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Didactic engineering supporting the use of gamification applied to the teaching of arithmetic operations

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Abstract

Background: This study proposes an instructional method aimed at resolving arithmetic problems in mathematics. It is specifically tailored to assist educators in their initial mathematical training and to enhance classroom mathematics teaching through the implementation of Gamification.

Aim: The objective of this research is to explore the contributions of didactic engineering and digital technologies, particularly those incorporating gamification, in full-time secondary school education, with an emphasis on basic arithmetic operations.

Method: The methodology employed in this study is based on and structured around Didactic Engineering research techniques. It is an exploratory, qualitative research designed to simplify the understanding of mathematical problems through the use of Digital Technologies.

Results: The findings of this research are categorized into stages: preliminary analysis, a priori analysis, experimentation, and a posteriori analysis and validation. It was observed that the application of problems in the classroom validated the strategies employed.

Conclusion: The results indicate that the implemented gamified activities positively influenced teachers' perspectives on how these activities, particularly the two games designed in Google Presentations, support the teaching and learning processes in mathematics for students.

INTRODUCTION

The advent of Digital Technology (DT) has dramatically transformed teaching and learning approaches, enhancing classrooms, educational institutions, and interactive environments with unprecedented efficiency (Garcias et al., 2022; Scheunemann et al., 2019; Singh, 2021). As noted by Artigue (2021) an object of knowledge cannot be deemed teachable unless it can be woven into a pedagogical progression, linked to student activities, and evaluated for understanding. DT has ushered in innovative interactive platforms and applications, strengthening the bond between students and their educational milieu, peers, and personal learning journeys. This rapid evolution of DT presents dynamic, engaging, and educational alternatives to the traditional classroom setup, transitioning from the usual reliance on whiteboards, desks, and chairs to embracing a wealth of digital resources. These resources foster varied, assimilative, and inclusive teaching methods, utilizing compelling techniques to capture student interest and amplify learning opportunities (Abdelbary et al., 2023; Vidal & Miguel, 2020). Basic arithmetic operations, crucial for problem-solving and indispensable for any mathematical computation in primary education, are made more accessible through these evolving teaching methodologies.

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This study addresses the challenges associated with basic mathematical operations (addition, subtraction, multiplication, division), and specifically, the integration of Digital Technologies (DT) with the Google Presentations application. Various authors have shed light on the use of these technological tools. Notably, the insights provided by Rosa (2017) question how mathematics is cultivated in schools through the use of DTs, emphasizing the human and uncertain aspects of mathematical subjects and their classroom application. This underscores the realization that mathematics education manifests in diverse aspects of students' daily lives, generating different interpretations between institutional teaching and its practical application. This discrepancy mirrors the content and reality shaped by knowledge, representations, and conclusions derived from educational tasks. In this context, data from the Brazilian Basic Education Evaluation System (SAEB) indicate that students across all levels of Brazilian Basic Education encounter difficulties in mastering Mathematics (Acharya et al., 2021; Castilho et al., 2023; Peng et al., 2019).

According to the Basic Knowledge Matrix (MCB), arithmetic operations are identified as core content for classroom engagement (Ceará, 2021), suggesting a strategy to bridge learning gaps from elementary to high school education. Thus, we have devised a thematic treatment, guided by various elements of Didactic Engineering (DE), to structure our research. The importance of DE in the realm of classroom mathematics education is articulated (Artigue, 1988) as an experimental scheme foundational to didactic accomplishments, encompassing the design, execution, observation, and analysis of teaching sequences. Our research delves into the application of gamification in mathematics education, steered by the principal inquiry: how is primary mathematics learning structured using digital technologies in Basic Education for Full-Time High School students? Enhancing this experiential report, our study integrates perspectives from Douady (1993), Almouloud & Silva (2012), and Neto & Da (2021) concerning Digital Educational Games. Therefore, our goal is to explore the contributions of Didactic Engineering alongside the use of Digital Technologies (DT), including the active methodology of Gamification in an educational setting for Full-Time High School students, with a specific focus on basic arithmetic operations. The forthcoming section elaborates the theoretical framework of this research, delineating the definitions of Didactic Engineering and Gamification. Additionally, this study outlines the methodological procedures adopted, leading to the expected results and conclusions regarding the analyzed theme.

LITERATURE REVIEW

1. Didactic Engineering

The concept of classical or first-generation didactic engineering took root in the field of Mathematics Didactics in the early 1980s. By mid-1982, pioneers such as Guy Brousseau, the creator of the Theory of Didactic Situations (TDS), Yves Chevallard, the French author behind Didactic Transposition (DT), and Michèle Artigue in 1989, began to explore Didactic Engineering (DE) as a research methodology. This approach aimed to address didactic phenomena in environments akin to a conventional classroom setting. The term "didactic engineering" was conceptualized based on the analogy of an engineer's work, who initiates a project with a foundation in the scientific knowledge of his domain. This involves engaging in a scientifically rigorous process, dealing with complexities beyond those typically encountered

in science to solve problems that science alone may not address (Artigue, 1988). This process naturally fosters a triadic relationship among teachers, students, and knowledge.

Artigue & Trouche (2021) observed that the French didactic tradition has facilitated the development of didactic research through a dynamic interaction between researchers and educators, as well as a deep engagement with the realities of classroom environments. This is evident in the emphasis placed on didactic engineering within this tradition. Echoing Artigue's insights, French mathematician Regine Douady, known for her development of the so-called Board Game, elucidates the DE methodology by likening the teacher to an engineer. According to her, DE unfolds through interactions between the teacher and students, evolving based on students' responses and the educator's strategic choices and decisions (Douady, 1993).

Artigue (1988) further elaborates that this methodology employs an experimental framework in didactic situations concerning the design, execution, observation, and analysis of teaching sequences. This framework facilitates validation through both a priori and a posteriori analysis, encompassing dialectical phases: initial analysis, design, a priori analysis, experimentation, a posteriori analysis, and validation. In the initial analysis phase, critical insights are leveraged to formulate an intervention strategy, incorporating epistemological knowledge, the didactic dimension of teaching, and the cognitive challenges faced by students. This includes an epistemological analysis of existing teaching methodologies, students' conceptions, difficulties, obstacles, and the analysis of constraints and requirements of the didactic implementation (Almouloud & Silva, 2012). During the a priori conception and analysis phase, tools that facilitate cognitive asymmetry among students are selected. This stage also anticipates students' conjectures and behaviors during the teacher's proposed didactic sequence, laying the groundwork for planned activities.

> *Artigue (1996) highlights that the constructivist theory underscores the principle of students actively engaging in their knowledge construction through interaction with their environment. The theory of didactic situations, foundational to didactic engineering methodology, has always aspired to govern the relationship between meaning and situations*

Regarding a priori analysis, the choices made aim to steer students' behaviors and interpret these behaviors. This phase relies on hypotheses, the validation of which will indirectly be challenged during the confrontation stage (Artigue, 1996), leading to the fourth phase, the a posteriori analysis. The experimentation phase entails the execution of the didactic sequence, taking into account the outlined assumptions, the objectives of the activity, and its realization during the research. This phase involves documenting the didactic contract and observations made during experimentation (Almouloud & Silva, 2012), including the application of research instruments and recording observations of student participants.

Finally, the a posteriori analysis and validation phase processes data collected during the experimentation stage, such as student writings, observation records, and audio and video recordings. This stage facilitates a comparison between the earlier a priori analysis and the subsequent examination of the didactic situation. This research adheres to the four stages of DE: preliminary analysis, a priori analysis and design of the didactic situation, experimentation, and a posteriori analysis and validation. It aims to apply these stages in teaching basic

mathematical operations (addition, subtraction, multiplication, division) through Gamification in the classroom setting

2. Gamification

Approaching problems in the classroom is both a challenging and interactive endeavor, presenting a realm of enjoyable games that require a foundational understanding of mathematics for students to solve. However, it is common practice to utilize materials previously created by other educators, typically those available for download on the internet (Tolomei, 2017). Engaging with games allows for the learning of negotiation within a rule-based environment and the deferment of immediate gratification. It facilitates teamwork and collaboration among students to make decisions for the optimal outcome.

In line with this approach, teachers and students adapt to Gamification using Google Presentations online, focusing on selecting alternatives during classroom application to guide the learning process towards problem resolution. Gatti (2020) highlights the allure of such teaching materials from the students' perspective, presenting a significant challenge for educational institutions and professionals in primary education to transform school environments into spaces conducive to learning. Games offer various avenues for progressing through educational stages, with rewards obtained as challenges are overcome (McGonical, 2012). This speaks to the power of teaching, inspiration, and engagement through differentiated learning. In this context, Gamification has the potential to significantly increase student participation by incorporating the enjoyable aspects of games into mathematics education. Therefore, Kapp (2012) emphasizes that gamification is not merely about presenting activities; it's about the approach used in the classroom to foster interaction and create a positive environment for teaching and learning.

Grando (2000) discusses "the introduction of games into the teaching-learning context brings both advantages and disadvantages," a topic explored within the specialized literature on the subject. Teachers are encouraged to consider these factors when integrating virtual pedagogical objects with technological games into their educational planning. This involves a reflective engagement with methodological principles, aiming for a coherent approach that is evident in classroom practice. Figure 1 illustrates the advantages and disadvantages of using games in teaching and learning as identified by Grando (2000).

Digital games are noted for their ability to provide immediate and instantaneous feedback to user actions, offering simulated scenarios that can guide the learning of essential skills for improvement, thus opening opportunities for their educational use (Silva, 2021). Understanding the economic, social, and historical connections among these dimensions of social practice enables the comprehension of concepts as relational systems of concrete totalities aimed at explaining, understanding, and transforming them (Ramos, 2017).

VANTAGENS	DESVANTAGENS
- **fixação de conceitos** já aprendidos de uma forma motivadora para o aluno; - **introdução e desenvolvimento de conceitos** de difícil compreensão; - desenvolvimento de **estratégias de resolução de problemas** (desafio dos jogos); - aprender a **tomar decisões** e saber **avaliá-las**; - **significação** para conceitos aparentemente incompreensíveis; - propicia o relacionamento das diferentes disciplinas (**interdisciplinaridade**); - o jogo requer a **participação ativa do aluno** na **construção** do seu próprio **conhecimento**; - o jogo favorece a **socialização** entre os alunos e a conscientização do **trabalho em equipe**; - a utilização dos jogos é um fator de **motivação** para os alunos; - dentre outras coisas, o jogo favorece o desenvolvimento da **criatividade**, de **senso crítico**, da **participação**, da **competição** "sadia", da **observação**, das várias formas de uso da linguagem e do resgate do **prazer em aprender**; - as atividades com jogos podem ser utilizadas para reforçar ou recuperar habilidades de que os alunos necessitem. Útil no trabalho com alunos de diferentes níveis; - as atividades com jogos permitem ao professor identificar, diagnosticar alguns erros de aprendizagem, as atitudes e as dificuldades dos alunos.	- quando os jogos são mal utilizados, existe o perigo de dar ao jogo um **caráter puramente aleatório**, tornando-se um **"apêndice" em sala de aula**. Os alunos jogam e se sentem motivados apenas pelo jogo, **sem saber porque jogam**; - o **tempo gasto** com as atividades de jogo em sala de aula **é maior** e, se o professor não estiver preparado, pode existir um sacrifício de outros conteúdos pela falta de tempo; - as **falsas concepções** de que se devem **ensinar todos os conceitos através de jogos**. Então as aulas, em geral, transformam-se em verdadeiros cassinos, também sem sentido algum para o aluno; - a **perda da "ludicidade" do jogo** pela interferência constante do professor, destruindo a essência do jogo; - a **coerção do professor**, exigindo que o aluno jogue, mesmo que ele não queira, **destruindo a voluntariedade** pertencente à natureza do jogo; - a dificuldade de acesso e disponibilidade de material sobre o uso de jogos no ensino, que possam vir a subsidiar o trabalho docente.

Figure 1. Advantages and disadvantages of games in teaching and learning (Grando, 2000)

At its core, gamification employs the logic and structure of games to motivate, engage, and facilitate learning. Thus, gamification can be implemented with or without digital technology, indicating that its application is not strictly reliant on technical or digital resources (Barbosa et al., 2020). The discussion above reveals that gamification transcends the mere creation or use of games, embodying a broader culture that challenges students to reason, integrate, and engage, thereby fostering motivation and goal achievement.

Based on the literature review conducted, this study proposes an innovation in mathematics education by integrating didactic engineering with gamification principles. This innovation aims to create a dynamic and engaging learning environment that not only encourages active student participation but also enhances their engagement in the mathematical learning process. By combining a systematic didactic engineering approach with captivating gamification strategies, this study seeks to address the negative perceptions of mathematics as a challenging and dull subject. Therefore, the purpose of this research is to explore how didactic techniques and digital technologies, particularly gamification, can contribute to mathematics education at the secondary school level, focusing on the teaching of basic arithmetic operations.

METHODS

The research methodology unfolded across the complete spectrum of Didactic Engineering (DE) phases: preliminary analyses, a priori analysis and design, experimentation, and a posteriori analysis and validation. However, this exposition will focus on selected results within these stages. During the Preliminary Analysis phase, the study was structured around two main

aspects: I) providing a brief epistemological overview of the teaching of the four basic mathematical operations, and II) evaluating textbooks on basic operations content to select relevant questions for Gamification research.

For aspect I, insights were drawn from authors such as de Holanda et al. (2020) and Jacomelli-Alves & Sabel, (2022), who have explored the pedagogy of basic operations. It was observed that a significant challenge in mastering these operations is students' lack of interest and motivation, exacerbated by insufficient exposure or absence of these concepts in prior academic years. This challenge is intensified in an era where Digital Technologies (DT) are an integral part of the teaching and learning process. In aspect II, a review of textbooks approved by the National Textbook Program (PNLD) 2018 revealed minimal coverage of basic operations, often limited to brief explanations. Among the volumes reviewed, only Balestri (2016) introduced some problem-solving exercises in early chapters. The approach to teaching these concepts to high school students typically follows traditional methods, with occasional integration of GeoGebra software applications, which may encourage rote learning through repetition. According to Galvão & Chagas (2022), this pedagogical approach requires a reevaluation of the use of symbols and activities in teaching.

The a priori Analysis and Design phase saw the development and planning of an interactive gamification strategy incorporating essential high school mathematics content. This approach aimed to bridge the gap between traditional education and the digital culture that significantly influences contemporary society. The goal was to maintain educational objectives while navigating the complexities introduced by the digital world. The research adopted an exploratory qualitative methodology, justified by the limited number of studies employing Gamification in High School settings within Action Research frameworks. According to Gil (2002), exploratory research serves to deepen understanding of the problem for all stakeholders, while qualitative research addresses aspects of reality that are not quantifiable, focusing on the lived experiences of the school environment without statistical treatment of student data (da Costa & da Costa, 2001).

In the Experimentation phase, the study engaged two high school classes at Assis Bezerra Full Time School, involving 54 students, with 32 participating in the gamified activity. The research instrument comprised three stages: 1) A bibliographic review of textbooks, the school curriculum, and the SAEB descriptors matrix; 2) Development of games on the Google Presentations platform; and 3) Implementation of Gamification with both classes.

The initial stage involved reviewing digital textbook platforms to enhance student reasoning. The second stage consisted of interactive workshops using game slides, and the third stage applied the digital games developed on Google Presentations, outlining the rules and framework for Gamification in the classroom. Interactive groups were formed in the workshops to facilitate learning of mathematical content through digital games, fostering mathematical thinking and reasoning applicable to Gamification.

Figure 2. Virtual game in Google presentations

Figure 2 displays a virtual game created on Google Presentations, showcasing an innovative approach to engaging students with mathematical concepts. The a posteriori analysis and validation phase involved examining the data from game outcomes against the a priori analysis objectives and hypotheses of this study. This included evaluating the inclusion of arithmetic problems solved by students and their feedback on Gamification in the classroom setting.

RESULTS AND DISCUSSION

This research led to the creation of two educational games developed by the mathematics educator utilizing the Google Presentations platform. The overarching aim of these games was to present the subject of Mathematics in a manner that is both interactive and enjoyable, thereby enhancing student performance in both internal and external assessments. The implementation of these games engaged 32 students from the Assis Bezerra Full-Time School in Quixeramobim, Ceará, Brazil, within the allocated mathematics instruction period. The gamification session included students who were present on the designated day.

The challenges integrated into the games were derived from textbooks covering basic mathematical operations. These challenges were designed to highlight open-ended and interpretative questions, leveraging the students' pre-existing knowledge as a foundation. One of the games, dubbed "Primary Math Museum," drew inspiration from a maze-like structure, termed "Labyrinth," with the objective of fostering mathematical reasoning in a playful context. Another game, "Stop Egypt," featured a roulette mechanism alongside images that, when interacted with, would reveal the mathematical topic to be addressed by the students.

- Game 01 offered a variety of mathematical problems centered around basic operations, set against the backdrop of different virtual environments. Players navigated through random stages as they progressed.
- Game 02 was designed to enhance mathematical logical reasoning, challenging players to select from a grid of 16 questions displayed 4x4 on the screen. Adjacent to this grid was an option for players to choose any number that would assist in solving the presented question.

Following the introduction of these games, interactive group discussions were prompted among the students to deliberate on the problem scenarios introduced during the classroom activity. This was succeeded by a presentation of the two games developed on the Google Presentations platform, as depicted in the visual representation (Figure 3).

Figure 3. Games applied in the classroom

During the gamification session, the educator outlined the rules and the sequential steps necessary to navigate through each game. The initial engagement of students with the game, coupled with the teacher's instructions, facilitated the students' attempts at problem-solving. To preserve anonymity in line with ethical standards regarding human research, students' contributions were anonymized as E1, E2, E3, E4, etc. This careful approach was adopted in both the data collection and its subsequent analysis within this study. For instance, participant E8, in dialogue with interactive group 03, remarked:

E8: "*In Game 01, I noticed that each level guides us through the basic mathematical operations step by step. The first level introduces addition, and subsequent levels cover subtraction, multiplication, and division. This structure allowed me to apply my prior knowledge from previous years of study to each challenge*."

The discussion progressed as the educator prompted further insights from other participants. Responses from subjects E23, E31, and E10 highlighted diverse experiences:

E23: "*When I reached the division part, I was initially uncertain because I lacked the knowledge to tackle these questions. However, after your guidance, I discovered alternative methods to solve them, which I can apply to future challenges*."
E31: "*I managed to solve a few problems and am now focusing on learning how to address the tougher ones presented in both games*."
E10: "*I preferred Game 02 because it offered fewer choices and the scenarios were more aligned with what we experienced in elementary school*."

The integration of gamification in education has shown promising results in enhancing the learning experience by making abstract concepts more accessible and appealing to students. Brousseau's concept of a dialectical situation in education, where the validity of knowledge is tested through interactive learning scenarios, aligns with the participatory and reflective nature

of gamification (Bouchrika et al., 2019). Research recommends incorporating gamification techniques into the curriculum to create engaging learning opportunities and to enhance students' enjoyment and learning (Regudon et al., 2022). Furthermore, studies by Bigdeli et al. highlight that gamification, through game design techniques, fosters a more effective and engaging teaching and learning environment, supporting the notion that gamification can bridge the gap between traditional and digital learning methods (Lester et al., 2023).

These studies collectively underscore the positive impact of gamification on student engagement, motivation, and learning outcomes in educational settings. By embedding game elements within a non-game context, gamification has the potential to overcome challenges in traditional teaching methods and enhance the didactic potential of educational tools. These findings suggest that gamification can play a crucial role in modernizing educational approaches and meeting the digital competencies required in contemporary learning environments.

CONCLUSIONS

In the course of this study, the exploration of fundamental arithmetic operations through interactive gamification and Didactic Engineering (DE) methodologies highlighted the importance of expanding such practices to additional Comprehensive High School classes. The utilization of Google Presentations as a technological aid facilitated the didactic transposition of complex problems, enhancing comprehension and offering insights into effective problem-solving strategies. This research aimed to bridge gaps identified in mathematics education at the elementary level, focusing on basic operations and measures of central tendency via engaging digital platforms. The integration of mathematical challenges within Google Presentations provided an innovative digital didactic framework, diverging from conventional and monotonous textbook approaches, and fostering students' responsibility in developing their mathematical reasoning and knowledge. The findings advocate for the adoption of this methodology as a resource for educators seeking to enrich basic mathematics instruction and integrate related content. As part of an ongoing investigation, the intention is to further apply and refine these didactic models within the digital landscape of Google Presentations throughout the academic year, aiming to gather additional data and insights to enhance educational practices.

AUTHOR CONTRIBUTIONS STATEMENT

PVS designed the research framework and led the epistemological analysis, while selecting the main technological tools for this research. FRV is responsible for the development and implementation of educational games within Google Presentations, as well as facilitating gamification workshops in Comprehensive Middle School classes.

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