Games in Mathematics Education: Trends and Methodological Approaches in the Context of the Congress of European Research in Mathematics Education (CERME) Review

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Abstract: This study aimed to examine the studies on digital games presented in The Congress of European Research in Mathematics Education (CERME) using a systematic analysis approach in terms of research method, data collection tool, and how they define digital games. Sixteen studies related to games were selected from the proceedings. The findings of the research revealed that the number of studies on games has increased in recent years, and the interest of the mathematics education community in this subject has gradually increased. It was seen that qualitative research approaches were used in most of these studies. As a data collection tool, a semi-structured or clinical interview form was mainly used. To reach more comprehensive results, it is necessary to give importance to quantitative research approaches and even to prefer the use of both approaches together. It was indicated that the tendency towards mathematical reasoning and puzzle games has continued predominantly in recent years. Although it was seen that the number of studies on digital games has increased in the last five years, only six studies in total were presented at the CERME. Moreover, three digital games developed by using the tools in the context of dynamic geometry environments were found. Another significant finding was that most of these studies did not define games. Only a few studies that defined the game considered the game as a tool used to acquire a mathematical concept or knowledge. Based on the findings, it can be argued that digital games are not among the interests of the mathematics education community. Finally, it was observed that mathematical theorems and approaches were central to the studies reviewed. Games were generally defined as tools within these studies. Therefore, future research should particularly consider fundamental game features such as game mechanics to create more integrated research environments with mathematics education.

Keywords: CERME, Digital Game, Non-digital Game, Mathematics Education

1. Introduction

Games have long been a subject of research in mathematics education. Non-digital games are known to have a positive impact on students' academic achievement, communication, and critical thinking skills (Russo et al., 2024). Similarly, digital games are also known to develop students' cognitive skills such as creative thinking, critical thinking, and problem-solving, as well as their affective skills such as attitude and motivation (Rodriguez-Aflecht et al., 2018; Lin and Hou, 2016; Brezovszky et al., 2019). These studies demonstrate that games have an important place in mathematics education and will continue to be used in the future. In this light, it is important to present a framework for how mathematics educators approach games as a research topic.

In recent years, rapid adoption of educational games in classroom settings for diverse purposes has been observed, emphasizing their potential to enhance learning and instruction. During this period, several literature reviews have addressed a broad spectrum of disciplines, including science, technology, engineering, and social studies (Cheng et al., 2015; Peterson et al., 2022), as well as focusing on mathematics education (Byun & Joung, 2018; Hussein et al., 2021; Joung & Byun, 2021; Pan et al., 2022). Since mathematics education often requires different skill sets compared to other disciplines, games intended for teaching mathematics may necessitate specific attributes (Pan et al., 2022). Furthermore, a crucial step towards effectively utilizing games in educational settings is understanding their potential and evaluating learning outcomes. This enables educators to conscientiously select games that align with their pedagogical goals and contribute effectively to learning environments. Therefore, it is imperative to analyse the findings of these reviews, as this analysis facilitates a comprehensive understanding of the potential benefits of educational games and their impact on learning outcomes in educational settings.

In this study, the papers presented at the Congress of the European Society for Research in Mathematics Education (CERME) were examined. CERME is a conference that has been ongoing for over twenty-five years, sharing significant research in mathematics education. The knowledge accumulated during this time has reached

a level that can be analysed in different review research (Herfort et al., 2023; Donevska-Todorova and Trgalova, 2017). Therefore, we believe that examining the papers from this conference and presenting the studies within a framework of various perspectives over 25 years will provide valuable insights into the role of games in mathematics education.

2. Method

This study employed a systematic review method. To achieve this, all full-text articles published in the CERME symposium were examined, including those presented at 12 CERME conferences held since 1999. The full texts of CERME papers were accessed through the website http://erme.site/cerme-conferences/. Initially, papers related to games were identified by scanning for the keyword "game" in their titles. These texts were then examined in greater detail. An initial review of the abstracts and titles identified 32 full-text papers. During the subsequent detailed examination, several key criteria were considered. Studies that were not available as full texts were excluded from the list. Additionally, papers that were not research articles and did not involve the use of a game were excluded from the study. Furthermore, only studies that investigated the impact of a game on a specific variable were selected. After applying these criteria, 16 out of the 32 studies were excluded from the list, leaving 16 studies for detailed analysis. The criteria for excluding full-text papers in this study are summarized in Table 1 below.

Table 1: Criteria for excluding studies

Criterion	Frequency
The study is not related to games.	6
The game is not central to the study.	3
Not a research study.	2
Related to game design instruction.	5

The remaining 18 studies were examined according to specific criteria. The year of the study, its purpose, target audience, research method, assessment tool, mathematical subject area, name and type of the game, the purpose of using the game, theoretical framework used, and how the game was defined were all analysed. The details of these studies are listed in Table 2 below.

Table 2: Details of the examined studies

No	Reference
1	Sensevy, G., Mercier, A., & Schubauer-Leoni, M. L. (2001, February). A model for examining Teacher's didactic action in mathematics, the case of the game" race to 20". In *CERME 2 Proceedings*.
2	Vankúš, P. (2007). Influence of didactical games on pupil's attitudes towards mathematics and process of its teaching. In *European Research in Mathematics Education: Proceedings of the Fifth Congress of the European Society for Research in Mathematics Education* (pp. 369-378).
3	Jančařík (2007). Creatıng a mental image of dice blackjack game. *Proceedings of the Fifth Congress of the European Society for Research in Mathematics Education*, (pp. 446).
4	Vighi, P. (2013). Game promoting early generalization and abstraction. *Proceedings of the Eighth Congress of the European Society for Research in Mathematics Education* (pp. 2238-2247).
5	Avraamidou, A. (2015, February). Instances of mathematical thinking through collaborative gameplay. In *CERME 9-Ninth Congress of the European Society for Research in Mathematics Education* (pp. 2453-2459).
6	Soldano, C., Arzarello, F., & Robutti, O. (2015). Game approach with the use of technology: A possible way to enhance mathematical thinking. In *Proceedings of the Ninth Congress of the European Society for Research in Mathematics Education* (pp. 2552-2558).
7	Soldano, C., & Arzarello, F. (2017). Learning with the logic of inquiry: game-activities inside Dynamic Geometry Environments. In *Proceedings of the Tenth Congress of the European Society for Research in Mathematics Education* (pp. 267-274).
8	Moomaw, S. (2017). Teddy Bear Preschool Mathematics Assessment: Validation of a constructivist game-and story-based measure. In *Proceedings of the Tenth Congress of the European Society for Research in Mathematics Education*.
9	Cramer, J. C. (2019, February). Games as a means of motivating more students to participate in argumentation. In *Eleventh Congress of the European Society for Research in Mathematics Education*.
10	Meletiou-Mavrotheris, M., Paparistodemou, E., & Tsouccas, L. (2019, February). A case study of teacher professional development on game-enhanced statistics learning in the early years of schooling. In *Eleventh Congress of the European Society for Research in Mathematics Education (CERME11)* (No. 27).

No	Reference
11	Soldano, C., & Sabena, C. (2019, February). Exploring non-prototypical configurations of equivalent areas through inquiring-game activities within DGE. In *Eleventh Congress of the European Society for Research in Mathematics Education* (No. 30).
12	Thoma, G., & Biza, I. (2019, February). Problem-solving techniques in the context of an educational video game: the Mudwall puzzle in Zoombinis. In *Eleventh Congress of the European Society for Research in Mathematics Education* (No. 35).
13	Misailidou, C., & Keijzer, R. (2019, February). Making Mathematics fun: The 'Fear Room'game. In *Eleventh Congress of the European Society for Research in Mathematics Education* (No. 19).
14	Nilsson, P. (2022, February). Game-variation to support probabilistic reasoning. In *Twelfth Congress of the European Society for Research in Mathematics Education (CERME12)* (No. 18).
15	Vilchez, C. S. U., & Lemmo, A. (2022, February). A videogame for supporting teachers' scaffolding in whole-class discussions. In *Twelfth Congress of the European Society for Research in Mathematics Education (CERME12)* (No. 17).
16	Baccaro, S., & Cusi, A. (2022). A teaching methodology focused on the use of a videogame: analysis of the engagement of students with special educational needs. In *Proceedings of the Twelfth Congress of the European Society for Research in Mathematics Education (CERME12)* (pp. 1-8).

3. Findings

Initially, the years of the conducted studies were examined. Table 3 lists the years in which the studies were conducted.

Table 3: Year of the studies

Year	Frequency
2002	1
2007	2
2013	1
2015	2
2017	3
2020	6
2022	3

Upon examining Table 3 above, it can be observed that research involving games has remained relatively stable over the years. However, a notable increase in game-related studies occurred in 2020. In other periods, the number of studies remained balanced. This surge in 2020 can be attributed to the post-COVID era, during which interest in tools like games, especially digital games used by individuals or small groups, increased significantly.

Table 4: Target groups

Target Group	Frequency
Teachers	2
Ages 7-10	1
Prospective Mathematics Teachers	1
Kindergarten Students	3
Ages 11-14	7
Ages 15-18	3
disabled student (Middle School)	1

When the studies are examined, it is seen that the majority of the studies are aimed at secondary school students (see Table 4). There are no studies regarding university education. However, apart from this, there are studies for all target groups.

Table 5: Objectives of the studies

Objective	Frequency
Cognitive development	8
Emotional development	5
Teacher development	3
Assessment	1

Upon examining the objectives of the studies, it is evident that cognitive development takes precedence (see Table 5). Cognitive development encompasses areas such as knowledge, reasoning, geometric reasoning,

strategic thinking, mathematical thinking, and mental tools. Emotional development focuses on aspects like attitudes and motivation. The remaining topics include teacher development and the investigation of games as an assessment tool.

Tablo 6: Methods

Research method	Frequency	Research design	Frequency
Qualitative	13	Case Study	4
		The teaching experiment	2
		The teaching intervention	1
		Discourse Analysis	1
Quantitative	4	Experimental	1
		Descriptive	3

The analysis of Table 6 reveals a dominance of qualitative research methods, employed in (13) of the studies, compared to a smaller number of quantitative studies (4) employed. Furthermore, a closer examination of the qualitative methods suggests a preference for case studies (4).

Table 7: Data collection tools

Data collection tool	Frequency
Observation and Interview	6
Observation	3
Survey	3
Scale and Survey	1
Think-Aloud	1
Observation and Game Score	3

Upon reviewing Table 7, it is observed that the combination of observation and interview is the most frequently used data collection method. Additionally, observation, survey, and observation-game score studies are equally the least used, whereas think-aloud and scale-survey approaches are used to a lesser extent.

Table 8: Subject areas

Subject area	Frequency
Numbers	5
Geometry	4
Measurement	3
Algebra	3
Probability and Statistics	2

Upon examination of Table 8, it is observed that the most studied subject area is numbers. Within the realm of numbers, the topic most frequently explored is number sense (in four studies). Only one study pertains to problem-solving. There are four studies related to geometry. Regarding measurement, two studies focus on the concept of area, while one study addresses the topic of money.

Table 9: Game types

Game Type	Frequency
Didactic Games	2
Puzzle Game	5
Dynamic Mathematical Software	3
Board Game	2
2d Platformer	1
(Non-Digital) Puzzle	1
Sandbox Game	10
Chance Game	1

Game Type	Frequency
Life Simulation	1
Combinatorial Game	1

Table 9 demonstrates that digital puzzle games are the most favoured choice for research. Additionally, didactic games are prominent, especially in the early 2000s. Over time, while the usage of digital games increases, the number of non-digital games decreases. Only one entertainment digital game, Sims 3, is utilized in the studies.

Table 10: Theoretical framework

Theoretical framework	Frequency
Didactic Situation Theory	2
Constructivism	3
Jaakko Hintikka Theory	3
Polya's Problem-Solving Steps; Downs and Mamona-Downs (2007) Mathematical Problem	1
Realistic Mathematics Education' ('RME') and 'Inquiry Based Learning' ('IBL')	1
Deci & Ryan's (1993) Self-Determination Theory	1
Dörfler's Theory Meaning, Hejny's Theory the "Motivation"	1
Deci & Ryan's (1993) Self-Determination Theory	1
TPACK	1
Combinatorial Game Theory	1

Upon examination of the theoretical frameworks in the studies, three theories stand out: didactic situation theory, constructivism, and Jaakko Hintikka's theory (see Table 10). Particularly, games hold significant importance in the didactic situation theory. However, this theory has been predominantly utilized only in the 2000s. Hintikka's theory, on the other hand, has been employed within the framework of dynamic mathematical software. Overall, theories of mathematics education take precedence in the theoretical framework.

Table 11: Definition of games

Game Definition	Frequency
Research that does not define games	13
Research that defines games	1

It is observed that most of the research does not provide a definition of the term "game" (see Table 11). However, among those that do, games are defined as follows:

"Epistemic games are about knowledge, but they are about knowledge in action - about making knowledge, applying knowledge, and sharing knowledge." (Shaffer & Gee, 2005, p. 16).

In another paper: *"Strategic games within Dynamic Geometry Environments (DGEs): these are games in which players have to make strategic choices meant for setting up and coordinating actions aimed at the achievement of a goal"* (Soldano & Arzarello, 2017).

From these two studies, it is evident that action is central to the definition. In another study, a distinction between games and didactic games is emphasized in defining games:

"The main differences between the normal meaning of children's game and between the didactical game are:

1. *Children's game is totally free, in didactical game all pupils have to participate.*
2. *Didactical game is used to realize chosen educational goals; the main aim of children's game is just fun and pleasure.*
3. *The didactical game has its external management (teacher)."*

In this definition, as in the others, the focus is on the objective.

4. Discussion and Conclusion

It was observed that the interest in the game was particularly high in the studies conducted in 2020, but then decreased in the last conference. One of the main reasons could be attributed to the increased interest in digital tools during the COVID-19 pandemic (Vargo et al., 2021). Additionally, while non-digital games were

predominant in the initial symposiums, there has been an increase in the number of digital games over time. This can be attributed to the rise of independent digital game development, leading to an increase in the number and variety of games produced by various independent institutions (Josef et al., 2022). Consequently, the number of educational digital games may have increased as a result.

The research predominantly employs qualitative research methods, reflecting a broader trend in mathematics education research (Maamin, et al., 2020). This preference is also notable in research concerning games. Contrary to the findings, studies related to games predominantly focus on quasi-experimental designs (Hussein et al., 2021). Another significant finding pertains to the types of games utilized. While non-digital games were prevalent in the early 2000s, digital games have been increasingly employed in recent years. This can be attributed to the accessibility of Dynamic Geometry Software and various digital games, particularly those developed by independent developers or companies, with puzzle games being prominent. The dynamic geometry approach has become popular in mathematics education, especially since the 2010s (Ondes, 2021). This situation can be observed in these academic congresses. Among all the studies, only a single entertainment digital game (The Sims 3) was utilized, indicating that entertainment digital games are not widely perceived as valuable from a mathematical perspective by researchers. Dynamic Geometry Software (DGY) games constitute the second most utilized type of game. However, games developed using DGY may have certain mechanical limitations, making it challenging to classify them as digital games. Studies utilizing DGY tend to prioritize action in their definition of games, emphasising the active engagement of students with the tools (Zengin, 2022). The absence of purely dynamic action and fundamental mechanics such as rewards or penalties in DGY complicates its classification as a game (Arnab et al., 2015). In the context of games within mathematics education, importance is also placed on the roles of teachers (Alkan & Ada, 2023; Fujita et al., 2018). This emphasis is particularly evident in non-digital didactic games. Therefore, it can be argued that studies made by mathematics educators, especially within the framework of mathematical theories and tools, differ from educational digital games or game-based instructional theories.

5. Implications

Upon analysis, the primary objective of the studies was to utilize theorems and approaches related to mathematics education within a game environment. Consequently, future research should aim for greater integration of these theories and approaches with game-based methodologies. Specifically, studies that examine the impact of fundamental game features, such as game mechanics, on mathematical development should be prioritized. This focus on transferring mathematical theories and approaches to the game environment is expected to enhance the effectiveness of educational games. Additionally, it has been observed that mathematics educators often interpret games differently, sometimes categorizing activities using software like GeoGebra as games. However, GeoGebra and similar software are not inherently designed for game development as they lack many essential game mechanics. Therefore, conducting a theoretical investigation to delineate when an activity qualifies as a game versus an educational activity could significantly benefit future research in educational games.

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