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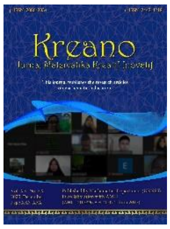

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46 Developing a Computational Educational Game "Math Squirrel" to Improve the Learning Motivation of 6th Grade Elementary School Students

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Abstract

48 Educational games hold substantial potential to create enjoyable and meaningful learning experiences for students. In today's educational landscape, one of the main challenges is maintaining students' interest and
9 motivation, especially amid the rapid advancement of technology and the pervasive influence of digital entertainment. By integrating interactive and engaging elements, educational games can foster learning environments that are both motivating and enjoyable. This study aimed to demonstrate that the computational educational game Math Squirrel is a valid, practical, and effective learning medium for
33 enhancing the learning motivation of sixth-grade elementary school students in mathematics. Developed using the Unity engine and based on the 4D development model, the game underwent validation by subject matter and media experts, yielding average scores of 94.44% and 83.92%, respectively—indicating a high level of feasibility. A trial involving 30 students at SDN 1 Cipocok Jaya resulted in a positive response rate of 87.08%. During gameplay-based learning sessions, students appeared highly engaged, enthusiastic, and actively involved in solving problems embedded in the game. The interactive challenges, colorful visuals, and immediate feedback contributed to a fun and stimulating learning atmosphere. This study concluded that Math
4 Squirrel computational educational game is a valid, practical, and effective tool for increasing the learning motivation of sixth-grade elementary students in mathematics. These findings suggest that Math Squirrel not only enhances learning motivation but also provides an engaging and joyful educational experience, making it a highly feasible and innovative tool for improving student motivation in elementary mathematics instruction.

Keywords: Educational Game; Learning Motivation; Mathematics Learning; Elementary School; Math Squirrel.

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Abstrak

Permainan edukatif memiliki potensi besar dalam menciptakan pengalaman belajar yang menyenangkan dan bermakna bagi siswa. Dalam lanskap pendidikan saat ini, salah satu tantangan utama adalah mempertahankan minat dan motivasi belajar siswa, terutama di tengah pesatnya kemajuan teknologi dan pengaruh hiburan digital yang meluas. Dengan mengintegrasikan elemen interaktif dan menarik, permainan edukatif dapat membangun lingkungan belajar yang memotivasi dan menyenangkan. Penelitian ini bertujuan untuk menunjukkan bahwa game edukasi berbasis komputer Math Squirrel merupakan media pembelajaran yang valid, praktis, dan efektif untuk meningkatkan motivasi belajar matematika siswa kelas enam sekolah dasar. Game ini dikembangkan menggunakan mesin Unity dan model pengembangan 4D, serta divalidasi oleh ahli materi dan media dengan skor rata-rata masing-masing sebesar 94,44% dan 83,92% yang menunjukkan tingkat kelayakan yang tinggi. Uji coba terhadap 30 siswa di SDN 1 Cipocok Jaya menunjukkan respons positif sebesar 87,08%. Selama sesi pembelajaran berbasis permainan, siswa tampak sangat antusias, terlibat aktif, dan termotivasi menyelesaikan soal-soal yang disajikan dalam permainan. Tantangan interaktif, visual yang berwarna-warni, dan umpan balik langsung menciptakan suasana belajar yang menyenangkan dan merangsang. Penelitian ini menyimpulkan bahwa game edukatif Math Squirrel merupakan media pembelajaran yang valid, praktis, dan efektif dalam meningkatkan motivasi belajar matematika siswa kelas enam sekolah dasar. Temuan ini menunjukkan bahwa Math Squirrel tidak hanya meningkatkan motivasi belajar, tetapi juga memberikan pengalaman pendidikan yang menyenangkan dan inovatif, sehingga sangat layak digunakan sebagai alat bantu pembelajaran untuk meningkatkan motivasi siswa dalam pembelajaran matematika di sekolah dasar.

INTRODUCTION

Student motivation is a central element of successful learning, with studies showing that highly motivated students demonstrate greater persistence and academic achievement (Novitasari Widyastuti & Herwin, 2024; Radišić et al., 2024, 2024). Motivation plays a pivotal role in determining students' willingness to engage with challenging content and persevere through cognitive difficulties, particularly in subjects like mathematics. Students with high motivation levels are significantly more likely to perform well in mathematics across various countries, including those in Southeast Asia, and this effect is especially pronounced among sixth-grade elementary students undergoing developmental transitions in cognitive, emotional, and social domains (Hanin & Gay, 2023). Motivation in learning mathematics is closely linked to learners' self-regulation, autonomy, and sense of competence, as highlighted by research on Self-Determination Theory (Shank et al., 2025; C. Wang et al., 2022). Learning motivation refers to the internal drive that compels students to engage in academic tasks, sustain attention, and persevere in solving problems. A growing body of literature underscores that students who are intrinsically motivated tend to adopt deep learning strategies and demonstrate stronger conceptual understanding (Kamberi, 2025). At this developmental stage, students begin to form self-awareness regarding learning objectives and exhibit heightened sensitivity to stimuli that either promote or inhibit their engagement. As a result, the teacher's role becomes not only to deliver content but to create an environment that fosters sustained engagement and positive affective responses. Therefore, understanding the structure of motivation, how it appears in observable behavior, and under what pedagogical conditions it flourishes becomes essential in designing effective and contextually appropriate instructional strategies, particularly in the era of digital learning (Jeon & Lee, 2023)

Motivation to learn is influenced by various interrelated factors, such as student characteristics, instructional methods, learning environments, social support, and particularly the integration of media in the learning process (Almagro & Edig, 2024). Among these, the strategic use of digital media has emerged as a highly influential component in contemporary educational contexts. Numerous studies emphasize that digital tools, when aligned with learners' cognitive and affective profiles, can significantly boost motivation and facilitate deeper engagement (Reinhold et al., 2024). Media that caters to students' interests, such as gamified learning platforms and visual-interactive content, has been shown to support sustained attention and foster a sense of enjoyment in academic tasks, especially in mathematics (Yanuarto et al., 2023). For sixth-grade students who are in a developmental phase marked by increasing independence and digital fluency the integration of educational content with digital applications offers not only novelty but cognitive relevance. Research suggests that immersive educational technologies, including mobile-based applications and educational games, play a critical role in cultivating both intrinsic motivation and collaborative learning tendencies (Abdullah, 2024; Zheng & Wang, 2023). The widespread use of smartphones and internet-based platforms has led to the popularity of game-based learning tools among students, which can be leveraged to transform passive consumption into active, goal-directed learning behavior (Nadeem et al., 2023; Solihah, 2023). When thoughtfully integrated, these digital games can serve as dynamic tools to enhance not only engagement but also conceptual understanding and learning persistence across disciplines, including mathematics. This connection sets the stage for the subsequent discussion on how such tools address observed motivational gaps in real classroom contexts.

Preliminary observations at SDN 1 Cipocok Jaya revealed that students exhibited low engagement and enthusiasm during mathematics lessons conducted through conventional lecture-based methods. Classroom observations indicated that many learners appeared disengaged, expressing feelings of boredom and difficulty in sustaining attention throughout the sessions. Interviews with teachers reinforced these findings, revealing that existing instructional strategies often failed to capture students' interest or stimulate meaningful participation. The learning environment tended to rely heavily on textbook-centered approaches, with limited integration of interactive or student-centered methodologies. At the same time, informal conversations with students uncovered their extensive familiarity with mobile gaming and other digital platforms, which they accessed frequently outside the classroom. This growing disconnect between learners' digital inclinations and the analog nature of classroom instruction presents a critical pedagogical challenge. Similar observations have been documented in Indonesian and international contexts, where traditional models of instruction have struggled to accommodate the digital learning preferences of Generation Z students (Limilia et al., 2022). Consequently, the mismatch between instructional delivery and students' technological fluency underscores the urgent need for contextually responsive innovations in mathematics education that integrate interactive digital media to enhance motivation and cognitive engagement (Godsk & Møller, 2025; Ní Shé et al., 2023). This empirical gap provides a compelling rationale for exploring the development of computational educational games as a means to bridge this disconnect.

Despite the risks associated with excessive gameplay, which may distract from academic responsibilities, educators and parents can strategically leverage students' affinity for digital games by introducing computational educational games as instructional media (Gundersen & Lampropoulos, 2025). When designed with pedagogical intent and aligned with curriculum standards, these games can transform entertainment-oriented platforms into productive learning environments. Educational games are defined as learning tools that integrate instructional content and assessment features in formats that appeal to learners' cognitive and affective domains (Deng et al., 2023). They support active participation and encourage exploratory learning, making them suitable for enhancing understanding in conceptually demanding subjects like mathematics (Hidayat et al., 2024). Recent research has demonstrated that well-structured educational games improve students' problem-solving skills, creative thinking, and content retention, particularly when interactive feedback and adaptive difficulty are included (Boom-Cárcamo et al., 2024). These features are essential in facilitating intrinsic motivation, as they provide students with autonomy, challenge, and a sense of accomplishment (Sbitnev, 2024). Additionally, computational educational games can foster positive emotional responses and reduce anxiety associated with traditional instruction, thereby supporting inclusive and engaging learning environments (Mirani Sergzi et al., 2020). Further assert that such games help students grasp content by learning through play, which aligns well with the developmental needs of elementary students (Bang et al., 2023). This foundation sets the stage for further exploration into how game-based learning, particularly when developed using professional platforms like Unity, can be effectively implemented in classroom settings to address both motivational and instructional challenges.

Numerous studies have highlighted the effectiveness of game-based learning in mathematics education, particularly in enhancing motivation and interest in a subject often perceived as difficult (Debrenti, 2024). However, most of these studies have not integrated advanced development platforms or aligned their game content specifically with local curricula. Additionally, few have explored the use of game engines such as Unity to build scalable and interactive educational tools tailored to the cognitive level and learning environment of Indonesian elementary school students.

In the current digital landscape, students are increasingly attracted to interactive, responsive, and gamified learning experiences that mirror the technological environments they engage with outside school. Traditional classroom settings, which often rely on static instruction and passive reception, struggle to maintain students' attention and interest over extended periods. As such, computational educational games present a robust pedagogical alternative by embedding academic goals within engaging gameplay structures such as levels, point systems, avatars, and scenario-based challenges (Lu et al., 2023). These elements not only increase learner motivation but also foster deeper cognitive processing by encouraging exploration, problem-solving, and iterative learning cycles (Mandasari & Rosalina, 2024). Furthermore, games designed with immediate feedback mechanisms and adaptive pathways can personalize instruction, addressing individual learner differences and supporting differentiated instruction (Yang & Li, 2018). Such personalization enhances both self-efficacy and persistence, especially in subjects like mathematics where learners often face high cognitive load and anxiety (Zourmpakis et al., 2023). Importantly, these games can be implemented in inclusive classroom environments, allowing for broader accessibility and equity in learning outcomes. As education systems worldwide aim to equip learners with 21st-century competencies such as critical thinking, creativity, digital literacy, and collaboration the integration of computational educational games into formal instruction emerges as a timely and evidence-based strategy aligned with global educational goals (Pan et al., 2024).

Unity, a powerful cross-platform game development engine, supports both 2D and 3D environments, making it highly versatile for educational purposes. Its intuitive interface and asset integration enable developers to concentrate on visual storytelling and interactive mechanics without requiring deep programming expertise (Zhang et al., 2025). This accessibility has made Unity a preferred platform for developing game-based educational tools across disciplines, including mathematics. In the context of instructional design, Unity facilitates modular development by allowing clear separation between content logic and visual components, thereby streamlining the collaborative workflow between educators, designers, and programmers (Djakadana et al., 2022). Additionally, Unity supports the incorporation of dynamic feedback systems, real-time data tracking, and adaptive learning pathways, which are critical in supporting personalized and student-centered learning environments (Amrinada et al., 2022). Recognizing the increasing demand for interactive and engaging instruction in mathematics education, particularly for digital-native learners, this study introduces a computational educational game titled Math Squirrel, developed using Unity. The game integrates fundamental mathematical concepts into an immersive format tailored to the cognitive and motivational profiles of sixth-grade students. Grounded in the 4D development model, the design process emphasizes iterative refinement, curricular alignment, and expert validation to ensure the game's relevance and pedagogical integrity. This study aims to rigorously evaluate the validity, practicality, and effectiveness of Math Squirrel in enhancing learning motivation and providing a joyful and meaningful mathematics learning experience, particularly within the context of elementary education in Indonesia. Based on the above background, this study is guided by the following research questions: (1) Is the Math Squirrel game a valid and practical educational tool for teaching mathematics to sixth-grade students? (2) Can it effectively enhance students' motivation in learning mathematics?

METHOD

The research was conducted from March 2022 to September 2022. The subjects consisted of 30 sixth-grade students at SDN 1 Cipocok Jaya. The product was developed using the Research and Development method with the 4D development model. The 4D-development model was developed by Sivasailam Thiagarajan, Dorothy S. Semmel, and Melvyn I. Semmel can be used to develop various types of learning media (Arkadiantika et al., 2019; Suarmita et al., 2025). The model consists of four stages: definition, design, development, and dissemination. The research procedure includes the stages shown below (see Figure 1).

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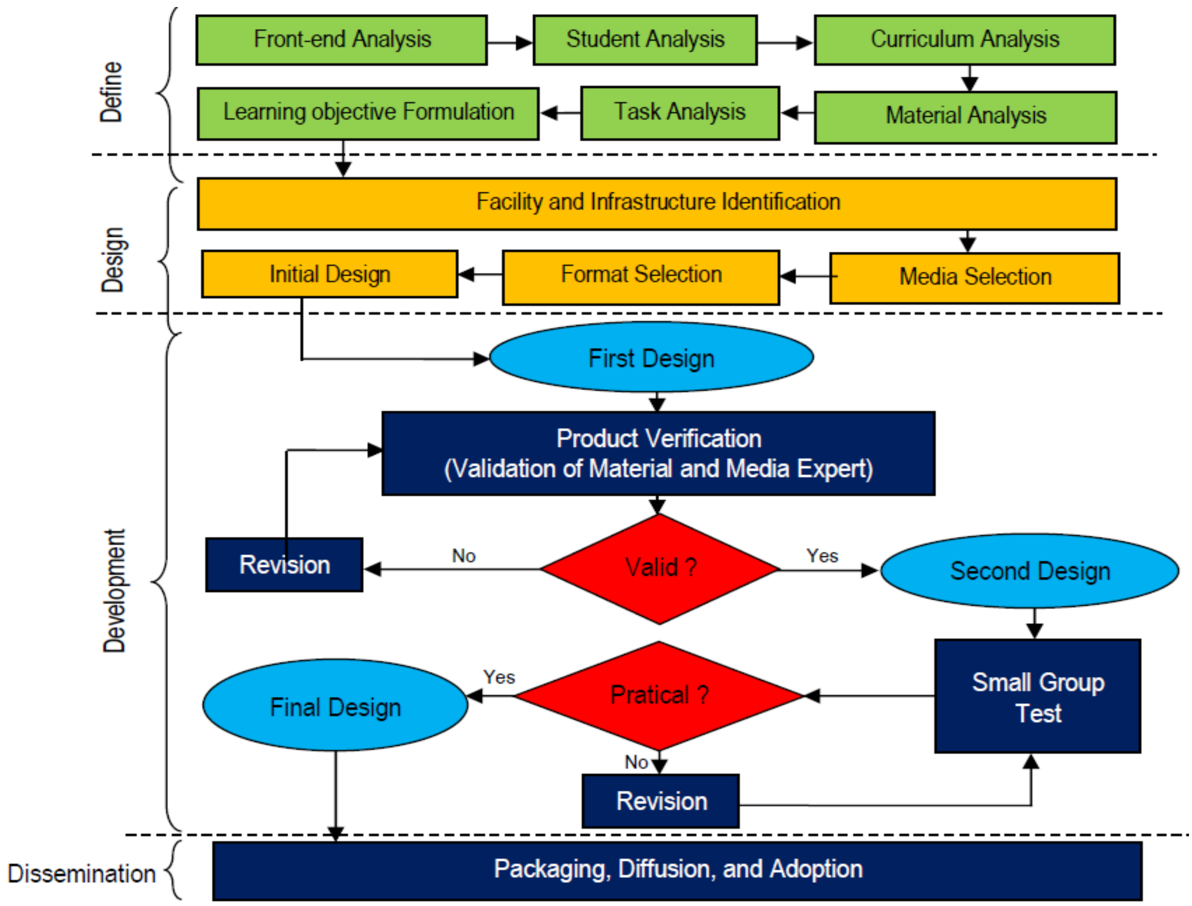

Figure 1. 4D-development Model

In the development research, the validation of learning media was carried out in two stages (Fatmawati & Habiby, 2024). The first stage is validation by media experts and material experts. The second stage is validation by the target user. Data collection methods included both quantitative and qualitative approaches. Quantitative data is obtained from the assessments and responses by validators and target users. Meanwhile, qualitative data is obtained from the criticisms, suggestions, and responses of the test subjects and validators.

1. Qualitative data in the form of written responses were converted into quantitative data using the following criteria:

Table 1. Scoring Rules for the Assesment Sheet for Computational Educational Game Applications

Opinion	Excellent	Good	Fair	Poor
Score	4	3	2	1

The scoring rules for the computational educational game application assessment sheet for validators and target users use the rules as shown in Table 1: a score of 4 is Excellent, 3 is Good, 2 is Fair, and 1 is Poor

2. Count the number of points earned for each assessment item.
   Calculating the ideal percentage

$$Final\ score(\%) = \frac{Score\ obtained}{Maximum\ score} \times 100\%$$

The ideal percentage value is identified by using conditions such as those in Table 2.

Table 2. Likert-type Scale Conversion

Opinion	Scale	Range Value	Interpretation
Excellent	4	76%-100%	Very Feasible
Good	3	51%-75%	Feasible
Fair	2	26%-50%	Less Feasible
Poor	1	1%-25%	Inappropiate

Source : (Firmandasari et al., 2020)

RESULT AND DISCUSSION

Results

The development of learning devices followed the 4D development model by Thiagarajan, as detailed below:

Based on the Research and Development design that has been proposed, the development of the computational educational game, "Math Squirrel" is carried out in 4 stages of development (4D model), namely

Define

This stage aims to determine and define the requirements needed for learning by analyzing the objective and limitations of the material developed in the computational educational game. This stage includes six main steps:

a. Front-end Analysis

The process began with observations and data collection on mathematics learning among sixth-grade elementary school students who found it difficult to catch lessons when the teacher was conducting the learning process. The teacher uses the usual lecture method, which makes students bored, especially when it comes to matching.

b. Student Analysis

In a previous study, (Darmawan & Hasanah, 2022) stated that the characteristics of 6th-grade elementary school students at SDN 1 Cipocok Jaya are included in the category of students who use smartphones for a long time every day. In addition, students like online games, and 93,8% expressed their interest in playing online games with lessons. This is the motivation to develop the computational educational game, "Math Squirrel" so that students do not become bored or disengaged while studying.

c. Curriculum Analysis

A curriculum analysis is helpful for reviewing the applicable curriculum to determine the competencies to be achieved. Since 2019, the Ministry of Education and Culture of the Re-public of Indonesia has carried out an educational revolution by launching the Kampus Merdeka Program at all levels of formal education (Nurulaeni & Rahma, 2022; Resti et al., 2025)). That the concept in the program is basic to constructivist learning. From this per-spective, students build knowledge as a result of interactions between experiences and ob-jects they encounter when learning takes place.

Thus, students must always be active and able to create learning techniques that are right for them. Teachers act as mediators, facilitators, and partners who help build an ideal learning environment for student development. The implementation of Kampus Merdeka in the environment shows that it has not been fully realized due to various problems. The preparation of human resources and supporting facilities are some factors influencing the success of Kampus Merdeka. Based on this, computational educational games are developed to facilitate the success of Kampus Merdeka program.

d. Material Analysis

Material analysis is carried out by identifying the main materials that need to be taught and included in the learning media, collecting and selecting relevant materials and systematically rearranging the. The selected material focuses on multiplication and division, as students still need more practice in calculations. With the computational educational game "Math Squirrel", students are accustomed to counting while using the principles of multiplication and division to win the game, to help them become more proficient in calculations.

e. Task Analysis

The tasks given by teachers at SDN 1 Cipocok Jaya were not fully completed by the students. After the interview process, the students stated that they did not like doing the task because they did not understand it and were less motivated to finish it. In fact, the task given by the teacher are so that students study over again the material that has been taught and students practice their abilities according to material. Therefore, this computational educational game contains tasks given by the teacher by incorporating challenges that can enhance students' motivation to complete the tasks

f. Learning Objective Formulation

The purpose of learning with the development of the computational educational game "Math Squirrel" is so that the students can understand the principles of multiplication and division and then use them in daily calculations. In addition, the learning objective to be achieved with this computational educational game is to improve students' motivation in learning mathematics, especially multiplication and division material.

Design

- Facility and Infrastrukture Identification

This identification is undertaken to determine the availability of facilities and infrastructure to support the product. After carrying out initial observations and interviews with the students, it was found that the learning facilities and infrastructure were adequate.

- Media Selection

This study uses two devices, namely PC (Personal Computer) and Android Mobile. Meanwhile, a pen tablet is used to create UI/UX design. Three programs were used, namely Photoshop to design and character in the game, Visual studio as a sketch to create c# programming code for the game objects, and Unity engine 2D to create videos, objects, and systems in video games.

- Initial Design

The initial design refers to the first version of the computational educational game that will be tested.

- Scene Screen/Scene Credit

Figure 2. Scene Screen

- Main Menu

In the main menu, there are 3 buttons that lead to stage lobby, settings, and help. These buttons can assist the player find out what they need.

Figure 3. Main Menu

- Display of Stage Lobby/Menu

This menu displays various stage levels that the player must complete. If the player does not have data storage, it will start from the beginning of the game or start the initial stage.

Figure 4. Display of Stage Lobby

- Display of the Start Screen

At the beginning of the game, if the player does not have saved data in this game, the player will be given a notification or information on how to play it so the player can understand the game.

Figure 5. Display of the Start Screen

- Display of the Question Wall

The player cannot pass through the question wall to get the key (cherry) in this section. This wall can be opened by answering a calculation question so that it will get a key (cherry). However, if the player answer incorrectly, then the player will receive a damage effect by reducing one blood point.

Figure 6. Question Wall

- Display of the Mission Completed

This info will appear if the player successfully completes the mission contained in the stage of game. Immediately, the game proceeds to the score scene.

Figure 7. Display of the Mission Complete

- Display of the Mission Failed

This occurs when the player hit objects until three points of blood run out and results in defeat. If the player falls into a hole, it will result in the sudden death.

Figure 8. Display of the Mission Failed

Develop

At this stage, two activities are carried out: [1] expert appraisal, a technique to validate product design, and [2] developmental testing, product design trial activity on the real target subject. Both activities use the following steps:

a) Product Verification

Product Verification was carried out by media experts and material experts. This stage aims to produce the final design of the computational educational game "Math Squirrel". The final design of this game will be completed after revisions are made based on criticism, suggestion, and recommendation from experts and students' respons. The assessment instrument is used to obtain data and suggestion from experts of material expert assessment instruments, media expert assessment instruments, and students' responses instruments as the target users of the computational educational game "Math Squirrel". The results from experts and students from in the development stage can bee see in Table 3.

Based on the results obtained from material and media experts, the overall appearance of the computational educational game "Math Squirrel" is 89,18%. Furthermore, the value of material and media expert's assessment is converted with a conversion table so this game is considered very feasible.

b) Revision of Product

Revision of product based on validation data by experts. According to data obtained in critical, suggestion, and recommendation from material and media experts. It is brought out in revisions or improvements to this computational educational game. Meanwhile, the improvements made to this game are by the suggestion of material and media experts as follows:

- Using consistent language
- Some sentences must be adjusted to EYD while adhering to the rules of writing appropriate questions and answers.
- Enhancing the visual appeal of shapes and colors.

Table 3. The Result of Material Expert and Media Expert Assesment

No	Respondent	Value (%)	Qualification
1	Material Expert	94,44	Very Feasible
2	Media Expert	83,92	Very Feasible
Overall Percentage		89,18	Very Feasible

c) Small Group Test

Small group test was carried out on 30 6th-grade students at SDN 1 Cipocok Jaya as a sample of target users. Meanwhile, the result of this test is 87.08%. Thus, the quality of computational educational game is classified as Very Feasible. This is in line with several studies that have been conducted that show the use of the games can improve students' motivation in learning mathematics because it is fun, enjoyable, and easy to use (Ratnaningsih, 2022).

Disseminate

The dissemination phase was conducted after completing the development and validation stages. The final version of the Math Squirrel game was compiled into both Android and PC formats and made accessible to sixth-grade teachers and students at SDN 1 Cipocok Jaya. To support product implementation, a user guide was developed to assist teachers in navigating the game features and integrating it into mathematics instruction. A short orientation session was also conducted to familiarize the teachers with gameplay mechanics, pedagogical objectives, and classroom integration strategies

In addition to classroom application, digital copies of the game and supporting materials were shared with educators in neighboring elementary schools within the Serang district through online communication platforms. This effort was intended to explore the scalability and broader adoption of the game in similar educational contexts. The dissemination activities demonstrate the product's readiness for use and alignment with the Kampus Merdeka initiative, which encourages the adoption of innovative learning tools to promote student engagement and autonomy. These steps ensured that the game was not only developed and validated but also introduced into actual educational settings, thus marking the completion of the research process

The dissemination was designed to highlight the practical utility of Math Squirrel in real classrooms, reinforcing its feasibility and potential impact beyond the research site. This process addressed the final phase of the 4D development model and confirmed that the study had progressed beyond development into implementation, thereby validating its status as a completed research project.

Discussion

The findings of this study support the hypothesis that computational educational games can significantly enhance students' motivation to learn mathematics, particularly in sixth-grade elementary education. The high validation scores from subject matter experts (94.44%), media experts (83.92%), and student feedback (87.08%) affirm the validity and practicality of the Math Squirrel game. These results reflect a rigorous and responsive development process grounded in the 4D model, highlighting the importance of iterative feedback and user-centered design. Consistent with prior research, educational games such as Math Squirrel have been shown to foster both affective and cognitive engagement by providing dynamic interactivity, immediate feedback, and visually stimulating interfaces (Hellín et al., 2023; Meng et al., 2024; Puig et al., 2023). These features align well with the principles of cognitive load theory, which emphasizes the role of multimedia in facilitating meaningful learning when extraneous load is minimized (Ertem Akbaş & Yildirim, 2024). In this study, students demonstrated increased persistence and positive emotional responses, which are indicators of deeper processing and long-term retention. Moreover, the observed learning behaviors such as self-initiated repetition, peer collaboration, and exploratory play are aligned with constructivist learning theory and active learning models that prioritize learner autonomy and authentic context (Çibukçiu, 2025). These outcomes also mirror broader findings that digital games foster creative, participatory, and active learning environments conducive to developing 21st-century skills (Bulut et al., 2022; Robert et al., 2023).

Additionally, the game's success exemplifies how students' affinity for digital games can be repurposed to support academic goals. During the Define phase, student analysis revealed that learners were already familiar with mobile games and eager to engage with them in educational contexts. This finding echoes broader trends in digital education where game familiarity serves as a foundation for increased engagement and academic persistence (Chen & Liang, 2022). The Math Squirrel game strategically capitalized on this by embedding mathematics content into a playful, interactive, and visually engaging environment that felt both familiar and motivating to students. This dual-purpose design not only addressed common motivational barriers in mathematics instruction but also supported key tenets of constructivist learning theory, emphasizing autonomy, relevance, and active problem-solving (Deng et al., 2023; Park et al., 2025; Pungong et al., 2023; Wiehe et al., 2025). Moreover, the integration of contextualized challenges and self-paced exploration mirrors successful applications of serious games in STEM education, where learning is mediated through iterative feedback and meaningful decision-making (L.-H. Wang et al., 2022). These elements are especially crucial in the context of the Kampus Merdeka curriculum, which prioritizes flexible, student-centered approaches. Ultimately, this approach reinforces the value of experience-driven knowledge construction and supports long-term learning gains across diverse learner profiles (Zhong et al., 2025).

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Furthermore, the study uncovered a potentially important but underexplored aspect: differences in gender-based responses to the educational game. While gender was not a primary variable in the study design, classroom observations consistently noted that male students displayed more competitive, animated, and fast-paced behaviors during gameplay. In contrast, female students often demonstrated more focused, strategic, and collaborative approaches when engaging with the same game elements. These contrasting behaviors suggest that gender-based engagement styles may affect how learners experience and benefit from game-based learning environments. This preliminary insight is consistent with prior research indicating that gender differences can shape digital game preferences, learning strategies, and motivation levels in educational settings (Baker et al., 2025). Although the study did not employ statistical testing to confirm these patterns, the qualitative observations offer valuable direction for future research. Game designers and educators could explore adaptive learning pathways or customizable features that better accommodate different engagement tendencies across genders. Addressing these differences through inclusive design may enhance the equity and efficacy of future educational games.

From a methodological perspective, the use of the 4D model ensured that each phase of development was guided by formative feedback, iterative testing, and alignment with pedagogical goals. The Define, Design, Develop, and Disseminate phases were systematically applied to establish the product's usability, contextual relevance, and educational integrity, as well as to ensure responsiveness to student needs and curriculum standards (Abidin et al., 2024; Agbo et al., 2023; Gui et al., 2023; Putra & Rambe, 2023). This approach is in line with recent instructional design research emphasizing user-centered and adaptive development cycles in educational technology projects (Suryani et al., 2024). Moreover, by embedding stakeholder input throughout the process, the study reinforces the importance of co-design principles, especially when targeting young learners in diverse educational settings. Through this process, the development of Math Squirrel demonstrates how a game-based learning tool, grounded in both theoretical foundations and field-based practices, can simultaneously meet curriculum expectations and foster digital engagement. The innovation of this study lies not only in its contextual adaptation of Unity-based design for Indonesian elementary students but also in its successful integration with the national education reforms, particularly those aimed at supporting independent learning and digital literacy. Therefore, the methodological rigor and curricular alignment achieved through the 4D model represent a critical contribution to scalable educational game development frameworks. Taken together, these findings confirm that the Math Squirrel game is both a valid and practical instructional tool and an effective medium for enhancing sixth-grade students' motivation to learn mathematics

Implication of Research

The implications of this study are significant for both educational practitioners and digital content developers. First, the success of Math Squirrel demonstrates the feasibility of embedding mathematics content within game mechanics that foster engagement and motivation. This can serve as a model for other educational games targeting different subjects or learning outcomes.

Second, integrating Unity-based educational tools into classrooms supports the principles of differentiated and inclusive learning, addressing diverse learner needs through personalized and interactive experiences. Third, preliminary gender-related behavioral differences observed during implementation indicate that future game design could benefit from incorporating adaptive features or narrative elements that cater to varied learning preferences. Finally, the alignment of this initiative with Indonesia's Independent Learning policy reinforces its policy relevance and scalability within the national curriculum framework

Limitation

Despite its contributions, the study has several limitations. The research was conducted in a single elementary school, which restricts the generalizability of the findings across different geographic or socio-economic contexts. The sample size was relatively small, and the evaluation relied partly on subjective measures such as student observations and teacher feedback. Additionally, while the Unity platform allows for scalability and integration of advanced features, technical challenges may arise when implemented in schools with limited infrastructure or ICT support. Gender observations, although noted qualitatively, were not subjected to statistical analysis, which limits the strength of conclusions regarding differential effects. Future research should aim to include larger, more diverse samples and consider conducting controlled trials to evaluate the impact of gender, prior gaming experience, and digital literacy on students' interaction with educational games in mathematics.

CONCLUSION

This study concludes that the Math Squirrel computational educational game is a valid, practical, and effective learning tool for enhancing sixth-grade students' motivation to learn mathematics. Developed through the 4D development model and validated by subject matter and media experts, the game demonstrated high levels of feasibility, with validation scores of 94.44% and 83.92% respectively. Furthermore, a trial implementation with 30 sixth-grade students resulted in a positive response rate of 87.08%, indicating that the game was not only engaging but also well-received as an instructional medium. The interactive design elements, immediate feedback, and game-based challenges successfully increased student engagement, supported autonomy, and promoted a joyful learning experience. These features are essential in overcoming motivational barriers in elementary mathematics learning.

Aligned with constructivist learning theory and Indonesia's Independent Learning curriculum, Math Squirrel supports the development of students' cognitive and affective domains by integrating meaningful digital content into classroom instruction. The study also revealed preliminary gender-based differences in gameplay behavior, with boys displaying more competitive tendencies and girls demonstrating more collaborative strategies. While not statistically tested, these observations suggest a direction for future research on personalization in educational game design. Overall, this research contributes to the growing body of literature affirming that well-designed computational educational games can transform traditional instruction into dynamic, engaging, and inclusive learning environments. Math Squirrel not only meets the academic and motivational needs of elementary learners but also holds promise as a scalable innovation for broader application within Indonesian mathematics education.

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