How Digital Games are Engaging Our Children Toward STEM Careers?

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***Abstract*—Mathematics is a crucial skill in modern society, enhancing problem-solving abilities across various fields, from medicine to philosophy. Its concepts underpin major information systems, including machine learning and mobile applications. Nonetheless, many countries experience significant gaps in students' understanding of fundamental mathematical concepts, leading to widespread math anxiety, particularly concerning fractions. Moreover, numerous studies indicate that digital games positively influence learning outcomes by providing an engaging teaching method. To understand how existing digital games have been used to teach fractions, we conducted a Systematic Literature Review (SLR) that explores digital games that support teaching fractions and examines how they have been integrated into teaching strategies, including how their pedagogical effectiveness is assessed. Our findings underscore the need for more tools compatible with Learning Management Systems (LMS) and improved accessibility to the games/tools mentioned in the literature. Additionally, there is an urgent need to develop metrics for evaluating the effectiveness of game-based learning tools for fractions.**

Keywords: ***education, fractions, digital game, mathematics***

I. Introduction

Since 1945, when it first became possible for users to interact with content on digital machines, computers have been used to support the teaching and learning processes. Today, the integration of information and communication technologies (ICT) can offer students engaging and motivating learning experiences. Generally, ICT can provide significant benefits to education, particularly by addressing challenges found in traditional teaching methods. The teacher's role as a facilitator is crucial in helping students develop skills and gain a deeper understanding of key concepts in the educational process [1].

Mathematics is a fundamental knowledge in contemporary society, enhancing problem-solving abilities across various fields, not even the ones concerning the STEM careers, but also including medicine and philosophy. Moreover, its principles underpin many information systems currently employed in machine learning, networks, and mobile applications, among others. However, the literature indicates that there is a significant deficiency in students' grasp of basic mathematics in many countries. This issue often starts in K12, leading to a high prevalence of math anxiety among individuals [2].

Among the core mathematical concepts, fractions are one of the most challenging topics in basic education. In fact, in a previous literature review, fractions are identified as a topic which students still face difficulties to learn even in higher education [3]. This can elicit a range of emotions in students, from positive to negative, and sometimes lead to pathological responses. Consequently, many students doubt their ability to acquire the knowledge required for pursuing higher education in the natural sciences, technology, engineering, and mathematics (STEM).

In recent years, there has been increasing interest from committees focused on exploring the role of digital games in science and engineering education. In North America, the Federation of American Scientists hosted a conference in 2005 titled "Harnessing the Power of Video Games for Learning", and the National Academies Board on Science Education established a "Committee on Computer Games, Simulations, and Education in Science Learning"[4]. In South America, the Brazilian Computer Society has supported SBGames since 2004. This event, which is entirely focused on Games and Digital Entertainment, has included a dedicated track on games and education since 2018 [5]. In an effort to address traditional issues in teaching mathematics, such as fractions, as well as administrative problems like dropouts in science courses, evidence supporting the benefits of using digital games in education is informed as key findings from researchers. These findings guide the hypotheses regarding the advantages that digital games bring to the teaching and learning processes. In [6], the authors noted that the current generation of students, as well as the previous one, have video games as an integral part of their lives. They reported that approximately 98% of children and adolescents play video games at least once a week [7]. The use of video games is reported to enhance learning in STEM courses by 7 to 40% compared to traditional teaching methods.

In light of this context we conducted a Systematic Literature Review (SLR) to explore which educational games tailored for teaching fractions are documented in the literature and how these games have been used in teaching strategies.

This paper is organized as follows: Section II describes the adopted method to conduct the SLR, Section III outlines the SLR protocol, which includes the SLR Planning, Conduction, and Reporting stages.Section VI offers insights and key findings from the research, while Section VII presents the conclusion of the review.

II. Method

In order to conduct this SLR, we adopted Kitchenham and Charters [8] guidelines, which suggests following a process compose of three stages:

- planning;
- conduction;
- reporting.

The review planning begins with the confirmation of the review's need followed by the definition of the review protocol. The protocol comprises: (i) defining a research question; (ii) establishing the search databases; (iii) defining the inclusion and exclusion criteria. The review's conduction consists of running the protocol and make a critical reading of all the papers yielded after its running in order to extract and synthesize data to answer the research question that guided the SLR. The reviews report consists of reporting the review findings in a document and publicize them.

III. SLR Planning

This review was conducted to explore literature about (educational) games for teaching and learning fractions. To guide the research, we define RQ as the primary research question:

RQ: What are the available educational games that support teching fractions and how these games have been used in teaching strategies?

Having defined the research question, we establish *ACM Digital Library*[1], *IEEE Xplore Digital Library*[2], and *Scopus*[3] as the search repositories.

The next step was defining the search string. The general string is <fraction* AND game* AND (learn* OR teach*)>.

The planning ended with the definition of the inclusion and exclusion criteria. They were reported at table I and were refined throughout the search process.

IV. SLR Conduction

For this research, the general search string were adapted to each search base. Therefore, they were executed in each base and the quantitative information regarding them are presented at table II. It is important to note that, due to the large volume of articles initially retrieved, the search was applied directly to the abstracts.

To store the data, it was necessary to export the results from each search engine. We utilized the export feature available in most search engines, which generates a file in .bib format (BibTeX extension). In cases where this export mechanism was not available, the selection was done manually, applying the Inclusion and Exclusion criteria at that stage.

To manage this review, we chose the tool *Parsifal* [4], which is designed to assist researchers in implementing all the steps outlined in the protocol defined by [8].

The search strings were applied to the previously mentioned sources and yielded 593 papers, of which 66 were relevant to the research. These articles are distributed as shown in Figure 1. Out of the 593 articles found, only 90 underwent the initial selection process based on reading the title and abstract. A second selection, based on reading the full text of these articles, resulted in 66 articles. Figure 1 illustrates the total number of search results in each database concerning the selected articles.

Data indicate a rise in publications about game tools for teaching fractions from 1999 - the year the first article was identified - to 2021 - the year of the most recent article. Publications are notably concentrated in the period from 2015 to 2020, accounting for approximately 62.12%, as shown in Figure 2, even though research on tools has been ongoing since the 1990s.

Figure 3 displays the total search results from each database regarding the acceptance of the articles. The selected articles were read in full to extract answers to the research questions.

[1]dl.acm.org. Accessed May 7, 2024
[2]ieeex-plore.ieee.org. Accessed May 7, 2024
[3]https://www.scopus.com/. Accessed on May 7, 2024
[4]https://parsif.al/Accessed on May 3, 2024

Table I
INCLUSION AND EXCLUSION CRITERIA FOR ARTICLES IN THE SLR

Inclusion Criteria		Exclusion Criteria	
I1.	Present a digital game that teaches at least one fraction topic.	E1.	Works not in Portuguese.
I2.	Works in English.	E2.	Works not in English.
I3.	Works in Portuguese.	E3.	Works that are not available online.
I4.	Relevant works for research.	E4.	Works that cannot be accessed in full.
		E5.	Works in which the search string does not apply to the abstract.
		E6.	Duplicate jobs.
		E7	Secondary jobs.
		E8.	Works that do not answer the research questions.

Table II
SEARCH STRINGS APPLIED TO SEARCH BASES

Search bases	*String*	Period	Returned	Valid
IEEExplore	("Abstract":fraction* AND "Abstract":game* AND ("Abstract":learn* OR "Abstract":teach*))	All	60	14
ACM DL	[Abstract: fraction*] AND [Abstract: game*] AND [[Abstract: learn*] OR [Abstract: teach*]]	All	248	9
Scopus	ABS (fraction* AND game* AND (learn* OR teach*))	All	285	43
Total			**593**	**66**

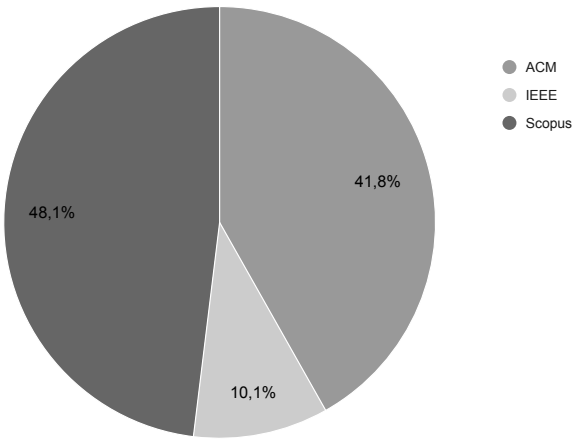

Figure 1. Articles selected by database

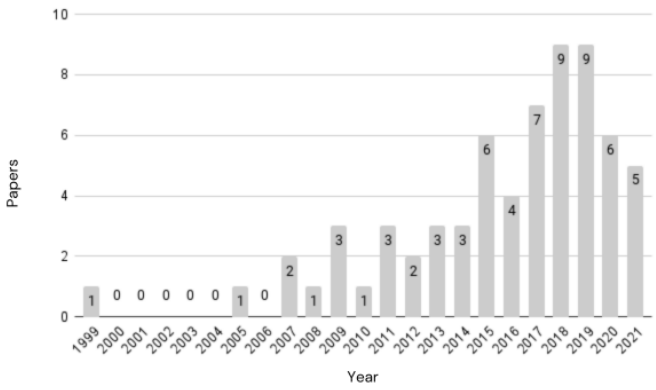

Figure 2. Search results by year

The collected data was analyzed and summarized into responses to these questions, as detailed in the section **??** below.

V. ANSWER TO RESEARCH QUESTION

The selected articles were read in their entirety to extract answers to the research question. To develop a more detailed response, the data were collected, analyzed, and summarized. Additionally, the research question was divided into three smaller sub-questions, as outlined below.

Subquestion 01: *What types of games are available for teaching fractions?*

Out of the 45 games identified, the majority—39 in total—are digital, with 3 of these being classified as hybrids [13, 14, and 37]. Hybrids require a physical tool to be used alongside them, such as game 37, which combines a mobile application with fraction rods. Only 6 games are purely physical [5, 6, 15, 16, 22, and 39].

Additionally, 24 games fall into the category of puzzles, where users must solve interactive puzzles to progress [2-7, 11, 12, 18, 19, 21, 24, 26-34, 41-43]. Following this, there are 10 quiz games [9, 17, 20, 23, 25, 36-38, 40, and 45], which are mental or intellectual games where players, either individually or in teams, attempt to correctly answer questions. Two other

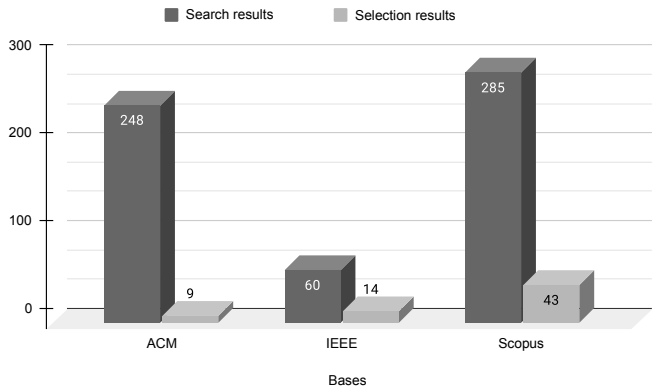

Figure 3. Relationship between results and selection of articles in each database.

notable categories are card games [15, 16, 22, and 35] and board games [20, 25, 39, and 40], each with 4 occurrences.

It was interesting to observe that some of the identified works suggest adapting existing games to the context of fractions (10, 13, 15, 16, 25, and 40). For instance, game 16 can be described as an intervention that incorporates several familiar card games, such as *twenty-one* (or *blackjack*), into the context of fractions.

Subquestion 02: *Are they compatible with Course Management Systems (CMS)*[5] *or Virtual Learning Environment (VLE)*?

Regarding integration with a CMS, which enables teachers to create or customize activities with the games or receive feedback on student progress, only 4 games meet these criteria (18, 27, 32, and 34).

Subquestion 03: *How are these games distributed?*

Of the 45 games reviewed, only 5 had a method for accessing the tool (2, 12, 18, 24, and 28). Among these, only 3 were located (2, 12, 18). For the games that did not offer a method for tool access, a Google search was conducted, which yielded access to only 3 additional games 27 (e.g. at https://apkpure.com/pizza-al-lancio/it.unipd.math.gaggi.Pizza_al_lancio___Bambini), 32 (), 33).

Regarding distribution, information was available for only 10 games. Of these, 8 are claimed to be distributed for free (2, 12, 18, 27, 28, 32, 33, and 34), with 2 of them described as open source tools (12 and 18). The remaining 2 games require payment for access (24 and 26).

Only 8 games (2, 12, 18, 27, 28, 32-34) have their respective papers specifying that the tool is distributed as free or open access. Of these, 2 games (12 and 18) are open source. Open Access refers to the unrestricted availability of scientific research results. In this context, Open Access aims to provide free access to research work, specifically tools for teaching fractions. In the free software community, open source means that the source code—the code that creates the computer program—is made freely available for consultation, examination, modification, and redistribution.

[5]Also found in the literature as Learning Management System (LMS)

Table III
LIST OF SELECTED ARTICLES

ID	Game	Reference
1	[Math App]	[9], [10]
2	Abydos	[11]
3	Catch the Monster with Fractions	[12], [13]
4	Cheese Factory	[14]
5	Cover-up, Un-cover	[15]
6	Cover-up, Un-cover	[15]
7	Discord	[16]
8	Discover a Whale Island	[17]
9	Easy Math	[18]
10	EduBingo	[19], [20]
11	Endless Sky	[21]
12	FracPotion	[22], [23]
13	Fraction Battle	[24], [25]
14	Fraction Body game	[26]
15	FRAX	[27]
16	From Pies to Numbers	[1]
17	Game of Fraction	[28]
18	iFractions	[29], [30]
19	Island of PI	[31]
20	Joyce	[32]
21	Keşfet Kurtul	[33], [34]
22	Math Zap	[35]
23	Mathirama	[36]
24	Monkey Tales	[37]
25	MONPEC	[38]
26	Motion Math	[39], [40]
27	Pizza al Lancio	[41], [42]
28	Refraction	[43], [44], [45], [46]
29	Run Fractions	[47]
30	Save Patch	[48], [49]
31	Semideus Exam	[50], [51], [52], [53]
32	Number Trace	[54]
33	ST Math	[55], [56]
34	The CandyFactory	[57], [58]
35	Tug-of-War	[59], [60]
36	U-Fraction	[61]
37	UFractions	[62], [63] [64], [65]
38	Tales & Fractions	[66]
39	We!Design!Fractions	[67]
40	Game without name 1	[68]
41	Game without name 2	[69]
42	Game without name 3	[70]
43	Game without name 4	[71]
44	Game without name 5	[72]
45	Game without name 6	[73]

Main Research Question: *What are the educational games*

for teaching fractions and how have these games been used in teaching strategies?

Table III displays the educational games for teaching fractions identified through this systematic review. The table indicates that 5 of these games were unnamed (40-45), while 39 games have their names listed (1-39).

According to the response provided in sub-question 01 V, the majority of educational games for teaching fractions are digital, with 39 instances, of which 3 are classified as hybrids (13, 14, and 37). Only 6 are physical games (5, 6, 15, 16, 22, and 39). This indicates that the literature suggests teachers are increasingly using technology to support teaching.

In sub-question 01, the review identified 24 games classified as puzzles (2-7, 11, 12, 18, 19, 21, 24, 26-34, 41-43), followed by quizzes, which appeared 10 times (9, 17, 20, 23, 25, 36-38, 40, and 45). Additionally, there were 4 instances of card games (15, 16, 22, and 35) and 4 instances of board games (20, 25, 39, and 40). This highlights a gap in the inclusion of role-playing games (RPGs) and indicates the need for creating games with varied contexts and challenges.

Since most of the related articles fall into the puzzle category, these games have been utilized to tackle interactive "problems" to progress to the next stage. In fact, they have been used not only to solve problems but also to introduce basic concepts of fractions.

The fact that some studies suggest adapting existing games to the context of fractions aids students in understanding fraction concepts by linking them to familiar games.

VI. Result

The systematic review revealed that few studies integrate with course management systems, which would enable teachers to customize the course and provide immediate feedback on student performance. This feedback is crucial for teachers to understand students' learning and adjust the teaching methodology if needed.

The main findings of this research are related to absence of tools integrated with the Web learning systems, absence of a clear path to access the tools and the absence of metrics to measure the educational efficacy of the tools. These findins are detailed on the next three subsections.

A. There is a need for more tools compatible with Web course systems (LMS)

A course management system (usually named Learning Management System - LMS) offers both synchronous and asynchronous resources that support the learning process, enabling its planning, implementation, and evaluation. This type of environment features functionalities designed to store, distribute, and manage learning content in a progressive and interactive manner, and can also track and report on learner activities and performance.

The SLR revealed that few studies offer integration with course management systems. Such integration is crucial because it enables the monitoring of student behavior while using the game. Additionally, it allows teachers to customize activities within the game and receive feedback on student progress.

Creating tools compatible with these systems enhances the exchange of knowledge among participants, facilitating the creation of new insights. It also offers valuable support in coordinating and organizing activities. Furthermore, teachers receive summaries and statistics on student responses, can quickly access any specific response, and download all student submissions. Students, in turn, have access to summaries of their activities, including their grades.

B. Jobs need to be clearer about how to access the tools

This review revealed that out of the 45 games identified, only 5 provided a means of accessing the tool. However, only 3 of these were successfully located, indicating that even when access was indicated by the authors, the provided links no longer worked. For the games without a direct access method, a Google search was conducted, which resulted in access to only 3 additional games.

It is crucial to provide a clear, objective, and functional method for accessing the tool, as this would allow other researchers to use it practically for developing new research ideas. Furthermore, access to the tools would enable readers to explore and test the application, gaining a better understanding of the findings reported in the papers. Reliable and direct access also serves as a means of promoting the tool.

C. We need to develop metrics to test gaming tools for teaching fractions

Evaluating games is always a complex issue. The first step is to determine what aspects of an educational game should be assessed, which is not always straightforward. Various aspects can be evaluated, such as usability, gameplay, graphics, sounds, and learning outcomes, among others. These aspects can be assessed using different methodologies and tools. However, among the studies reviewed, no diversity in evaluation methods was identified.

Typically, evaluations focus on learning outcomes through pre- and post-tests and occasionally on usability through quality questionnaires. This highlights the need to explore alternative approaches to evaluating educational games, or at least to test other models and tools to analyze results and understand the impact of such methodologies on teaching.

Rodio [74] identifies two approaches to game evaluation: the empirical approach and the analytical approach. The empirical approach relies on user performance or feedback, while the analytical approach involves examining the game through a set of theories and models. According to Rodio [74], the analytical approach is more advantageous because it can be applied during the early stages of game development and is cost-effective.

Therefore, employing analytical techniques throughout the lifecycle of an educational game is a valuable approach. This practice can make game development more precise and cost-effective, and also offer teachers a method for evaluating digital educational games they plan to use as tools to support the teaching and learning process.

VII. Conclusion

This review is the need for papers to provide a clear method for accessing their tools. Out of the 45 games identified, only 5 papers included a means of access. Furthermore, in some cases, the provided access was broken, resulting in only 3 papers being accessible. This indicates a significant number of papers without proper access, which is crucial for disseminating the study of the tool in scientific research.

Regarding distribution, few articles specified the type of license for their tool. This information is crucial because it determines whether the tools can be made available for free, either publicly through online platforms or privately.

This review highlighted an issue with digital educational games for fractions: their evaluation. These games are crucial not only for assessing learning but also for evaluating usability, cooperativity, and other features. Most of the articles employed pre- and post-tests to measure the impact of the tool on learning. However, to effectively achieve learning goals, it's important to consider various elements of the game. After identifying these elements, the next step is to design evaluations based on scientific research and then implement and analyze these evaluations.

Future research could examine which technologies the game supports, whether it is 2D or 3D, and which fraction topics are addressed in the articles. Investigating whether the tool specifies its target audience or outlines any testing or development methodologies could also be valuable. This systematic review offers the opportunity to analyze and systematize a tool with key characteristics for teaching and learning fractions, as well as to identify its intended audience.

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