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PAPER

Development of Software that Supports the Improvement of Mathematical Skills in Children

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ABSTRACT

Several applications have currently been developed to assist children in learning mathematics. However, many of these applications were created in different languages or designed for distinct social contexts, and some are now outdated. Given the factors mentioned above, a mobile application was created to help children develop mathematical skills. Through expert testing, an application was developed that meets both content and usability standards, ensuring that users feel comfortable while using it. The software was validated through multiple tests, yielding promising results.

KEYWORDS

applications, mathematics, skills

1 INTRODUCTION

Software development refers to a set of computer-based activities dedicated to the process of creating, designing, deploying, and supporting software. Software itself is the collection of instructions or programs that tell a computer what to do. It is independent of hardware and makes computers programmable [1].

The benefits of play are widely recognized and well documented. These include improvements in executive functioning, language development, early math skills, social growth, peer relationships, physical development, and overall health—including emotional health [2]. The objective of this study was to analyze the relevance of using games in children's learning of mathematics and logic. The results indicate that games such as crosswords, puzzles, and pattern-copying activities, among others, are effective in fostering logical reasoning. Furthermore, to stimulate logical-mathematical thinking at the initial level, it is essential to create an environment conducive to concentration and employ various games that contribute to its development [3]. In María's study [4], the objective was to evaluate the influence of digital games on improving logical-mathematical thinking

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in four-year-old children at an educational institution. The overall results confirmed a significantly positive impact on the development of logical-mathematical thinking; after implementing "Play Math Kids" with four-year-olds, they achieved positive scores.

Mobile technology has become an indispensable tool in daily life, and its use has expanded to all age ranges [5] [6] [7]. Therefore, this research proposed creating a mobile device application to assist the development of mathematical thinking in preschool children. This application is designed to help children develop basic math skills, as well as improve their memory and attention. User-centered design principles will be employed.

Based on the causes outlined above, a learning object (LO) [8] was developed for multi-touch devices, aiming to support the development of mathematical thinking in preschool children. This LO proposal focuses on basic mathematics such as addition, subtraction (originally "restas"), and multiplication.

2 RELATED WORK

The benefits of playing are highly significant and thoroughly documented. They enhance executive functioning and language skills, early mathematics abilities (such as number handling and spatial concepts), social development, peer relationships, physical development, and overall health—including emotional health—likely because play helps buffer anxiety and stress [9].

One study aimed to examine the significance of using games in children's learning of mathematics and logic, primarily grounded in various types of games as a useful tool [10]. The results show that, for fostering logical reasoning in children, games such as crosswords, puzzles, copying patterns, cooking recipes, board games, virtual games, and technology-based games should be used. Moreover, to stimulate logical-mathematical thinking at the initial level, it is necessary to provide a suitable environment for children to concentrate and to implement a variety of games contributing to this development [10]. Logical-mathematical concepts are deemed very important and useful in children's thinking, as they enable children to express knowledge in their daily educational experiences [10].

Another investigation aimed to determine the influence of digital games on improving the logical-mathematical thinking of four-year-old children in an educational institution. The results demonstrated a significant positive effect on logical-mathematical thinking; after implementing "Play Math Kids" with four-year-olds, they obtained positive scores [11].

Basic math operations are challenging for everyone. The AndMaths game for Android devices was created to assist primary school students in learning these basic math skills in the number ranges of 20, 50, 100, and 1000. Users can freely select the numeric ranges [12]. Another study aimed to find the relationship between educational games and mathematics learning for four-year-old children. The objective was to determine the correlation between educational games and math learning in these children. The conclusion indicated a moderate correlation between the research variables, and the hypothesis was confirmed [12].

In a different project, a linear number-line game was designed based on mental number-line theory. This study examined the effectiveness of the linear number line game in learning numerical concepts and arithmetic skills in children, comparing it with two other games—a nonlinear number line game and a game without a number line [13].

Finally, one article briefly examines examples of how these environmental assessments have enhanced the understanding of child development in diverse areas. It also provides an in-depth look at the contributions of analyzing one type of environment to one type of learning: how biased distributions of problems in math textbooks influence children's learning of fraction arithmetic [14].

3 METHODOLOGY

In the context of this study, and given the complexity of the domain being studied, a methodology was established with the aim of understanding the specific guidelines needed to create the application and enhance user skills.

To develop this project, the User-Centered Design (UCD) methodology was utilized as the approach for software development [15]. This method focuses on prioritizing the user in every design decision. UCD is defined as a philosophy that positions the user at the core of the design process, taking into account the characteristics, needs, and desires of the individuals who will use these products. Its primary strategy involves research techniques and methods designed to keep the user at the heart of the design process. The following sections describe how each phase of this methodology is contextualized within the present work.

Figure 1 outlines the methodological approach undertaken in this research, which consists of the following steps: definition of users, analysis, design, and evaluation.

Fig. 1. Methodological process of the research

3.1 Definition of users and determining requirements

For the development of this project, the first phase involved researching the type of user for whom the application is intended, considering the limitations provided by the literature. The requirements were defined based on a bibliographic review of the topic. Additionally, a review of the various applications developed for users with autism was conducted to gain insight into their development and design.

3.2 Analysis

This phase involved the following tasks [16]:

- Introduction of the primary issue that requires resolution.
- **Recording, refine, and selecting** the most feasible ideas.
- **Creation of storyboards** during these sessions.

3.3 Design

During this phase, a set of prototypes was created for each activity within each module, starting with the application's login screen, as shown in Figure 2. In addition, the initial screen of the application was developed to display each of the levels it will contain, also illustrated in Figure 2.

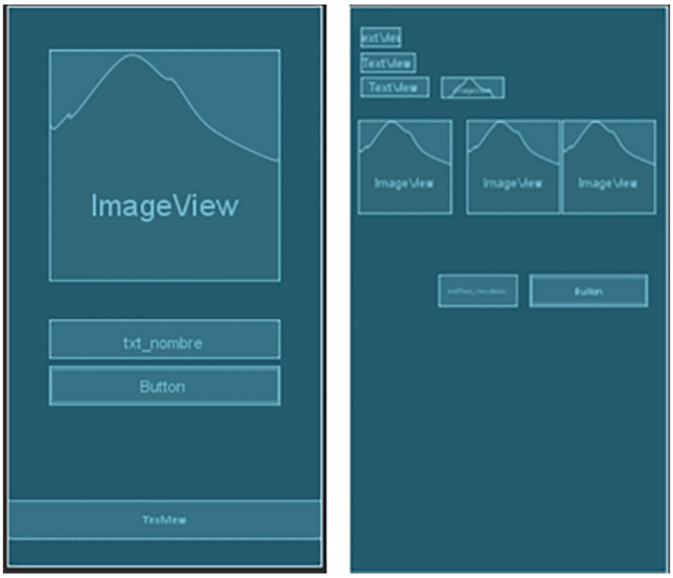

Fig. 2. Prototype

In Figure 3, we can see the intended design for the game. The plan is to keep it simple and avoid excessive information, preventing the child from feeling lost and making it easier to assimilate the information presented. The **initial screen** shows only one field for the child to enter their name, followed by a button to start playing. It also displays the **high score** previously achieved by the child.

Once the child starts playing, another screen appears, which includes:

- **Current score**
- The **name** the child entered on the initial screen
- The number of **lives**, represented here by three apples
- A **label** showing the calculation to be solved
- A **field** for the child to enter their answer
- Finally, a **button** to check their entered answer

If the answer is correct, the game displays the next calculation to solve. If not, the child loses one apple (i.e., one life).

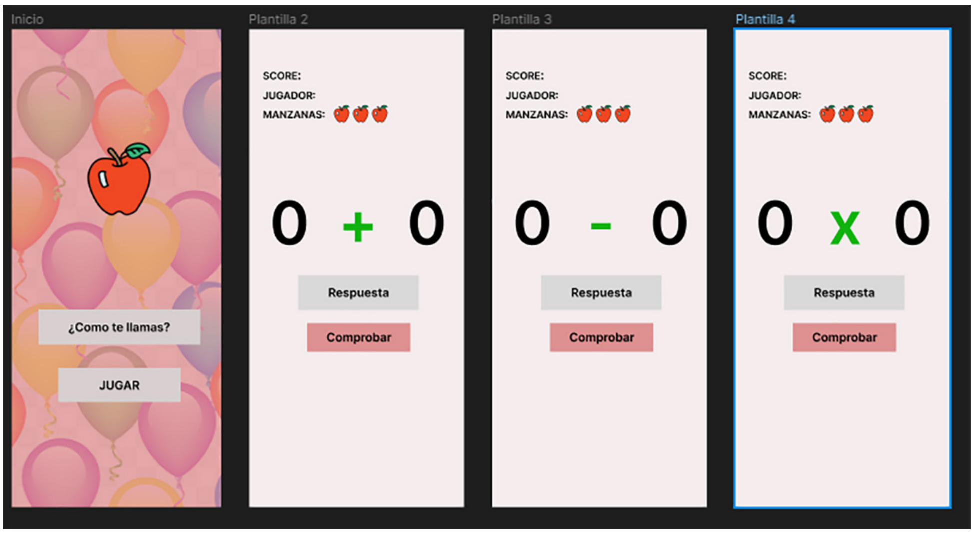

Fig. 3. Mockup

3.4 Evaluation

A first functional prototype was evaluated, with the objective of ensuring that the individuals involved in this project (children, parents, and teachers) used the product, thereby verifying the interaction between the users and the OA. The details of this stage are presented in the OA Validation section.

This phase was crucial because, based on the improvement suggestions identified, modifications were made to the product, and the UCD methodology cycle was repeated. This process will be carried out as many times as necessary until the product fully satisfies the needs of the end users—in this case, preschool children. The details of this stage are presented in the "Tool Validation and Preliminary Results" section.

4 APP MATHEMATICS

Following two iterations of the proposed methodology, the primary interface of the App Mathematics project is shown in Figure 4.

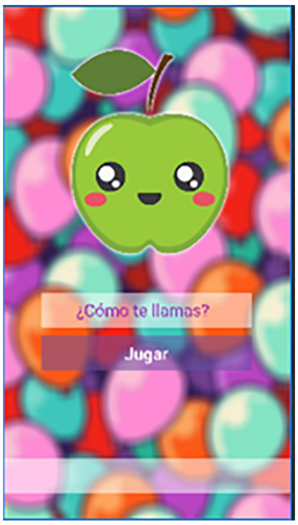

Fig. 4. Main activity

In Figure 4, we can see the initial screen of the learning object (LO). This is the starting point of the project, configured so that children do not experience any issues with the information displayed. It contains only a visually appealing image, a field where the child enters their name, a button to start the game, and a box at the bottom to display the highest score achieved, along with the same user's name.

The LO app "Mathemathics" consists of six levels:

Level one: Simple addition

Level two: Moderate addition

Level three: Subtraction

Level four: A combination of addition and subtraction

Level five: Simple multiplication

Level six: A combination of all the above

In Level 1, the child encounters basic addition problems, allowing them to learn the game's dynamics and become familiar with how it works. In this first level, the operations are, for example, 1 + 2, 2 + 2, and 3 + 1, using small numbers to make them easier to solve. In Level 2, the difficulty increases slightly with moderate additions, meaning somewhat larger numbers appear. These operations are displayed randomly—never in the same order—to introduce an element of complexity.

Once the child has completed the addition exercises, Level 3 introduces subtraction with randomly generated numbers, much like the previous level. This level involves greater difficulty, meaning the child may take relatively more time to respond to the presented operation. Figure 5 shows an example of this screen.

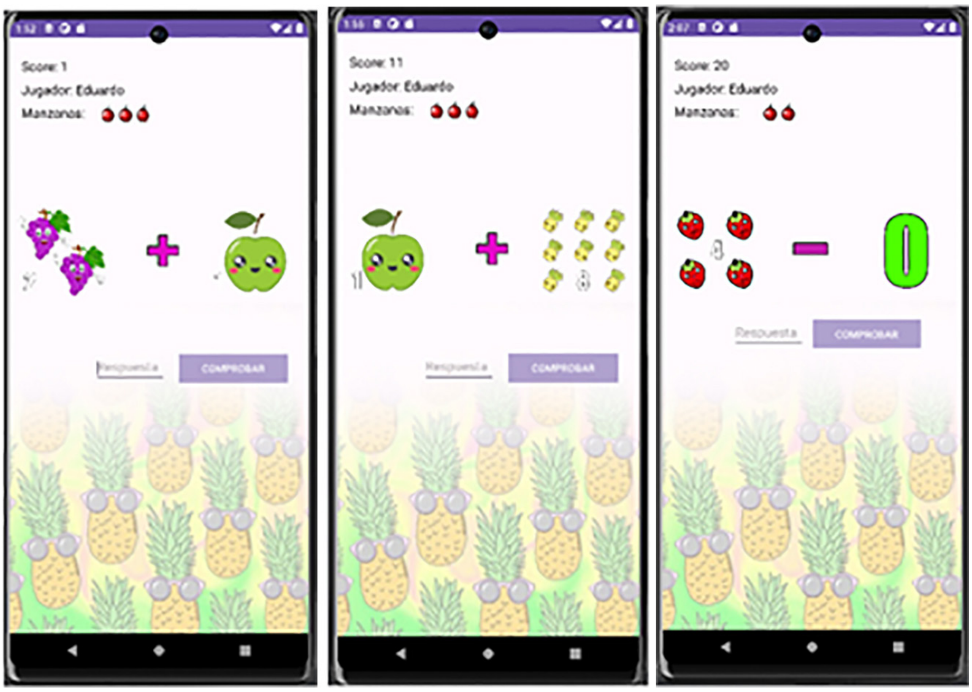

Fig. 5. Level 1, Level 2, and Level 3

In Level 4, we encounter a combination of the two previous topics—addition and subtraction—which increases the difficulty somewhat, as the operation to be solved is randomly generated. Likewise, the numbers (now larger) are also presented randomly, making this level more complex.

In Level 5, we come to the final topic: multiplication. This area is indeed more complex, and, as in the earlier levels, the numbers appear randomly. As shown in Figure 6, as users progress through the levels, the score increases with each correct answer.

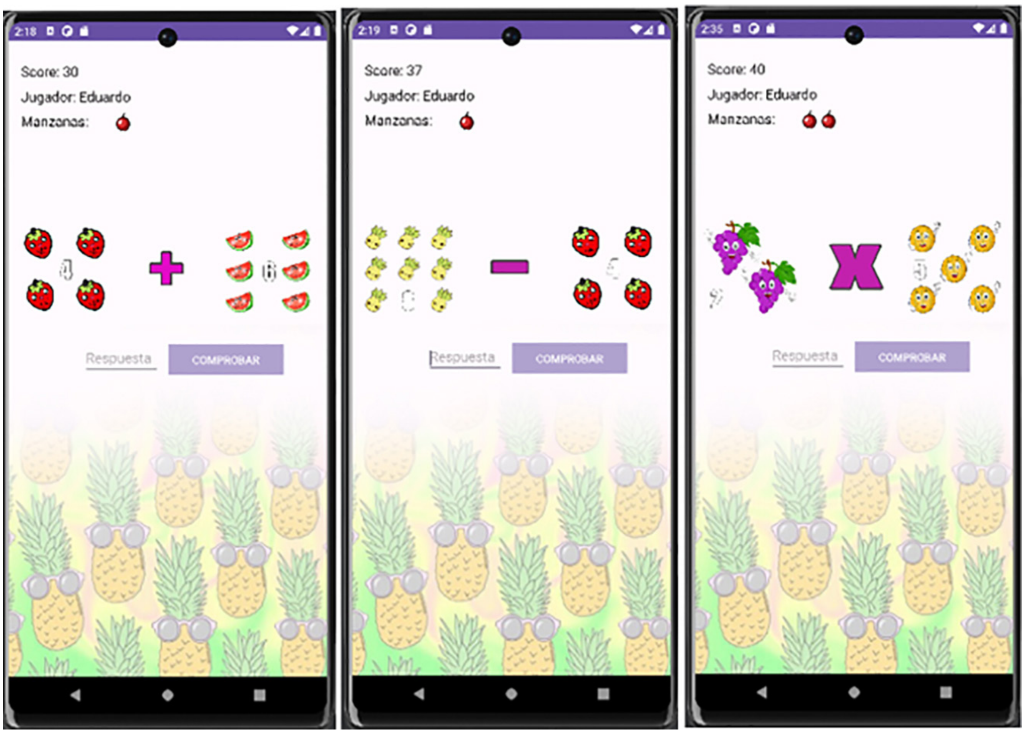

Fig. 6. Level 4 and 5

Finally, Level 6 combines the three topics covered throughout the game—addition, subtraction, and multiplication. Because it is the last level, it has a higher degree of difficulty, testing the child's knowledge based on the progress they have made throughout the game. Once the child completes all levels, they reach the highest score, which is then displayed on the main menu.

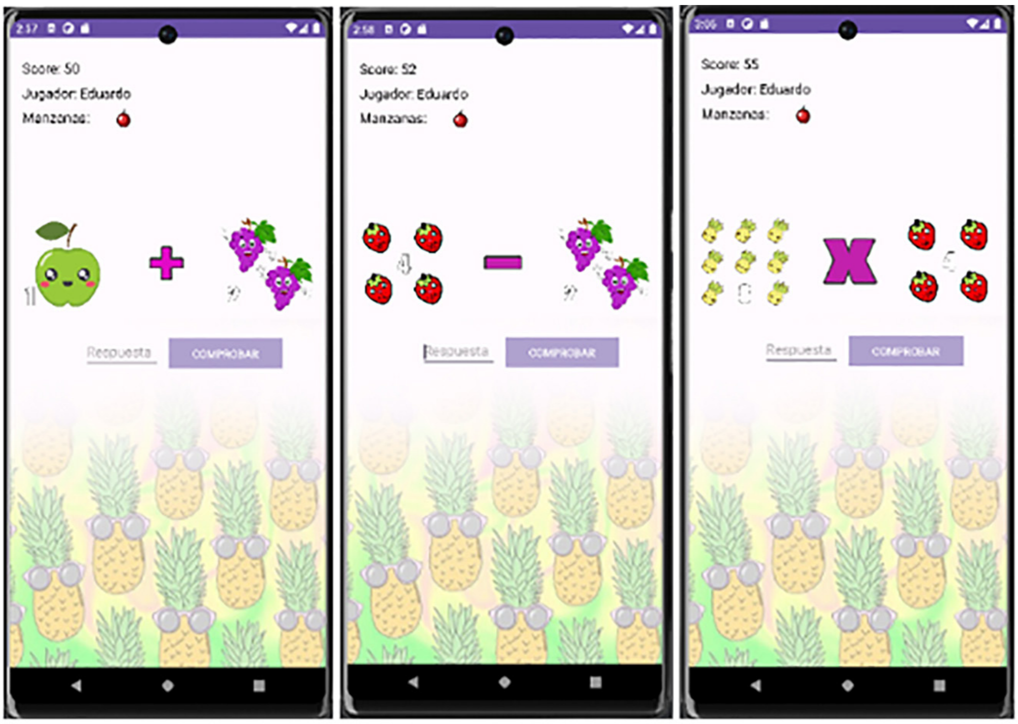

Fig. 7. Level 6

5 TOOL VALIDATION

To validate both the **utility** and **usability** of the tool, a strategy was designed consisting of two stages:

1. Heuristic evaluation
2. Expert testing

The results obtained in each stage are presented below:

5.1 Heuristic evaluation

A heuristic evaluation was carried out on the first version of the application to detect potential usability issues and resolve them early on through a process of continuous improvement. Three professionals—academics with experience in this method—conducted the evaluation. The four most critical problems identified are listed below:

1. Progress indicators were not clear enough for the child.
2. There is no training period (or tutorial) to teach the child how to use the software.
3. The font size is too small.
4. In some levels, images tend to be very small.

5.2 Expert testing

In the first iteration, interviews were conducted with two preschool teachers. They were asked three open-ended questions regarding children's learning and five questions related to their impressions of the proposed software. The following points summarize the experts' feedback:

- Activities should be presented in an audio storytelling format as a form of reinforcement.
- Progress indicators should be like those used by the teachers.
- Positive feedback should match that used by the teachers, and it should be customizable and varied.

In a second phase, the tests were conducted with students who are experts in mobile application development. For these tests, a group of 13 experts was considered. After using the application, they were asked to respond to an instrument based on the study and evaluation of learning objects (LO evaluation metric) [17]. This instrument evaluates four aspects (interactivity, design, engagement, and usability), which were adapted to the mathematics application.

Table 1. Interactivity results

Interactivity	Excellent	Acceptable	Deficient
Meaningful interactions	31%	46%	23%
Overall control	46%	31%	23%
Multimedia adds learning value	38%	23%	38%

Table 2. Design results

Interactivity	Excellent	Acceptable	Deficient
Consistency	31%	38%	31%
Layout	62%	15%	23%
Labelling	54%	23%	23%
Readability	46%	31%	23%

Table 3. Engagement results

Interactivity	Excellent	Acceptable	Deficient
Quality of feedback	54%	23%	23%
Attractive	46%	15%	38%
Graphics	62%	15%	23%
Amount of multimedia	38%	31%	31%
Motivating	31%	54%	15%

Table 4. Usability results

Interactivity	Excellent	Acceptable	Deficient
Natural to use	62%	15%	23%
Orientation	38%	31%	31%
Navigational cues	38%	31%	31%
Instructions	54%	23%	23%
Appropriate language level	85%	15%	0%

The conclusions from the expert evaluation results provide us with the following analysis:

Regarding interactivity, it was well rated by the professionals among the three evaluated aspects. The highest-rated facet was "Multimedia enhances learning," with 46% approval, followed by "General control," where 38% of the evaluators considered the system interactions to be meaningful. These results suggest that the professionals believe the application provides significant interactions and learning experiences, which will enable children to benefit from its use in the future.

Regarding the design, the approval is encouraging, as none of the professionals gave a negative evaluation to any item. The aspect with the highest approval is related to the structure of the stages, suggesting that their distribution was appropriate and not disorganized. Furthermore, it can be concluded that the message intended to be conveyed through these stages was clearly understood.

Regarding engagement, the evaluation was also very positive, similar to the results in the Interactivity table, as no professional gave a negative rating to any item. The most highly rated aspect was graphic design, with an approval rate of 62%.

The usability of the application also received positive results, exceeding 85% approval in all aspects under the "excellent" category, which represents the highest level of approval. The most highly rated aspect was the ease of use of the application. This is crucial, as the instructions must be clear and explicit to avoid confusing the children while they perform the activities.

6 CONCLUSIONS AND FUTURE WORK

The project successfully achieved all the objectives set and has developed an application that helps enhance mathematical skills in preschool-age children.

This development aims to support the improvement of mathematical skills in children. The goal is to create a model that defines guidelines for developing applications focused on enhancing children's mathematical abilities.

As future work, the experimentation will be conducted with children aged four to six in preschool. Additionally, the application will be evaluated by experts in the field, including teachers at that level and parents of the children, to assess its usability. Based on this information, a statistical analysis will be conducted to measure the application's performance and improve its usability if necessary.

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