = 0.003$) with a moderate effect size (Cohen's d = 0.55). This reduction indicates enhanced processing efficiency and arithmetic fluency, suggesting that learners were able to complete tasks more quickly without compromising accuracy. Such improvements are consistent with studies reporting that well-designed educational games can reduce extraneous cognitive load and support more efficient problem-solving in learners with intellectual disabilities [6], [10].

Taken together, these results indicate that the usability and engagement characteristics identified in Section 3.3 were closely associated with improvements in learning effectiveness. The alignment between cognitively accessible interface design, motivational reinforcement, and instructional structure appears to have enabled learners to allocate greater cognitive resources to arithmetic reasoning rather than navigation or task interpretation, supporting both accuracy and efficiency in task performance [6].

While the findings demonstrate robust short-term improvements in arithmetic performance, the persistence of these learning gains over extended instructional periods was not examined in this study. Future research is therefore recommended to investigate long-term retention, skill transfer, and the potential benefits of adaptive difficulty mechanisms in sustaining arithmetic learning outcomes for children with mild intellectual disabilities [10].

3.5. Discussion

The results indicate that the instructional impact of the BRILIAN educational game is best explained by the design coherence achieved through the ADDIE framework—specifically, the tight alignment between learner needs identified in the analysis phase, the accessibility-oriented interaction principles applied during design and development, and the multi-layered evaluation conducted in authentic classroom settings. For children with mild intellectual disabilities (MID), arithmetic learning is often constrained not only by conceptual difficulty, but also by limited working memory, reduced attentional capacity, and challenges in sustaining motivation during repetitive practice [1]–[8]. BRILIAN addresses these constraints by reducing extraneous cognitive load through consistent navigation, minimal text, enlarged visuals, and clear visual hierarchy, while simultaneously increasing germane cognitive processing via progressive task sequencing, immediate corrective feedback, and multimodal instructional scaffolding (audio cues, narration, and instructional videos). This combination helps explain why learners could allocate more cognitive resources to arithmetic reasoning rather than to interpreting interface mechanics—an outcome that is particularly critical in special education settings where interaction complexity can quickly derail learning engagement.

A key contribution of this study is the empirical demonstration that usability, user experience, engagement, and learning effectiveness can be improved simultaneously when the system is developed as an integrated instructional intervention rather than as a standalone game artifact. The usability results (SUS scores above the common benchmark) and the highly positive UX ratings (UEQ-S pragmatic and hedonic dimensions) suggest that the interface successfully achieved clarity and efficiency while also sustaining enjoyment—two conditions that are often treated as competing priorities in learning technology design. These experiential outcomes are consistent with classroom observations and GUESS results showing strong satisfaction and high engagement, reinforcing that the motivational layer was not superficial but structurally connected to instructional flow. Importantly, these design and experience indicators align with the learning outcomes: the significant improvement in arithmetic scores from pre-test to post-test, accompanied by a large effect size, suggests that students were not merely "playing more," but were learning more effectively. Similarly, the meaningful reduction in task completion time indicates improved efficiency and fluency rather than only increased familiarity with the interface. In short, BRILIAN demonstrates that when accessibility features and instructional scaffolds are treated as core design requirements (not optional enhancements), usability gains can translate into measurable learning gains for learners with MID.

Relative to prior game-based numeracy interventions for special education, which often emphasize either motivational appeal (e.g., gamified repetition) or usability outcomes without rigorous learning analysis, this study strengthens the evidence base by linking design decisions directly to both experience metrics and learning performance. Earlier mobile arithmetic games have shown engagement benefits but frequently lacked comprehensive feedback systems, consistent interaction patterns, or expanded arithmetic coverage [12]–[14]. BRILIAN advances this line of work by pairing familiar game mechanics (snake-and-ladders; coin racing) with structured arithmetic progression (addition up to 60; subtraction up to 20), reinforced through immediate multimodal feedback. This design reduces the likelihood that learners progress through activities via guessing or trial-and-error without conceptual correction. The ADDIE-guided development process also supports the argument that instructional quality in special education technologies depends on iterative alignment between objectives, interaction constraints, and evaluation—addressing the research gap identified in the introduction regarding fragmented evaluation approaches and limited empirical evidence of learning effectiveness [10], [11], [13], [14], [16].

From a pedagogical perspective, the convergence of high usability, strong engagement, and significant learning gains supports the positioning of educational games as viable instructional tools in special education rather than supplementary or recreational media.

In classroom practice, tools that reduce dependence on teacher intervention—through predictable navigation, clear feedback, and guided instruction—can increase opportunities for independent practice and help teachers allocate attention to individualized support where it is most needed. BRILIAN's design suggests that effective special education games should be built around three interacting pillars: (1) cognitive accessibility (reducing perceptual and interaction burden), (2) instructional scaffolding (progressive content and error-sensitive feedback), and (3) motivational reinforcement (rewards and enjoyable pacing). The results imply that removing friction from interaction does not merely improve satisfaction; it can directly support learning by stabilizing attention and enabling repeated, successful engagement with arithmetic tasks.

Nevertheless, several considerations temper interpretation and point to future work. First, the evaluation focuses on short-term gains; retention over longer instructional periods and transfer to non-game arithmetic tasks were not assessed. Second, classroom-based trials may include novelty effects that temporarily elevate engagement and performance. Third, although triangulation was applied (students, teachers, standardized instruments, observations, and performance tests), broader generalization would benefit from larger and more diverse samples, longer exposure, and comparative designs (e.g., control groups or alternative interventions). Future research should therefore examine long-term retention, skill transfer, and adaptive difficulty mechanisms that personalize arithmetic ranges and scaffolding intensity to individual learner profiles. Even with these limitations, the evidence consistently suggests that BRILIAN's effectiveness does not come from any single feature in isolation, but from the deliberate integration of accessibility-oriented interface design, scaffolded task progression, and feedback-driven interaction—implemented through a structured instructional design model and validated through comprehensive classroom-based evaluation.

4. CONCLUSION

This study demonstrates that an educational game developed through the ADDIE instructional design framework can effectively enhance arithmetic learning outcomes, usability, and learner engagement among children with mild intellectual disabilities. Consistent with the discussion, the findings indicate that the effectiveness of BRILIAN stems from the systematic alignment of instructional objectives, cognitively accessible

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interface design, multimodal feedback, and progressive task structuring, which together reduce cognitive load while sustaining motivation and supporting arithmetic reasoning. The convergence of usability metrics, user experience evaluations, teacher observations, and learning performance outcomes confirms that instructional design–driven game-based interventions can simultaneously address cognitive and motivational dimensions of numeracy learning in special education contexts. Nevertheless, the study is limited by its relatively small sample size, short intervention duration, and focus on immediate learning gains, which restrict conclusions regarding long-term retention and generalisability. Future research should therefore examine the longitudinal impact of game-based arithmetic learning, incorporate adaptive personalisation and learning analytics, and evaluate scalability across more diverse learner populations and instructional settings to further validate and extend the pedagogical potential of such systems.

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