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Challenges and possibilities of digital games in mathematics teaching: a situational overview of recent years in Brazil

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Abstract: This paper is an extended version of the literature review already presented by the authors in SBGAMES 2023 and had as objective to investigate the possibilities and challenges that researchers face during the use of digital games in mathematics teaching in Brazilian basic education. The digital games, whether in Smartphone or Personal Computer, are example of activates that are part of the students' life, and for being immersed in this universe they can have difficulties in the classroom, that's why some teachers and researchers have tried to use the digital games in the classroom to make the classroom more comfortable for the students who are already immersed in the world of Information and Communication Technologies. The research object, the research string, the time, and the platforms on which the research would be conducted were defined. 129 studies were found, and after three steps of reading, six of them were selected for the data analysis. It was noticed that the students liked the activities conducted, because the game brought context to the concepts and turned possible that they could have a more open dialogue between them and with the teacher to take questions or explain the logics used to reach a certain result. It was also noted that they had challenges, but these were overcome with adaptations in the activities.

Keywords: Digital Games, Mathematics, Teaching

1 Introduction

We live in an age where it is difficult to imagine life without Information and Communication Technologies (ICT). From the moment we wake up to the moment we go to sleep, we are surrounded by devices, whether in the palm of our hands or on our desks, which are constantly connected to the Internet, receiving, and sending data and information, and constantly interacting with the world beyond the four walls.

This flow of information makes our daily lives easier. Whether at home, work or school, ICT is part of people's lives, and it is impossible to imagine a world without it. From this perspective, we can see that ICT is not only used for work, but also for entertainment, especially for younger audiences who enjoy all the resources available, from social media to games. Although ICT is often associated with leisure, these technologies are also good tools to support teaching and learning.

Faced with the changes brought about by ICTs and their potential to improve education, some educators have embraced them as allies. They are using technological tools as teaching aids, using software, introducing elements of games into the classroom through gamification, or even using analogue or digital games as another means of disseminating or supplementing knowledge. This is because games capture the attention of the player and lead them to spend a considerable amount of time solving complex problems individually or in a group [Moita *et al*., 2019].

Considering these characteristics, one can think of games in the pedagogical context, but we automatically think of educational games, but it should be noted that an educational game does not always have what the teacher is looking for or addresses exactly the topic that the teacher is dealing with. In this case, the teacher needs to look for other games that best fit what is essential now, leaving the world of educational games, and bringing pure entertainment games into the classroom.

In the context of digital games (or electronic, both terms will be used in this research), there are teachers who, not finding what they are looking for in the set of educational electronic games, decide to develop and use their own game and apply it. In this way, there is a guarantee that the subject in question will be covered without the game used ending up covering other subjects that do not currently require this focus, or that the teacher considers unnecessary for the moment.

Developing a game requires considerable time and effort [Souza and Prates, 2024]. Consequently, some individuals opt for a more efficient approach by utilizing digital games developed by third parties. These games may not have been originally designed for educational purposes, but they can be repurposed for such applications. In these instances, educators need to invest time in understanding the game mechanics and strategizing its use in an educational context.

However, the adaptability of these pre-existing games is limited. In other words, it is not always feasible to add or remove features. Take the game Angry Birds, for example. It serves as an excellent tool for studying quadratic functions when the birds are launched [Moita *et al*., 2013]. However, if an educator wants to explore other mathematical functions, the game falls short as it was not designed for such purposes and does not allow for modifications by the user.

In the field of mathematics, for example, we can find various software and games with an educational perspective, but they do not always fit the context in which they are to be used. As already mentioned, in situations like this, the teacher can choose several ways to achieve the desired objective, expanding the range of possibilities, with everything requiring more care so that the activity does not lose its educational focus.

Based on this context, this qualitative research aims to review the literature to find the main advantages and difficulties encountered by researchers in the use of digital games in the teaching of mathematics in Brazilian primary education.

In addition to this introduction, this article is divided into four sections. Section two presents a brief theoretical content. Section three presents the methodology used for this literature review, the platforms on which the research was conducted, the keywords used, and the inclusion and exclusion criteria. Section four presents the data analysis conducted based on the research questions presented in the same section. Finally, section five presents the concluding reflections of this article.

2 Digital games and mathematics learning

When talking about digital games, it is first necessary to understand what a game is. Huizinga [2012, p.10] states that "games are a function of life, but they are not subject to a precise definition in logical, biological or aesthetic terms". Therefore, it is possible to note that it is difficult to define what a game is, which is why some authors try to describe games based on some characteristics.

The definition that Huizinga [2012, p.33] gives to the game is: a voluntary activity that must have a limited time and space, must have rules, and must provide a feeling of tension, but also a feeling of pleasure. For the author, the game must be "different from 'everyday life'".

About games, Crawford [1984, p.1-2,4] states that "games are a fundamental part of human life", he also divides games into four types: "board games, card games, sports games and computer games", characterizing them in "four common factors", according to the author:

Representation: the game must contain rules that can cover all the different situations that can occur in the game. The author supports the idea that the game must be formally closed, avoiding discussions about situations for which there is no defined rule.

Interaction: Interaction brings a "social or interpersonal element" to the game, it changes the challenge of the game as the player is not just a spectator, so the challenge is no longer passive, it is an active challenge as the opponent reacts to the player and presents different responses to what the player does.

Conflict: "Conflict is fundamental to all games" and is linked to interaction. When playing a game, the player is given a goal, be it to solve the puzzle or to reach a certain point, and throughout the experience the player is made to face certain obstacles, which can be "passive or static" in the case of a game, such as a puzzle or a race, or "active or dynamic" when they react proportionally to the player's actions;

Safety: Games are a way of having low-risk experiences. The dangers and conflicts experienced within the game do not affect the player's physical performance. The author also says that "games are a safe way to experience reality", which is a little different from Huizinga's statement, but in line with the current reality in which simulation games, augmented reality and virtual reality have gained space and increasing notoriety.

According to Mattar [2009, p.46], "a game is an explorable dynamic system, but at the same time it is somehow constructed by the player's free choices. The user simultaneously participates in the construction of the environment and perceives what is happening around him". The author argues that the game is defined by the player's participation; if there is no interaction, it is not a game because, according to him, "games are 'written' by the player, not read".

Salen and Zimmerman [2012, p.95] state that there is no consensus between definitions of the characteristics of a game, even if authors agree on some points, no author shares all elements, but "not all elements need to be included in a game definition. Some elements, such as games being voluntary or inefficient, do not seem to apply to all games". The authors summarize the game as "a system in which players engage in an artificial conflict defined by rules, which implies a quantifiable outcome".

Regarding digital games, Salen and Zimmerman [2012, p.102] emphasize that game definitions "do not distinguish between digital and non-digital games; the qualities that define a game in one digital medium also define it in another", most definitions were created before computers existed, "but computer and video games are an important part of the game landscape because they bring a number of unique qualities".

The researchers then identify four qualities that, although more evident in digital games, "are not mutually exclusive [...] and do not constitute a definitive list of characteristics that appear in all digital games" [Salen and Zimmerman, 2012, p.103].They are: Immediate but limited interactivity, Information manipulation, Complex and automated systems, Network communication.

Regarding the reasons for using digital games in the classroom, Prensky [2012, p.21] in his book Learning Based on Digital Games says that "although learning methods and styles differ from person to person, to work with today's learners, the 'fun' element of all learning must always be present".

> *Learning based on digital games is in line with the needs and learning styles of the current and future generations [...] it motivates because it is fun [...] it is incredibly versatile, possible to be adapted to almost any situation, disciplines, information or skills to be learned and, when used correctly, is extremely effective* [Prensky, 2012, p.23].

Regarding the methods used in learning, Prensky [2012, p.105] emphasizes that "we urgently need new approaches to replace the exposure and evaluation system", as does Mattar [2009, p.40] when he adds that "the net-generation learns by

doing [...], working in groups and interacting. They are multitasking, interactive, exploratory, multimedia and expect relevant learning".

Reflecting on the differences between digital natives and digital immigrants, Mattar [2009, p.36], commenting on Prensky's concepts, says that "digital native students are used to receiving information faster than their digital immigrant teachers know how to transmit it. Immigrants prefer text to images. Continuing his analysis, the author adds that "today's students are no longer the people our education systems were designed for, and as a result, schools have been teaching the skills of the past", attributing this difference to the way both parties interact with the flow of information.

Mattar [2009] also highlights that "digital immigrants" tend to opt for order and seriousness, interacting with information in this way, in a slower way, individually, "one thing at a time", while on the other hand "digital natives" opt for randomness, speed, "they multitask", they learn by doing. The author does not deny the importance of printed text, but stresses that in the virtual world, unlike the physical, the visual is fundamental, while the "verbal has the function of adding up".

Digital objects (especially games) facilitate the formation of knowledge, even without physical interaction with game objects [Moita *et al*., 2019], Mattar [2009, p.43] states that "without being forced to learn, and by being involved in the game, we are more likely to learn". It is noted that the digital game provides the player with a learning environment, if he or she is encouraged to play, with full freedom to explore the game and know the mechanics. This is because mistakes in the game have a different effect than mistakes in the traditional classroom.

In the game, if the player loses, he can come back and try again; if he loses to a particular character, he can learn from it and try again to learn the mechanics that involve that phase or character. The weight and consequences attached to mistakes in a game end up being reduced and the player can take more risks, as opposed to traditional teaching where the weight and consequences of mistakes end up being greater [Mattar, 2009, p.44].

In this way, it is understood that the digital game can be used as a tool to support learning inside and outside the classroom, as the player exercises logical-mathematical reasoning during the game in all the activities they are practicing at that moment. The act of playing implies the same "basic knowledge for learning more complex mathematical content and also other curricular components" [Moita *et al*., 2019, p.276].

The use of games in mathematics education can contribute to "learning and the development of certain skills in students" [Sucheck *et al*., 2020, p.135]. Some students may have difficulties during mathematics lessons in an expository format, as the majority only use calculations, formulas and task lists, leaving aside other knowledge that is more practical and visual [Moita *et al*., 2019]. The authors go on to say that "this understanding should be expressed through different representations, going beyond the calculations and procedures carried out in so-called fixation exercises".

The game allows students to develop the skills they have acquired over time, both in and out of school. These are activities that encourage collaboration between students and allow them to express their knowledge in separate ways [Moita *et al*., 2019]. To use the game correctly, the teacher needs to understand its mechanics and how it can be used to collaborate with the concepts already studied, which is why it is important that the teacher knows how to choose the game to be used correctly.

In addition to the content covered, the age range of the students must be considered so that the challenge is appropriate. As the objectives are educational, it is up to the teacher to encourage the pupils to keep the main objective in mind, which is to learn. Digital games are up-to-date and inexpensive options that teachers can use to stimulate students' interest in the subject, as well as to encourage greater class participation, creativity and problem solving. However, it is important to be careful that the game does not become a leisure resource in the mathematics classroom, as it can be associated in this way [Sucheck *et al*., 2020].

3 Methodology

This research is a Literature Review (LR), as Coutinho [2014, p.219] explains, an LR "aims to collect information about research carried out in areas close to the one under investigation" and "consists of identifying, locating and analyzing documents that contain information related to the subject of a specific investigation". The purpose of an LR is to examine, interpret, and disseminate the results of knowledge obtained through published research. The author emphasizes the importance of publications in an LR, pointing out that:

> *There is a body of knowledge that has been established by other researchers and, therefore, published literature constitutes a significant resource for the researcher in the process of planning, conducting, interpreting and disseminating the results of the research that is about to begin* [Coutinho, 2014, p.55].

Our methodology aligns with the model proposed by Fernandes *et al*. [2018]. However, we modified some steps to suit our research topic. Like the original methodology, we developed inclusion and exclusion criteria and research questions (which will be presented later). However, we decided not to include evaluation criteria. We determined that it was not necessary to evaluate the quality of the research, as this was not the objective of our research.

This LR had a qualitative approach, which according to Coutinho [2014, p.287] "qualitative studies constitute a family of research plans that start from epistemological, philosophical and methodological assumptions characterized by a rejection of the research model in the natural sciences", Coutinho [2014, p.26] adds that:

> *the object of study is not behavior, but intentions and situations, that is, it is about investigating ideas, discovering meanings in individual actions and social interactions from the perspective of the actors involved in the process.*

In contrast to quantitative research, qualitative research seeks "to understand phenomena in their totality and in the

context in which they occur, so that the focus of the problem may be known only after the research or fieldwork has begun" [Coutinho, 2014, p.289].

The research involved the following steps: defining the theoretical categories and the objectives of the study, then defining the search term, the publication period, the target audience and the platforms on which the searches would be conducted. The next step was to define the inclusion and exclusion criteria to be applied to obtain a good sample size and the research questions to be addressed to achieve the objectives of this research (**Figure 1**). The following is a report of the research process.

Figure 1. Research development. Source: Authors.

3.1 Search process

Initially, the search string was defined and refined to ensure the accuracy of the results. Several strings were then evaluated on the Google Scholar platform to gain a general understanding of the potential results within the proposed time limit (from 2020 to mid-2022). Once a string yielded satisfactory results (approximately 100+), the search was executed on the platforms and the results were archived.

The research aimed to explore Brazilian databases and yield results from Brazil, as well as to facilitate access for future educators. Therefore, the search string was formulated in Portuguese. The search was conducted using the Portuguese string (refer to **Figure 2**): ("digital game" OR "electronic game") AND mathematics AND application. The term "education" was intentionally omitted to maximize the number of results.

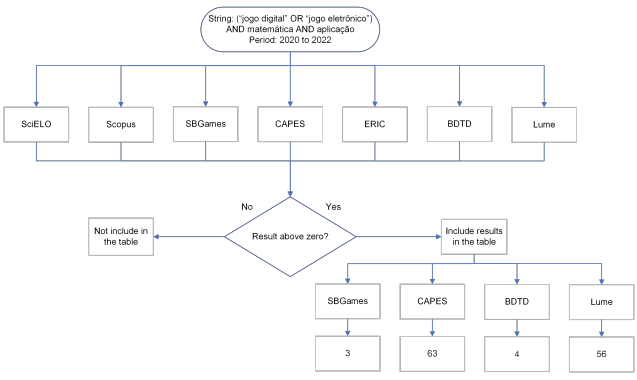

Figure 2. Research process. Source: Authors.

The search was carried out in 7 sources: Brazilian Digital Library of Theses and Dissertations (BDTD), Education Resources Information Center (ERIC), Periodical Portal of the Coordination for the Improvement of Higher Education Personnel (CAPES), Lume Repositório Digital, Brazilian Symposium on Games and Digital Entertainment (SBGames), Scientific Electronic Library Online (SciELO) and Scopus (see **Figure 2**).

Although it is an institutional repository, it was decided to consult the Lume platform to add some more valid content for analysis to the content of this research. The SciELO, Scopus and ERIC platforms did not return any valid results (0 being the search result), the others returned results as shown in **Figure 3** :

Search String	**Data Source**			
	BDTD	**CAPES**	**Lume**	**SBGames**
("digital game" OR "electronic game") AND mathematics AND application	7	63	56	3

Figure 3. Search String. Source: Authors.

On the SBGames website, only the word "mathematics" was used. The search was carried out using the browser's own search tool, as until the search was carried out there was no native search option on the site, but as it is an event focused on the games sector and as it is the only one in the country with a publication volume, it remained the same.

The search yielded 129 papers, and after removing duplicates, 121 files remained (**Figure 2**). All results were entered into a spreadsheet, classified with their own ID and stored in a folder for organization and subsequent analysis. The spreadsheet with the results and the folder where the files are stored are accessible via the link: https://tinyurl.com/ArqTCCRL

3.2 Inclusion and exclusion criteria

After the research phase, the criteria that would guide the analysis section were established. The inclusion criteria, as the name suggests, aim to include as many studies as possible, and the exclusion criteria aim to filter out from these studies those that will proceed to the analysis stage. **Table 1** and **Table 2** show the inclusion (CI) and exclusion (EC) criteria used in this RL:

Table 1. Inclusion Criteria. Source: Authors.

Criteria	**Description**
IC1	Research published between 2020 and mid-2022;
IC2	Searches in Portuguese;
IC3	Research published in annals, journals, conferences and newspapers, repositories, dissertations, theses;
IC4	Complete research, which reports the use of the game as a tool during the teaching-learning process.

- IC1: Initially, our focus was solely on studies conducted during the quarantine period. However, considering the potential for studies conducted in 2019 to be published

later, we decided to extend the review period from 2020 to 2022. We consciously chose not to include terms related to the coronavirus pandemic or COVID-19. Despite this, we acknowledge that research conducted during this period could provide valuable insights for future studies in times of social distancing;

- IC2: Given the objective of the research, it was decided to analyze only publications in Portuguese, considering the possibility that research within the theme could be published in this language, but on international platforms;
- IC3: To increase the number of results, results within these platforms were included, in addition to dissertations and theses that were consistent with the topic;
- IC4: To make the analysis as comprehensive as possible, only complete research projects were included, so that the results obtained after their development could be observed.

Table 2. Exclusion Criteria. Source: Authors.

Criteria	Description
EC1	Duplicate publications, or that present the development of the same research (use the most current);
EC2	Publications outside the specified period;
EC3	Short paper publications, or abstracts;
EC4	Research that is not in Portuguese;
EC5	Research whose texts are not available for free access;
EC6	Publications that are irrelevant or unrelated to the purpose of this research (consider: title, abstract and keywords).

- EC1: Where there was a possibility of finding duplicate research and publications that were a continuation of another research, only the most recent publications of the same research were considered;
- EC2: If there were results published outside the research period (2020 to 2022), these were excluded, and a more recent publication (if available) was used;
- EC3: Short articles or abstracts were not considered due to the amount of information required for data analysis;
- EC4: Considering IC2, research in languages other than Portuguese was not included in the analysis;
- EC5: Due to problems in accessing paid-for platforms, articles that were not available for free were not considered;
- EC6: Research that was not within the topic covered was rejected after reading the title, abstract and keywords.

After defining the inclusion and exclusion criteria and filtering duplicate results, we proceeded to read the papers and analyze the data.

3.3 Data analysis

Data analysis was separated into stages to organize the entire process (**Figure 4**).

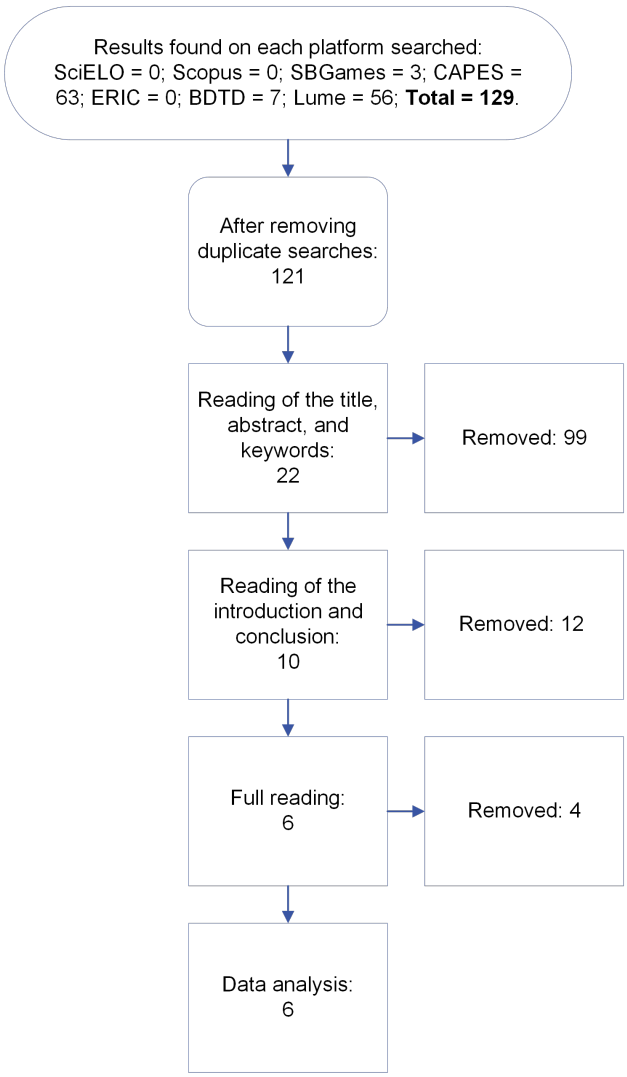

Figure 4. Analysis steps. Source: Authors.

The data preparation stage began with the filtering of articles, removing duplicate articles and papers that did not comply with IC3, leaving 121 papers. After this filtering, the first selection stage was conducted, in which titles, abstracts and keywords were analyzed, as in the proposed model. In this first stage, 102 articles that did not meet the inclusion criteria proposed for this research were excluded, leaving twenty-two texts for the second stage.

In the second stage, after reading the introduction and conclusion of the twenty-two studies, twelve were excluded. These included one that fell into EC1 but had not been noticed in the first stage of analysis, leaving ten studies that went on to the third stage. In the third and final stage, the ten studies were read in full and four of them were rejected. Although these studies dealt with topics like the one discussed in this LR, they were not in line with the aim of this research.

Finally, six papers remained, which were used in the analysis process and helped to find answers to the research ques-

tions. In the following we will use the following codes for the selected research:

TB10 – Digital game contributing to the understanding of operations with natural and decimal numbers (Jogo digital contribuindo na compreensão das operações com números naturais e decimais)

The researchers Ritter and Bulegon [2022] developed a game called "Ida à Padaria". The aim of the game is to work on basic operations in a context where the player buys and/or sells certain products.

In the game, the player is given a sum of money and has to manage it in everyday situations, questions are displayed and if the answer is correct, the player gets points and moves on to the next question; if the answer is not correct, no points are given, but the player still moves on to the next question.

TB11 – The PG digital quiz game in mathematics classes: possibilities for teaching and learning geometric progression (O jogo digital quiz PG nas aulas de matemática: possibilidades para o ensino e aprendizagem de progressão geométrica).

This research was developed using a mobile game called "Quiz PG", developed by the researchers themselves, de Oliveira and Ferreira [2021], and aimed at the study of geometric progression.

The research was conducted using a before-after model, a format in which the researchers first explained the content in an expository way and then put some questions on paper for the students to answer based on the content previously taught. The students were then instructed to use the same knowledge in the game, which consisted of twelve questions.

TB20 – Learning environments from the game JobMath (Ambientes de aprendizagem a partir do game JobMath)

The game used in this research is called "JobMath" and was developed by one of the authors. It consists of a challenge system in which the player's score increases as he or she answers correctly.

The challenges are arithmetical and each one corresponds to a profession. Each player chose how to play: individually, in pairs or in a group. At the end of the game, they were given sheets of paper to record the calculations they had made during the game [de Menezes and de Fraga Sant'Ana, 2021].

TB24 – Minecraft game as an ally in the process of teaching and learning special geometry (Jogo Minecraft como aliado no processo de ensino e aprendizagem da geometria especial)

The research was conducted using the game "Minecraft" and physical materials to study spatial geometry. Using both physical and digital resources, students were encouraged to identify geometric shapes in different areas of the school and try to represent them in the game and with physical materials.

To understand each student's level of knowledge, the researchers used questionnaires and seminars. The students were divided into groups during the activities [Boito and da Silva, 2020].

TB31 – Teaching and learning mathematics through digital games: a collaborative proposal in the computer laboratory (Ensino e aprendizagem da Matemática por meio dos jogos digitais: uma proposta colaborativa no laboratório de informática)

This study promoted intervention through computer lessons. The researchers Kirnew *et al*. [2020] selected students recommended by mathematics and remedial teachers and, after using questionnaires to identify knowledge gaps, selected games that addressed each area in which the students had difficulty.

The research was conducted in collaboration between mathematics tutoring classes and IT classes. The games selected were based on the content studied in the remedial classes, and during the sessions, in addition to the digital games, record cards were used with questions to be worked on in each game.

TB66 – The constitution of mathematical knowledge with the author's digital game: Adventure in Rhind (A constituição do conhecimento matemático com o jogo digital autoral: Aventura em Rhind)

For this research, the game "Adventure in Rhind" was developed, a role-playing game (RPG) that contains challenges that require logical reasoning, combinatorial analysis and functions.

The research was conducted virtually, and the mathematics lessons were based on the game. First, the students played the game and were able to explore all the functions available in the game. At another point, a discussion was held on the concepts covered in the game [Troian, 2021].

3.4 Research questions

To achieve the general objective described at the beginning of the work, which will be to review the literature, seeking to find the main possibilities and challenges encountered by researchers in the use of digital games in mathematics classes in Brazilian basic education.

Table 3. Research Questions. Source: Authors.

Questions	Description
RQ1	What are the target audiences for the research? In which Brazilian states and in which institutions was the research conducted?
RQ2	What content is covered in the researched works?
RQ3	What gaming platforms were used? Were the games developed to apply them in research or were commercial games used?
RQ4	How many works used games during the synchronous moment, and how many present the application of the game in an asynchronous moment?
RQ5	What were the difficulties faced by teachers and/or students when using the games?
RQ6	What were the benefits highlighted in the research?

Research questions were developed more specific, linked to the general objective, as proposed by Coutinho [2014,

p.289] when stating that "the problem is followed by more specific questions that will guide data collection".

The more specific questions, which were used as criteria for analyzing the articles, considered the content, the methodology, the participants, and the difficulties and possibilities highlighted by the researchers in the investigations (**Table 3**).

4 Results and analysis

Once the research questions had been defined, data analysis was conducted on the studies that remained in the third stage, a summary of which is given in **Table 3**.

RQ1: What are the target audiences of the research? In which Brazilian states and in which institutions was the research conducted?

[TB10, TB20, TB24 and TB31] applied their research in primary schools, with [TB31] developing their research with fifth graders, [TB10 and TB24] developing their research with sixth graders, and [TB20] developing their research with 7th and 8th graders. [TB11 and TB66] developed their research in the first year of secondary school.

Although the target groups are similar, it should be noted that in each case the research followed different areas of mathematics, which highlights the importance of trying to understand students' difficulties before applying the game. In this way, the game is not just an activity, but can also be seen as a challenge by those who play it, stimulating their curiosity. This is evident in all the studies analyzed.

Four of the six studies took place in the state of Rio Grande do Sul, two of them at the Federal University of Rio Grande do Sul (UFRGS) [TB20 and TB66], and two others at the Fransciscana University (UFN) [TB10] and the University of Passo Fundo (UPF) [TB24], which are private institutions. In addition, another research was conducted at the Federal University of Alagoas (UFAL) [TB11] and in the state of São Paulo by researchers from the University of Northern Paraná (UNOPAR) in partnership with the Universidade Anhanguera of São Paulo [TB31], both private institutions. It is therefore noticeable that there is a predominance of research in the southern region of Brazil and a division of publications between public and private institutions.

RQ2: What is the content of the researched works?

It was necessary to try to know what content is covered by each work that would be analyzed, so that there would be an idea of which areas of mathematics have received greater attention from researchers, considering that before developing the analyzed research, there was a case study to understand in which areas of mathematics students have the most difficulties, given that the field of mathematics is vast and many different subjects are covered in basic education.

It is worth noting that the readings covered a wide range of topics. [TB10, TB20 and TB31] focused on the four arithmetic operations, while [TB11] covered Geometric Progression, [TB24] dealt with Spatial Geometry, and [TB66] had a more general approach, working with logical reasoning, functions, and combinatorial analysis.

It is worth noting that all researchers focused their studies on the most challenging topics in the mathematics classes they analyzed. This suggests that difficulties with mathematics are often concentrated in specific areas and can be addressed through alternative teaching approaches if the teacher is willing to adopt them.

During the research conducted by [TB31], it was noted that there was a need to level everyone's knowledge in the four arithmetic operations. The researchers paid close attention to this aspect and the results were quite positive.

In previous studies, the care provided was comparable. However, in [TB31], it was noted that teachers collaborated during the information collection process to identify the subjects that students struggled with the most. They also assisted in selecting games that would best address each difficulty.

RQ3: What gaming platforms were utilized? Were the games developed for research purposes or were commercial games used?

To gain insight into the investigations, we aimed to identify the information and communication technologies (ICTs) utilized by the researchers during the interventions. Specifically, we sought to determine the hardware and software employed.

The investigations [TB10, TB24, TB31 and TB66] utilized personal computers to conduct the research, whether through web-based or desktop games. Conversely, [TB11 and TB20] employed portable devices, such as smartphones. Regarding games, [TB24 and TB31] used pre-made games such as Minecraft and web game platforms, respectively. However, the other works delved deeper and created their own games using platforms such as RPG Maker, APP Inventor, and even websites that allow game creation and socialization.

RQ4: What is the word count for games used during synchronous moments, and how many instances of game application occur during asynchronous moments?

The purpose of this question is to determine how the game was implemented, whether during class or outside of it, considering that during the period under investigation, the world was experiencing the COVID-19 pandemic and schools had transitioned to remote teaching, utilizing both synchronous and asynchronous activities as needed by the teacher.

[TB10, TB20 and TB66] used the game as a complement to the class. [TB66] used virtual meetings via Discord, while the others were only applied in person. [TB31] was applied as a complement to reinforcement classes, implying that it was conducted after school. [TB11 and TB24] in the methodological description imply that they were also conducted in a shift opposite to classes, with emphasis on [TB11] which mentions the 'before-after' methodology.

The research was conducted in the computer laboratory of the respective schools. However, it is unclear whether the research was conducted during class time. Based on the number of participants, it can be inferred that the activity was conducted after school.

Therefore, it is understood that none of the activities were conducted asynchronously. All activities were conducted in the presence of researchers and/or teachers who helped with questions and coordinated progress. Apart from [TB66], all activities were conducted in person, either in the classroom or in the computer laboratory.

RQ5: What challenges did teachers and/or students encounter when using the games?

[TB10] states that due to the lack of a computer laboratory at the research location, the researchers had to use smartphones and tablets to conduct their research. In [TB11, TB24 and TB31], the researchers reported difficulties related to the covered content. In [TB20], some students had trouble using their own smartphones. In [TB66], it was reported that difficulties were experienced with audio and video during remote meetings.

Overall, it is apparent that the challenges were primarily associated with the subject matter presented in the game, rather than the game itself [TB31]. This is further supported by [TB11, TB24 and TB66]. The student had already encountered some difficulties during class, and the teachers refrained from providing direct explanations during the research phase, allowing students to attempt problem-solving using their own reasoning.

At times, students may answer the questions proposed in the games using a trial-and-error method rather than the 'correct' logic [TB11, TB20 and TB66].

Students and teachers have openly discussed the challenges related to the content [TB10, TB20, TB24, TB31 and TB66]. In most cases, the teachers aimed to encourage students to reflect on the demands of the question or phrase [TB10, TB11, TB20, TB24, TB31 and TB66].

According to Mattar [2009, p.56], players must explore the game's logic to understand it. Results are obtained through trial and error, intuition, and stumbling upon things. The student arrived at the answer based on their own conjectures, learning from their failures and trying again. The teacher only provided answers a few times when unable to explain in simpler terms.

There were difficulties related to the equipment used, either due to defects or the students' lack of knowledge about its use. It is noteworthy that in [TB20], some students had trouble managing their devices, asking teachers how to install and open the game, and how to free up space in the device's memory. This contradicts the assumption that young people are born with knowledge of the use of ICTs. Despite being born in the digital era, individuals' knowledge is often limited to what they use daily. When faced with more complex functions, their lack of knowledge becomes apparent.

RQ6: What were the benefits highlighted in the research?

The benefits of interventions through digital games were highlighted by all researchers as positive. According to [TB10, TB11, TB20, TB24, TB31 and TB66], students were able to gain a more accurate understanding of the covered content and its practical application through game-based activities.

According to [TB10, TB20, TB24 and TB66], students enjoyed the activities because they were more closely related to everyday reality and made previously abstract concepts more visible. It is important to maintain objectivity and avoid subjective evaluations. According to Moita *et al*. [2019, p.278], games can offer valuable learning opportunities that can be applied in educational settings. Mattar [2009, p.56] also suggests that gamers learn the basic procedures of the scientific method through exploring the physics of game worlds, which involves the same steps as scientific exploration: exploration, hypotheses, and testing.

Research indicates that students may fear mathematics due to a lack of understanding of its real-life applications [TB10, TB24 and TB66]. However, through proposed activities, students can recognize the presence of mathematical concepts in everyday tasks, such as purchasing items at a bakery [TB10]. In [TB20], students discovered that mathematics is present in all professions, from working with geometric shapes to identifying numerical combinations and calculating travel time.

In [TB31 and TB11], students emphasized the value of instant feedback, which allows them to quickly identify whether they have answered correctly or not. Additionally, in [TB31], students described the mathematics in the game as making the practice more enjoyable and engaging. In all cases, the introduction of 'real world' concepts through games made mathematics more appealing to students involved in research. According to Mattar [2009, p.49],

> *what students learn in school does not easily transfer to the real world. There is a gap between the facts and rules that students memorize for exams in schools and the learning they need to solve real problems. Epistemic games do not have a disconnect between learning and application, as the necessary facts, information, and theories are learned and remembered through playing the game to solve real-world problems* (our translation).

In this case, Mattar [2009, p.48] discusses epistemic games, which are games designed to emphasize professional practice and encourage innovative thinking. It is noted in all the analyzed research that the scenario is similar. When playing the game, the player understands and applies the concepts, making mathematics more practical and accessible [TB10, TB11, TB20, TB24, TB31 and TB66].

5 Final considerations

Finally, it is evident that the experiences were positive for both the participating students and the researchers. The use of digital games contributed significantly to the development of students' skills, mathematical knowledge, and logical reasoning.

It was observed that the digital games used in the research sparked curiosity among the students. In each round, the game challenged them to use their knowledge to find solutions to the presented challenges, leading to dialogue and mutual knowledge exchange among the students. This generated a cooperative environment and facilitated open dialogues with the teacher to clarify doubts.

Difficulties were encountered with equipment during the research development. However, the researchers were well-prepared and quickly sought alternatives to overcome the problems.

Brazilian schools and universities are still lagging both in terms of technology and professional training. Despite the creativity of teachers in the face of challenges, we cannot accept low investments in education.

It was observed that some research participants had limited knowledge of the topics covered in the games. This led

to positive outcomes as it facilitated dialogue between participants and teachers, reinforcing the notion that the game promotes cooperation among players who assist each other by sharing knowledge and answering questions.

However, despite some initial issues, the research was designed in a way that allowed students to freely explore the games and apply their knowledge to solve challenges. They had the freedom to develop their own methods and arrive at answers to the questions.

The work researched in this investigation covered the COVID-19 pandemic period, a time when we were socially distancing. In some situations, we observed that digital games were a good ally in learning mathematics, with the possibility of remote monitoring [Monteiro *et al*., 2022]. This way we can apply these methodologies at other times in the student's life, such as vacations or weekends, so students can continue their studies in a fun and motivating way.

Thus, it is suggested that digital games can positively contribute and serve as effective tools for aiding in the learning of Mathematics. However, it is important for the teacher to ensure that the activity is based on the student's prior knowledge and that participation is voluntary rather than mandatory.

Declarations

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Authors' Contributions

Gilberto Batista Damaceno Júnior: Conceptualization, Investigation, Data Curation, Formal Analysis, Writing – original draft, Visualization; **Jesse Nery Filho**: Lead Methodology, Supervision, Project Administration, Writing – original draft, Writing – review editing, Visualization; **Maria Talita Rabelo Pinheiro:** Lead Methodology, Supervision, Writing – review editing.

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Research	Target	Platform + Media	Contents covered	Application method	Challenges	Possibilities
[TB10]	6th year, elementary school	PC + Own game called "Ida à Padaria"	Four arithmetic operations	Class complement	Lack of computer laboratory	Proximity to reality
[TB11]	1st year, high school	Mobile + Own game called "Quiz PG"	Geometric progression	Shift opposite class	Content covered	Practical application
[TB20]	7th and 8th year, elementary school	Mobile + Own game called "JobMath"	Four arithmetic operations	Class complement	Digital literacy	Use in different professions
[TB24]	6th year, elementary school	PC + Minecraft	Spatial Geometry	Shift opposite class	Content covered	Application of concepts in real life
[TB31]	5th year, elementary school	PC+ Games on Web Platforms	Numerical groupings and Four arithmetic operations	Shift opposite class	Content covered and leveling	Instant feedback
[TB66]	1st year, high school	PC + Own game called "Aventura em Rhind"	Logical reasoning, functions, and combinatorial analysis	Class complement	Problems with audio and video	Stimulation of logical reasoning

Figure 5. Summary of investigation results. Source: Authors.