

Embedded System Prototype Driving Innovative Math Education

Thais Sá Claudino
IFSC-Tubarão, Brasil
thais.c2003@aluno.ifsc.edu.br

Sarah Jane Souza da Silva
IFSC-Tubarão, Brasil
<https://orcid.org/0009-0001-5238-885>

Isnaldo Isaac Barbosa
UFAL-Maceió, Brasil
<http://orcid.org/0000-0003-3147-1780>

Abstract—This article presents the proposal for the continuation of an interdisciplinary extension project that integrates mathematics education, technology, and social inclusion. The initiative originates from a board game aimed at teaching basic mathematical operations, already applied with elementary school students, and proposes its evolution into an interactive digital version. Through collaboration with the Embedded Systems program, a prototype is being developed that uses an interactive screen controlled by a microcontroller, capable of presenting mathematical challenges dynamically, with real-time visual and sound feedback. The project is based on the use of low-cost hardware and free software, reinforcing the connection between technology, education, and inclusion to create replicable pedagogical solutions with high social impact. The project is part of the context of active learning methodologies, exploring the potential of playfulness combined with open technology to promote greater engagement, autonomy, and inclusion in the educational process. In addition, it seeks to expand accessibility for students with disabilities, strengthening pedagogical practices aligned with the principles of inclusive education and the use of low-cost technologies with potential for replication in different school contexts. The results that motivated this next step refer exclusively to the application of the physical board game. That initial phase, which showed a significant increase in student engagement, was fundamental for validating the playful pedagogical approach and served as the foundation to justify and guide the development of the digital prototype, which constitutes the current phase of the project.

Keywords — Mathematics Education; Microcontroller; Interactive Game.

I. INTRODUCTION

Mathematics education in Basic Education faces persistent challenges throughout Brazil, reflected in students' learning difficulties and low performance in national assessments. In a world increasingly driven by data and logical reasoning, the presence of Mathematics in everyday life makes its meaningful integration into the educational process even more urgent.

In the municipalities of Capivari de Baixo and Tubarão, the results of the Basic Education Assessment System (Saeb) and the Basic Education Development Index (Ideb) have remained below expectations. Between 2013 and 2023 [1,2], data indicate that most 9th-grade students remain between proficiency levels 2 and 4, showing difficulties in fundamental skills such as:

- Recognizing that angles do not change in enlarged or reduced figures;
- Locating points in a coordinate system;
- Determining perimeters and volumes using visual support;
- Understanding decimal fractions and their representations;
- Solving first-degree equations;
- Performing operations with rational numbers and percentages;
- Solving problems involving proportional relationships.

In response to this scenario, an extension project was developed with the aim of creating learning environments to help overcome these challenges, even in the face of foundational learning gaps and adverse socioeconomic conditions. The proposal seeks to innovate teaching processes, promote inclusion, and strengthen Basic Education.

The initiative focused on developing educational materials and resources that facilitate the teaching and learning of Mathematics, aligning with the Sustainable Development Goals (SDGs), particularly those related to inclusive and quality education. At the same time, it encouraged teachers to reflect on their pedagogical practices and motivated students to adopt a more active role in the construction of mathematical knowledge.

Schools and Mathematics teachers must keep up with the world's transformations, and using games in teaching has proven to be effective in this context [3]. Games are linked to children's intelligence [4], this brings their motivational and imaginative value [5].

Thus, the use of games and playful methodologies was adopted as a central strategy of the project, making learning more meaningful and enjoyable. Previous experiences by the team, using physical games (such as basic operations board games) in schools in Caçador, Tubarão, and Capivari de Baixo, demonstrated increased student engagement, improved performance, and greater classroom interaction.

Building on these positive outcomes, the current project proposed the evolution of the physical game into a digital and interactive version, exploring the potential of accessible technologies. The prototype is under development and is expected to be made available to participating schools later this year, further enhancing the positive impact of the playful approach. A key differentiator of this proposal is its commitment to democratizing access to educational

technology. By using low-cost hardware, such as the ESP32 microcontroller, and open-source development platforms like the Arduino IDE, the project becomes viable for schools with limited resources, while also promoting a culture of collaboration and open knowledge. This approach ensures that technological innovation becomes a tool for inclusion rather than a factor that deepens educational inequalities.

II. LITERATURE REVIEW

The low performance of students in mathematics is a reality not only in Brazil but also in many other countries [6]. This indicates the urgent need for transformations in education, which necessarily depend on the adoption of innovative pedagogical practices and teaching methodologies by mathematics teachers. In this regard, “[...] the contemporary world is rapidly changing, and schools, as well as educators, must remain in a constant state of alert in order to adapt teaching, both in terms of content and methodology [...]” [7].

In mathematics teaching, Digital Game-Based Learning has emerged as a promising strategy. Research shows that the interactivity and immediate feedback inherent in digital games increase student engagement, motivation, and persistence. These features align with active methodologies, which are crucial for constructing mathematical knowledge

Mathematical relationships are constructed by individuals when, in the presence of objects, they establish comparisons, since “[...] the child progresses in the construction of logical-mathematical knowledge through the coordination of simple relationships previously created with objects” [8]. However, it is crucial to emphasize that the absence of adequate teaching materials and technological resources cannot be considered the sole cause of weaknesses in teaching and learning processes. Other aspects must also be considered, such as teacher training and the physical infrastructure of schools.

The teaching-learning process is complex and multidimensional, and it is essential to recognize that the teacher must act as a mediator, facilitator, and articulator of knowledge, rather than merely a transmitter of information. “Learning is increasingly becoming a fundamental human right, almost at the same level as the right to life” [9]. Therefore, it is imperative that teachers are able to demonstrate to students the relevance of mathematics to their own lives. This perspective is reinforced by recent studies, which argue that, as mediators of knowledge, teachers must observe the context in which teaching and learning occur, with the purpose of fostering interaction with the social environment in which schools and students are embedded [10].

In this sense, the work developed by this project has been of great relevance in mitigating the challenges faced in education and in improving the teaching and learning of mathematical content. From a technological perspective, embedded systems, due to their versatility, low cost, and customization potential, have become essential tools in educational and interactive solutions [11], [12].

IV. METHODOLOGY

For the development of the interactive mathematics game, an approach integrating knowledge from pedagogy, mathematics, and embedded systems will be adopted. The project will be structured into sequential stages, as described below:

A. Hardware Requirements Definition

The selection of hardware components is a crucial step for the success of the project. After analyzing performance, cost, and ease of development, the following components were preselected:

- **Microcontroller:** The ESP32 will be the microcontroller of choice due to its processing power, large number of general-purpose input/output (GPIO) pins, and, most importantly, its built-in Wi-Fi and Bluetooth connectivity. The popularity of the ESP32 in educational applications is largely due to its balance between performance and accessibility [7].
- **Interactive Display:** A TFT (Thin-Film Transistor) display with a touch panel will be used. This component will allow the visualization of mathematical operations (addition, subtraction, etc.), numbers, and results, while also serving as the main input interface, enabling users to select
- answers directly on the screen.
- **Auditory Feedback:** A passive buzzer will be employed to provide instant audible feedback to the player. Different tones will be programmed to indicate correct and incorrect answers, reinforcing learning and making the experience more dynamic and engaging.

B. Software Development

The software will be developed using the Arduino IDE, taking advantage of the vast number of libraries available for the ESP32, which will simplify the interaction with the TFT display and buzzer. The code will be structured to:

- **Generate Mathematical Operations:** The system will randomly generate addition and subtraction operations, following the content of the original physical board game.
- **Display on Screen:** The operations and possible answers will be displayed clearly and intuitively on the TFT screen.
- **Process User Interaction:** The software will read the touch coordinates on the screen to identify the answer selected by the player.
- **Validate the Answer and Provide Feedback:** The user’s response will be compared with the correct result. If correct, a characteristic sound will be played by the buzzer and a congratulatory message will be displayed. If incorrect, a different sound will be triggered, and the correct answer may be indicated.
- **Record and Display Results:** The system will count the number of correct and incorrect answers, displaying the score on the screen.

C. Integration and Prototyping

The final stage of the methodology will consist of assembling the prototype by connecting the TFT display and the buzzer to the ESP32 microcontroller. A passive buzzer is utilized as the primary device for sonorous feedback within the prototype, delivering immediate auditory cues in response to player actions. The microcontroller (ESP32) sends specific Pulse Width Modulation (PWM) signals to generate distinct frequencies, allowing for different tones to indicate correct and incorrect answers. The user interaction with the prototype will follow a logical and intuitive flow. Upon startup, the system will display a welcome screen on the TFT display. Next, the player can select the type of operation (addition or subtraction) and the difficulty level. Based on this selection, the ESP32 microcontroller will randomly generate a mathematical operation and display it on the screen. This integration ensures that the auditory feedback is synchronized with the user's interaction, contributing to a more dynamic, engaging, and effective learning experience. Integration tests will be carried out to ensure that all hardware and software components work harmoniously, providing a smooth and educational gaming experience. The prototype will also be applied with elementary school students in the cities of Tubarão and Capivari de Baixo.

D. Assessment Instruments

To evaluate the impact of the intervention with the physical board game, three instruments were used. Initially, a diagnostic pre-test containing [number] questions on basic mathematical operations (addition, subtraction, etc.) was administered to assess the students' prior knowledge. After the period of the game's application, a post-test with the same structure as the pre-test was used to measure learning progress. Additionally, an evaluation questionnaire was given to students and teachers at the end of the project. The questionnaire contained closed-ended questions (using a 5-point Likert scale) to assess perceptions of engagement, fun, and the tool's effectiveness, as well as open-ended questions to collect suggestions and testimonials.

V. RESULTS AND DISCUSSION

The initial diagnostic analysis, carried out through a test applied before the introduction of the game, revealed significant challenges in the teaching-learning process: difficulties in solving basic operations, issues with mathematical interpretation, and low interaction between students and teachers during classes.

The implementation of mathematical games with students highlighted the potential of playful activities to transform tasks considered difficult into enjoyable experiences. This approach allowed students to take on a more active and leading role in their own learning process.

Figure 1 shows a workshop held with teachers from the municipality of Tubarão, during which the physical board game of basic operations was applied.



Fig. 1. Application of the operations board game with teachers from the municipality of Tubarão.

During the activity with basic education students, it was observed that the use of the board game encouraged greater participation, collaboration, and social interaction among the students. Figure 2 illustrates this moment, reinforcing the potential of playfulness as a strategy to foster engagement and motivation.



Fig. 2. Students interacting with the operations board game.

After the playful phase, a second test with questions similar to the first was applied, aiming to evaluate learning progress. The results showed that adopting a differentiated approach in contrast to the traditional “chalk and talk” method provided a more effective understanding of mathematical content, significantly contributing to the development of students' skills and competencies.

At the end of the intervention, both teachers and students responded to an evaluation questionnaire, intended to collect feedback for improving future activities. The results revealed that the project not only promoted advances in students' mathematical abilities but also encouraged teachers to reflect on the importance of innovating their pedagogical practices.

Moreover, the feedback indicated that, due to the specific needs of some students, adaptations are necessary for certain activities. Among these, the development of automated games stands out as a key strategy to further promote inclusion and engagement, especially for students with disabilities.

These results reinforce the view that playfulness, when combined with active teaching methodologies, plays a fundamental role in fostering motivation, interaction, and more meaningful learning.

Based on this experience, the project moved forward with the incorporation of technological resources to expand its educational impact. This new phase involved the development of a digital and interactive version of the operations board game, using an ESP32 microcontroller, a touchscreen display, and buzzers to provide immediate visual and auditory feedback. The aim is to create a more dynamic, accessible, and inclusive learning environment.

that offers students an immersive experience in understanding mathematical concepts, while also promoting the inclusion of students with disabilities.

Figure 3 presents the initial prototype developed using an Arduino UNO, an LCD display, and a 4x4 matrix keypad. This configuration was used to validate the basic logic of interaction between input and output devices, serving as a preliminary stage for the transition to the ESP32-based interactive version of the game. The keypad allows users to enter numerical operations, while the LCD display provides visual feedback, ensuring usability tests prior to implementing more advanced hardware.

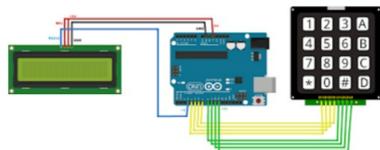


Fig. 3. Prototype of hardware integration using Arduino UNO, LCD display, and matrix keypad

An initial version of the project was first developed using the Tinkercad platform, which was selected for the preliminary simulation and testing phase. However, the Tinkercad environment does not feature the ESP32 microcontroller, necessitating the use of alternative components solely to validate the basic functionality of the circuit and the programming logic.

Despite this limitation, it was determined that the physical assembly of the board will be carried out using the ESP32. This decision is based on its advanced functionalities, such as the integrated Wi-Fi connectivity, which enables network communication and real-time data acquisition. This choice ensures greater potential for future enhancements, including the implementation of remote monitoring features, firmware updates, and integration with Internet of Things (IoT) platforms, thereby expanding the possibilities for the prototype's evolution.

VI. CONCLUSIONS

The proposal to develop an interactive version of a mathematical game using embedded systems represents a natural and promising evolution of an extension project previously validated in schools of the region. By combining playfulness, already proven effective in the teaching of mathematics, with interactive digital technology, the aim is to offer an innovative pedagogical tool capable of engaging with the reality of a generation of students increasingly connected and accustomed to digital interfaces.

This ongoing work highlights the relevance of interdisciplinarity and collaboration among different areas of knowledge—pedagogy, mathematics, and engineering—in building creative and impactful solutions to the challenges of education. Furthermore, it emphasizes the strategic role of open-source and low-cost technological resources, which enable the replication of this initiative in different educational contexts, thereby broadening its social impact. Embedded systems play a strategic role in creating intelligent educational interfaces [6], while other studies

emphasize their impact on interactive learning environments [8].

At the same time, the proposal reaffirms its commitment to inclusive education by incorporating accessibility resources into its design, enabling the participation of students with disabilities. Thus, the project contributes not only to the improvement of mathematics learning but also to the promotion of digital and educational inclusion.

The experience presented reinforces the transformative potential of integrating active methodologies, games, and embedded technologies, aligning with the principles of innovation, collaboration, and social impact. As a future perspective, the prototype is expected to be expanded with new functionalities, integrated into connected environments, and evaluated on a large scale in basic education. As a future perspective, the plan is to conduct larger-scale experimental tests in basic education, incorporating quantitative metrics, such as task completion time, accuracy rates, and progression analysis, to allow for a robust statistical evaluation of the tool's impact on the teaching-learning process.

REFERENCES

- [1] INEP. *Boletim da escola – SAEB 2023*. Disponível em: <https://saeb.inep.gov.br/saeb/resultado-final-externo/boletim?anoProjeto=2023&coEscola=42007402>. Acesso em: 9 out. 2025.
- [2] *Painel interativo de resultados*. Disponível em: <https://app.powerbi.com/view?r=eyJlIjoiOGZmMjNmOGQtOGFLYy00Y2NhlW14NmUtMGViZjAwNGJlNTAwIiwidCI6IjI2ZjczODk3LWM4YWVtNGIxZS05NzhmLWVhNGMwNzc0MzRiZiI9>. Acesso em: 9 out. 2025.
- [3] SILVA, S. J. S. *Modelagem matemática aplicada à engenharia de produção: proposta metodológica para o ensino e aprendizagem de matemática do ensino médio integrado*. 2024. 97 f. Dissertação (Mestrado Profissional em Matemática em Rede Nacional) – Instituto de Matemática, Programa de Pós-Graduação em Matemática, Universidade Federal de Alagoas, Maceió, 2023. Disponível em: https://sca.profnat-sbm.org.br/profnat_tcc.php?id1=7201&id2=171057035. Acesso em: 26 fev. 2024.
- [4] KISHIMOTO, T. M. *Jogo, brinquedo, brincadeira e a educação*. 14. ed. São Paulo: Cortez, 2011.
- [5] FILATRO, A. *Metodologias Inov-ativas na educação presencial, a distância e corporativa*. 1. ed. São Paulo: Saraiva Educação, 2018.
- [6] SADOVSKY, P. *Falta fundamentação didática no ensino da matemática*. São Paulo: Nova Escola, 2007.
- [7] PARRA, C.; SAIZ, I. *Didática da matemática: reflexões psicopedagógicas*. Porto Alegre: Artes Médicas, 1996.
- [8] KAMII, C. *A criança e o número: implicações da teoria de Piaget para a atuação com escolares de 4 a 6 anos*. 11. ed. Campinas: Papirus, 1990.
- [9] DEMO, P. *Professor do futuro e reconstrução do conhecimento*. Petrópolis: Vozes, 2004.
- [10] MUNHOZ, A. S. *Aprendizagem ativa via tecnologias*. Curitiba: InterSaber, 2009.
- [11] HEATH, S. *Embedded Systems Design*. 2nd ed. Oxford: Newnes, 2017.
- [12] BARRETT, S. F. *Embedded Systems Design with the Arduino*. 2nd ed. Cham: Springer, 2020.