EDUMATSAINS
JURNAL PENDIDIKAN MATEMATIKA DAN SAINS
E-ISSN:2527-7235
Volume 10 Issue. 3, January 2026, pp 162-174
http://ejournal.uki.ac.id/index.php/edumatsains

PEDAGOGICAL DESIGN OF DIGITAL EDUCATIONAL GAMES FOR IMPROVING STUDENTS' MATHEMATICAL CONCEPTS UNDERSTANDING : A SYSTEMATIC LITERATURE REVIEW

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Article Info
Article history:
Received : December 2nd, 2025
Revised : January 29th, 2026
Accepted : January 29th, 2026
Available online : January 31st, 2026

https://doi.org/10.33541/edumatsains.v10i3.7609

Abstract
The use of digital educational games has become a significant trend in 21st-century learning. Integrating technology into instructional activities offers a promising approach to mathematics education, particularly in enhancing students' understanding of mathematical concepts. This study aims to analyze how the development of digital educational games can improve students' conceptual understanding in research conducted between 2015 and 2025. Employing a Systematic Literature Review (SLR) with the PRISMA model, this study utilized the Publish or Perish 8 application to retrieve relevant articles from Scopus and Google Scholar. An analysis of 14 selected studies indicates that the development of digital educational games has a positive impact on students' understanding of mathematical concepts. However, supporting factors such as game pedagogical design, the validity and practicality of digital educational games as instructional media must be carefully considered. Adhering to sound game-design principles is essential for creating a competitive and enjoyable learning environment that fosters students' motivation and interest, which in turn enhances their conceptual understanding. Emotional aspects such as feelings of enjoyment, challenge, and pride after completing tasks within the game also show positive correlations with learning outcomes.

Keywords: Digital Educational Games, Game Based Learning, Understanding of Mathematical Concepts

1. Introduction

Research on game-based learning, particularly the use of digital educational games, has shown an increasing trend in line with the growing integration of technology in education (Qian & Clark, 2016). Educational games, as a subset of serious games, differ from entertainment games in

that they incorporate assessment components (Sukajaya et al., 2015). Learning technologies especially dynamic systems that incorporate movement offer promising new approaches to mathematics learning that are not possible through traditional methods (Chan et al., 2020). Computer games are interactive, governed by a set of agreed-upon rules and constraints, designed with clear goals, and provide continuous feedback that enables players to monitor their progress toward achieving learning objectives (Clark et al., 2016; Sukajaya et al., 2012).

One of the goals of education is the mastery of knowledge, including students' understanding of mathematical concepts. Conceptual understanding in mathematics is a crucial component of learning, as it represents a logical construction that clearly and meaningfully connects facts, procedures, and ideas, forming mental representations of mathematical objects (Bocatto & Toledo, 2009; Grouws & McNaught, 2008; Lovett & et al., 2019). It is a mental process that links prior knowledge with new knowledge, thereby forming an optimal cognitive framework (Smith, 2009; Suarsana et al., 2018). Students' conceptual understanding is influenced by several factors, such as reflective thinking, interaction, and the use of models or learning tools (Walle, 2008). Therefore, it is important to develop learning tools that encourage reflective thinking and facilitate interaction with instructional media, one of which is digital educational games.

Therefore, innovative learning media are needed that can encourage reflective thinking and facilitate active student interaction in learning. Varios studies have shown that digital educational games can enhance meaningful learning by offering elements such as challenge, curiosity, self-expression, discovery, immediate feedback, clear goals, player control, engagement, collaboration, competition, diverse rewards, and low-risk failure. Consequently, educational games can support contextual learning, enhance social interaction, increase motivation and engagement, and provide opportunities to develop 21st-century skills such as collaboration, critical thinking, and problem-solving (Agustini et al., 2024; Devi et al., 2025; Qian & Clark, 2016).

Several studies have shown that digital educational games can simplify mathematical concepts, increase student motivation, and enrich students' emotional experiences such as feelings of achievement and self-confidence which contribute positively to learning outcomes (Al-Nawaiseh, 2025; Jalloul, 2019). Learning becomes more enjoyable, varied, and accessible due to the attractive design of educational games, which integrate images, text, sound, and animation to motivate students (Agustini et al., 2024; Haloho et al., 2023; Suarningsih et al., 2024). In short, educational games can introduce new knowledge, reinforce previously learned content, train skills, enable experience-sharing, support concept discovery, and foster learning outcomes (Hong et al., 2009). A meta-analysis by Turgut and Temur (2017) further supports this claim by demonstrating the effectiveness of educational games in improving students' conceptual understanding. Therefore, this study aims to analyze the aspects considered in research on the development of digital educational games can enhance students' understanding of mathematical concepts. With the expectation that it may serve as a reference for future related research.

2. Methods

This study employed a Systematic Literature Review by examining the results of research on the development of mathematics educational games. The systematic review guideline used was the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which is comprehensive, transparant, and impartial on the results of previous studies on the development of digital games in mathematical learning. The stages in this study are (1) *identification*, is carried out by searching for articles using keywords in the Publish or Perish 8 application; (2) *screening*, is the process of sorting articles that have been obtained based on the criteria in table 1; (3) eligibility, is carried out by sorting articles that are in accordance with the research topic; and (4) included, is the placement of articles that are suitable for use as research material (Moher et al., 2010). The eligibility criteria are presented in the table below.

Table 1.
Article Eligibility Criteria

Criteria	Inclusion	Exclusion
Document Type	Articles published in international journals, international conferences, international seminars, or Sinta 1–4	Books, national seminars, Sinta 5–6 journals, papers, or other unpublished forms of publication
Publication Year	2015–2025	Before 2015
Accessibility	Downloadable articles	Articles that cannot be downloaded
Research Method	Development research, quantitative research, or Systematic Literature Review	Other research types that do not support this study
Research Subjects	Elementary, junior high, and senior high/vocational school students	Kindergarten, special education schools, or higher education
Subject Area	Mathematics	Non-mathematics subjects
Language	Indonesian or English	Articles in languages other than Indonesian or English

RESEARCH RESULTS

The researcher used the Publish or Perish 8 application to retrieve relevant articles indexed in Scopus and Google Scholar. Several keywords were employed in the search process, including *"math education game, understanding math concept," "educational games for understanding mathematical concepts," "game-based learning, understanding mathematical concept," "game edukasi, pemahaman konsep matematika,"* and *"edutainment, pemahaman konsep matematika."* A total of 495 articles related to these keywords were initially obtained. Subsequently, 481 articles were excluded as they did not meet the eligibility criteria outlined in Table 1. The remaining 14 articles included for review are presented in the table below.

Table 2.
Articles Reviewed in the SLR

No	Author(s)	Research Title	Research Findings
1	Fokides, E. (2018)	*Digital Educational Games and Mathematics: Results of a Case Study in Primary School Settings*	Learning outcomes using educational games to teach mathematical concepts were better than conventional learning, though not significantly higher than contemporary learning. Students showed positive motivation and interest, and were able to learn effectively.
2	Chan, J. Y-C; Lee, J-E; Mason, C.A.; Sawrey, K.; Ottmar, E. (2020)	*From Here to There! A Dynamic Algebraic Notation System Improves Understanding of Equivalence in Middle-School Students*	Students who learned using FH2T demonstrated better conceptual understanding than those who learned conventionally.
3	Sarma, H.; Shaik, M.; Tangirala, S. T.; Singh, S. K. (2023)	*Game-Based Virtual Reality Platform for Geometry*	Students' mathematical conceptual understanding increased, and 83% of students reported that they easily understood geometric shapes using the VR game-based platform.
4	Al-Nawaiseh, S.J. (2025)	*The Impact of Using the Digital Educational Games Blog on Enhancing Mathematical Concepts Among Sixth-Grade Students in Jordan*	Digital educational games had a significant effect on improving sixth-grade students' understanding of mathematical concepts. These games helped simplify complex concepts, increased students' motivation, and enhanced participation.
5	Setiyani; Sumarwati, S.; Sagita, L.; Fadhlurrohman, D. (2021)	*The Incredible Boong Gi: Educational Game RPG for Mathematical Understanding Ability*	The RPG educational game was found to be valid, practical, and capable of moderately improving students' mathematical understanding.
6	Putra, W. D. P. & Setyaningrum, W. (2019)	*The Effect of Game-Based Learning Toward Conceptual Understanding*	Game-based learning was found to be ineffective in terms of conceptual understanding. There

No	Author(s)	Research Title	Research Findings
			were differences in conceptual understanding between students who used game-based learning and those who learned conventionally.
7	Apriyantini, N.P.D.; Warpala, I.W.S.; Sudatha, I.G.W. (2024)	*Game Edukasi Berbasis Matematika Realistik untuk Meningkatkan Kemampuan Pemahaman Konsep pada Mata Pelajaran Matematika (Mathematics Realistic-Based Educational Game to Improve Conceptual Understanding in Mathematics)*	The realistic mathematics-based educational game was validated as practical and effective in improving students' conceptual understanding.
8	Enjelita; Oktaviana, D.; Ardiawan, Y. (2023)	*Pengembangan Game Edukasi Matematika Berbasis Android Menggunakan Software Construct 2 terhadap Kemampuan Pemahaman Matematis (Development of Android-Based Mathematics Educational Games Using Construct 2 Software on Mathematical Understanding Ability)*	The educational game developed using Construct 2 was valid, practical, and effective in improving students' conceptual understanding.
9	Ariyanto, L.; Rahmawati, N. D.; Haris, A. (2020)	*Pengembangan Mobile Learning Game Berbasis Pendekatan Kontekstual terhadap Pemahaman Konsep Matematis Siswa (Development of a Contextual Approach-Based Mobile Learning Game for Students' Conceptual Understanding)*	The contextual-approach mobile learning game was validated as practical and effective in improving students' conceptual understanding.
10	Firdausi, I. & Suparni (2022)	*Game Edukasi Deck Card untuk Memfasilitasi Pemahaman Konsep Siswa Materi Pecahan (Android Deck Card Educational Game to Facilitate Students' Conceptual Understanding of Fractions)*	The Android-based Deck Card game was validated as effective for facilitating junior high school students' conceptual understanding of fractions.

No	Author(s)	Research Title	Research Findings
11	Gunawan, M. S.; Nofriati, N. F.; Husnah, U. (2025)	*Development of the "GeoQuest AR" Educational Game Based on Augmented Reality to Enhance Geometry Concept Understanding in Junior High School Students*	The AR-based "GeoQuest AR" educational game was validated and significantly improved students' understanding of geometry concepts. Paired sample t-tests indicated significant improvements from pre-test to post-test. AR integration effectively enhanced engagement and understanding.
12	Pratiwi, N.; Djatmika, E. T.; Munzli (2023)	*Media Pembelajaran Interaktif "Kerkaba"" Berbasis Game Edukasi untuk Meningkatkan Pemahaman Konsep Operasi Hitung Perkalian dan Pembagian Bilangan Cacah ("Kerkaba" Interactive Learning Media Based on Educational Games to Improve Understanding of Multiplication and Division of Whole Numbers)*	The "Kerkaba" interactive game-based learning media was validated as practical and effective in improving students' understanding of multiplication and division concepts.
13	Laswadi; Handican, R.; Nasution, E.Y. P. (2023)	*Instructional Edutainment Media "Number Game" Based on Mobile Technology to Improve Mathematical Conceptual Understanding*	The "Number Game" edutainment media was validated as practical and effective in improving students' mathematical conceptual understanding.
14	Ardani, R. A. & Salsabila, N. H. (2020)	*Media Pembelajaran Berbasis Game : Dapatkah Meningkatkan Pemahaman Konsep Matematis? (Game-Based Learning Media: Can It Improve Mathematical Conceptual Understanding?)*	The game-based learning media for plane figures met validity criteria and was suitable for use. Its effectiveness was attributed to five principles: (1) intrinsic motivation, (2) intense enjoyment in learning, (3) authenticity, (4) autonomy, and (5) experience-based learning. The media improved students' mathematical conceptual understanding.

Most of the studies employed a Research and Development (R&D) design. Several R&D models were used, including ADDIE (4 studies), Lee & Owens (2 studies), SAM (1 study), and PPE (1 study). These were followed by experimental research designs, consisting of true experiments and quasi-experiments, as well as qualitative research. The types of research designs used in the reviewed articles are presented in Diagram 1. The majority of the developed games were educational types that consisted of question and answer formats. Other game types included platform-based games such as Microsoft's Kudo Lab, blog-integrated games, and games embedded within interactive learning media. Additionally, some studies developed adventure games, role playing games (RPG), and puzzle based games. The various types of games developed in these studies are presented in Diagram 2.

Figure1.
Types of Research Designs in the Reviewed Articles

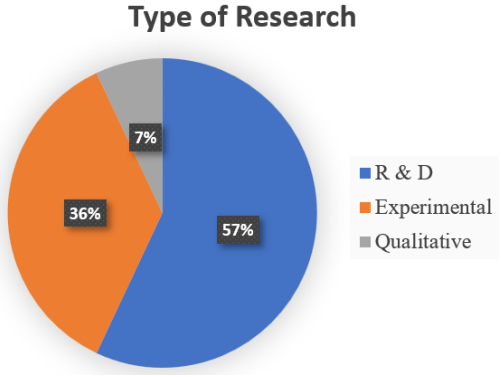
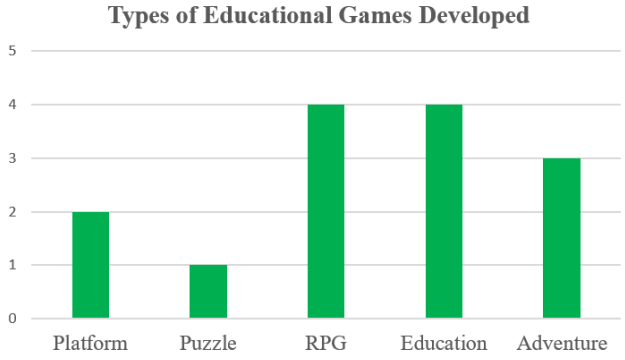


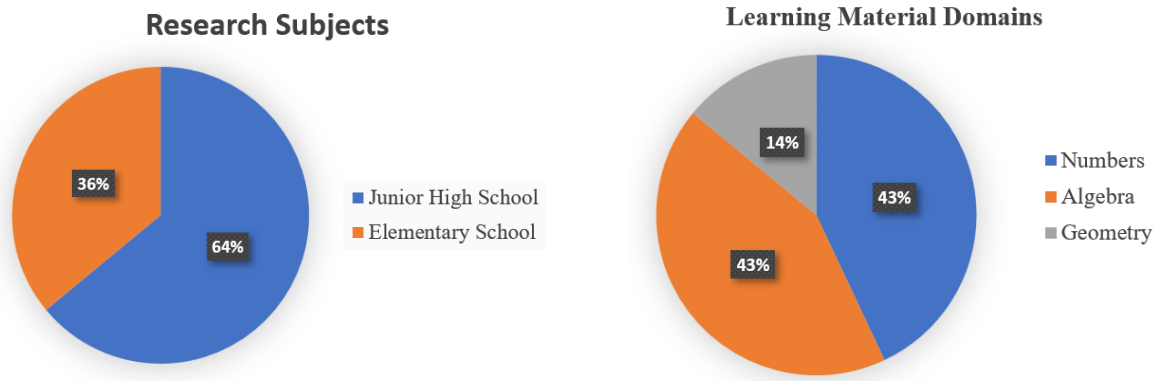
Figure 2.
Types of Digital Educational Games in the Reviewed Studies



The majority of the research was conducted at the junior high school level (64%), with the remainder at the elementary school level (36%). The educational levels used as research samples and the learning material domains in educational games are presented in the diagram below.

Figure 3.
Research Subjects

Figure 4.
Learning Material Domains in Digital Educational Games



3. Result and Discussion

Research and Development studies have shown that the developed digital educational games are valid, practical, and effective in improving students' understanding of mathematical concepts (Apriyantini et al., 2024; Ariyanto et al., 2020; Enjelita et al., 2023; Gunawan et al., 2025; Laswadi et al., 2023; Pratiwi et al., 2023; Setiyani et al., 2021). Experimental research also indicates that students who learn using educational games achieve better conceptual understanding than those who learn without them (Chan et al., 2020; Fokides, 2017). Learning that integrates educational games is more effective than conventional instruction. By integrating educational games into learning, students can be motivated to learn more innovatively, thereby improving their academic performance (Al-Nawaiseh, 2025). In a study conducted by Sarma et al. (2023), 83% of students reported that they could easily understand various geometric shapes using a Virtual Reality based game platform.

However, experimental research conducted by Putra & Setyaningrum (2019) found that game-based learning was not effective in terms of conceptual understanding. Nonetheless, differences were still observed between students taught using game-based learning and those taught through conventional methods. This indicates the risk of superficial learning, where students focua more on achieving scores, levels, or winning than on exploring concepts, strategies, dan reflecting. Sukajaya et al. (2015) also noted that limited time reduced students' ability to determine appropriate solutions, especially for students who require more time to develop their understanding.

In implementing and developing educational games, it is important to consider that technology often reduces the need to prioritize knowledge deeply, use metacognitive strategies, question prior ideas, generate examples, compare alternative solutions, connect with experiences, understand new experiences, create new connections, and analyze previous meaningful connections (Putra & Setyaningrum, 2019)). Therefore, several factors that may influence the success of game-based learning must be considered. The validity and practicality of digital educational games as learning media are also essential. Game validity includes the relevance of the content to the competencies students must master, as well as design validity, which should be attractive, clear, easy to understand, and free of bugs. The practicality of educational games encompasses four aspects: ease of use, display, content, and user satisfaction (Setiyani et al., 2021).

To ensure that educational games become effective learning media, five principles must be considered: (1) intrinsic motivation, (2) learning through intense enjoyment, (3) authenticity, (4) independence and autonomy, and (5) experiential learning (Ardani & Salsabila, 2020).

Teachers must pay attention to students' motivation as a crucial aspect of creating an enjoyable learning environment. Educational games should have clear learning objectives, simple rules, and content appropriate to students' developmental levels, with visual and auditory effects that enhance learning quality (Al-Nawaiseh, 2025). Immediate feedback should be provided, along with challenges and reinforcement to ensure continuous learning, motivating students to progress and fostering deeper cognitive engagement (Al-Nawaiseh, 2025; Apriyantini et al., 2024). Motivational aspects significantly engage and attract students in digital game-based learning. Moreover, digital game-based learning actively supports, strengthens, and accelerates the learning process, contributing to the development of higher-order cognitive skills (Hong et al., 2009). Educational games can also be designed to manipulate symbolic representations of mathematical objects (Chan et al., 2020).

Intrinsic motivation in educational game use can be enhanced by: (1) creating engaging storylines or missions, (2) adjusting game difficulty to student characteristics, (3) gradually increasing difficulty, (4) providing rewards and feedback, (5) using appealing graphic designs, and (6) balancing game elements with mathematical content (Ardani & Salsabila, 2020). This aligns with Chen & Ren (2013), who explain several reasons educational games are suitable for learning: (1) they combine entertainment and education, making learning more engaging; (2) mathematical problems are presented through storylines, enabling students to complete tasks without focusing solely on formulas and equations; (3) games provide challenges; and (4) games generate satisfaction for students when playing them.

Educational games offer advantages, as they can be controlled directly by students individually, in groups, or as a whole class, enabling learning to be adjusted to students' needs and levels of understanding (Pratiwi et al., 2023; Sulasteri et al., 2021). Student participation can be optimized by using digital educational games that emphasize active engagement and learner autonomy. The use of attractive animations and narration in educational games increases students' interest, enthusiasm, and motivation to learn (Apriyantini et al., 2024; Gunawan et al., 2025; Laswadi et al., 2023). Educational games can be designed using interactive buttons and activities that enhance understanding by allowing students to observe examples and non examples, with the possibility of repeating the game if they choose incorrectly. Such learning aligns with constructivist theory by increasing student activity in making connections between the game and mathematical concepts, thereby improving conceptual understanding (Gunawan et al., 2025; Laswadi et al., 2023; Purwadi et al., 2019). This confirms that game pedagogical design is a crucial factor in distinguishing games as entertainment tools from games as meaningful learning media.

Theoretically, these findings reinforce constructivism and cognitive flexibility theories. Educational games provide a learning environment that allows learners to construct their knowledge through exploration, manipulation of symbolic representations, and interaction with educational games (Sukajaya et al., 2020). Through game – based learning, there is a shift in epistemological perspective from an objectivist to a constructivist viewpoint (Setiyani et al., 2021).

Learners are viewed not merely as recipients of knowledge. These findings also emphasize the importance of intrinsic motivation in learning. The priciples of autonomy, challenge, feedback, motivation, scaffolding, and assessment in educational games contribute to deeper cognitive engagement (Lutfiyatun, 2015).

4. Conclusion

An analysis of 13 out of the 14 studies indicates that digital educational games can positively enhance students' conceptual understanding. Meanwhile, one study reported that game based learning was not effective when assessed from the perspective of conceptual understanding. In the development and implementation of educational games, it is important to consider gameplay duration so that students have sufficient time to demonstrate their performance effectively, while ensuring that the session is not too long to avoid boredom. The use of educational games must also take into account that technology often reduces the need to prioritize deep knowledge, employ metacognitive strategies, question prior ideas, generate examples, compare alternative solutions, make comparisons with personal experience, understand new experiences, form new connections, and analyze prior meaningful connections.

To achieve the intended learning outcomes, the pedagogical design of the game, the validity and practicality of digital educational games as mathematics learning media are important factors must be considered. The development of educational games should be guided by five principles: (1) intrinsic motivation, (2) learning through intense enjoyment, (3) authenticity, (4) independence and autonomy, and (5) experiential learning. The use of a responsive game interface, point and reward systems, time limits, and the presentation of contextual problems can effectively create a competitive and enjoyable learning environment. These aspects help foster students' motivation and interest in learning. Therefore, in the development and use of digital educational games, it is necessary to prioritize the alignment between learning objectives, game activities, and students' thinking processes (*learning trajectory*). Teachers as facilitators play a role in guiding students to connect the experience of using educational games with formal mathematical concepts. This is necessary to prevent students from only learning superficially and to ensure that the use of educational games contributes to improving conceptual understanding.

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