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Developing Arithmetic Competence in Primary Learners with the Aid of Educational Technology

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ABSTRACT

The development of math skills is crucial from an early age because it helps children enhance their ability to calculate, estimate, understand, and work with numbers, as well as solve math problems. It also lays a key foundation for developing critical thinking and problem-solving skills. Due to its importance, a research project was conducted to reinforce arithmetic knowledge and strengthen the development of numerical, operational, and systematic skills that students need from early education onward. As part of this effort, an educational application was created and launched—a mobile app featuring four video games: Little Races, Mischievous Spirits, Chocolaty, and Make Your Pizzas—designed for elementary school students. The app enables them to practice arithmetic operations with whole numbers and decimals, work with fractions, and find equivalent fractions. The interactive design encourages engagement with the topics presented in each game. This article describes the development and implementation of the software, as well as its evaluation with 189 elementary school students over two months as part of their school activities. Using Bonferroni's post hoc test, significant differences were observed in several comparisons between the games. Little Races scored significantly higher than Chocolaty ($p = .013$), Make Your Pizzas ($p < .001$), and Mischievous Spirits ($p = .039$), consistently receiving higher ratings.

Keywords: Elementary Education, Arithmetic, Educational Software, Arithmetic skills.

INTRODUCTION

In everyday life, children, adolescents, and adults all rely on mathematical skills and abilities, which are essential not only for simple daily tasks—like buying something or calculating discounts offered by various businesses—but also for more complex activities, such as understanding investment interest rates, managing personal finances, or filing tax returns.

When solving calculation problems (e.g., 37 + 7 or 29 − 5), children need to follow a series of steps that involve recalling mathematical operations from long-term memory, borrowing or carrying, breaking the problem into smaller parts, switching between different operations, and checking intermediate solutions while managing other information at the same time. This process requires a significant amount of memory capacity and multitasking, highlighting the crucial role of working memory in overseeing and coordinating these activities (Lopez-Pedersen et al., 2022).

The development of math skills in early childhood is essential because it enables individuals to learn to calculate, estimate, understand, and work with numbers, as well as solve mathematical problems (Menacho et al., 2024). Additionally, it forms one of the key foundations for building critical thinking and problem-solving abilities.

This article is based on a research project registered with the Secretariat of Research and Postgraduate Studies of the National Polytechnic Institute (SIP-IPN) under number 20240910, titled: "Implementation of a computer application to support the development of systematic processes in the study of arithmetic in primary education" (SIP-IPN, 2024). The goal was to reinforce specific arithmetic knowledge and strengthen the development of numerical, operational, and systematic process skills essential for primary school students. An educational app for mobile devices was created, featuring four video games: Little Races, Mischievous Spirits, and Make Your Pizzas. These games helped students practice arithmetic operations with whole numbers and decimals, enabling them to work with fractions and find equivalent fractions. The interactivity of the games encouraged students to engage more deeply with the topics presented in each game.

The article includes a section on theoretical aspects, which presents the reference framework supporting the creation of the software, based on the primary education program, curriculum, and textbooks in Mexico. The methodology section outlines the actions taken during the stages of software development, implementation, and testing. The results section presents data collected from a sample of 189 students from a public primary school regarding their satisfaction and perceived usefulness of the four video games that comprise the software. It also includes the analysis conducted and the conclusions drawn.

THEORETICAL ASPECTS

Arithmetic, which includes mastering basic operations such as addition, subtraction, multiplication, and division, as well as working with natural, whole, fractional, and decimal numbers, forms the foundation for more advanced mathematical learning later on (Kilpatrick, Swafford, and Findell, 2001). Nelson et al. (2023) emphasize that early mastery of arithmetic skills prevents future learning difficulties and reduces math anxiety. Ribner et al. (2023) emphasize that arithmetic serves as a democratizing tool, promoting full participation in social and economic life. Meanwhile, Risk and Priatna (2019) emphasize that arithmetic facilitates the understanding of concepts in science, engineering, and technology.

In the context of current educational policies, organizations such as UNESCO (2021) have stated that early arithmetic skills are closely linked to performance in STEM fields, everyday problem-solving, and educational equity. Researchers such as Thevenot et al. (2004) and Outhwaite et al. (2019) conclude that learning should begin early, be contextualized, supported by teacher mediation, and, when feasible, reinforced with technological tools.

The teaching and development of arithmetic skills depend on several perspectives. One prominent approach to teaching and learning is Piaget's constructivist approach (Piaget, 1970), which explains that children acquire numerical concepts in stages, progressing from concrete to abstract thinking.

Vygotsky's sociocultural theory (Vygotsky, 1978) highlights that social mediation and language are essential in learning mathematical concepts. The competency-based approach asserts that arithmetic encompasses more than just procedures; it also necessitates an understanding of concepts and their application to real-world problems (NCTM, 2014).

These perspectives agree that learning arithmetic should be progressive, contextualized, and meaningful, extending beyond simple memorization (Zhang et al., 2023). Numerous studies have demonstrated that early arithmetic skills predict overall academic achievement. Geary (2011) found that children with strong calculation and counting abilities perform better on math and logical reasoning tests throughout their education. Jordan et al. (2010) highlight that deficiencies in early arithmetic are associated with persistent gaps in mathematical understanding, even when interventions are provided later. Cognitively, arithmetic supports the development of processes such as working memory, selective attention, and cognitive flexibility, which are vital for solving complex problems (Nining et al., 2025). Over the past decade, research has identified three main trends:

1) Integrating arithmetic into real-world scenarios: programs like Realistic Mathematics Education in the Netherlands demonstrate that applying arithmetic to practical problems enhances knowledge retention and transfer (Van den Heuvel-Panhuizen, 2020).

2) Using educational technology: platforms like Khan Academy and Matific have shown significant improvements in calculation fluency when used as supplementary resources (Cheung and Slavin, 2013).

3) Implementing early and personalized interventions: Studies by Clements and Sarama (2015) show that tailored interventions, especially in the early elementary grades, help prevent future difficulties and reduce performance gaps.

Institutional Framework

Under the framework of the New Mexican School (NEM) and the 2022 Curriculum (SEP, 2022), arithmetic is integrated into various educational fields: 1. Scientific knowledge and thinking, 2. Languages, 3. Ethics, Nature, and Societies, 4. Human and community issues. Each of these areas provides context and skills that improve understanding, application, and the relevance of arithmetic in both school and everyday life.

From first to sixth grade, students receive three project books titled Classroom Projects, School Projects, and Community Projects. These books are published by the National Commission for Free Textbooks (CONALITEG, 2022a, 2022b, 2022c, 2022d) and distributed to students at the beginning of each school year. The projects in these books are organized into the four educational areas mentioned earlier, designed using problem-based learning (PBL) and integrated with cross-cutting themes such as critical thinking, gender equality, inclusion, healthy living, and reading/writing. The goal is for students and teachers to work together as a classroom community, involving families and the local context. The content is presented in an integrated, contextualized, and meaningful way, encouraging citizenship, collective problem-solving, and the well-being of the community.

The three project books for each grade were reviewed to provide a theoretical overview of the importance of arithmetic across all fields of knowledge, as shown below.

Arithmetic and Educational Areas

Scientific Knowledge and Thinking

This is the area most closely related to arithmetic, as it involves logical-mathematical reasoning, problem solving, the use of numbers and operations, measurement, data analysis, and basic algebraic thinking. It promotes the development of skills such as:

- Understanding place value and the number system.
- Performing mental and written calculations with basic operations.
- Interpreting and representing numerical information in tables and graphs.

Languages

Understanding arithmetic problems relies on thorough reading and accuracy in mathematical language.
This field helps develop:

- Interpretation of mathematical statements and directions.
- Use of specific vocabulary related to addition, subtraction, multiplication, fractions, and percentages.
- Writing justifications and explaining procedures.

Research, such as that of Jordan et al. (2010), indicates that difficulties in reading comprehension have a direct impact on arithmetic performance.

Ethics, Nature, and Societies

Arithmetic is applied within the analysis of social, economic, and environmental data.
Examples:

- Calculating recycling rates within a community.
- Interpreting health or climate data.
- Managing expenses and resources in school projects.

This field promotes the use of arithmetic skills for responsible and sustainable decision-making.

Human and Community Issues

Connects arithmetic to daily life, family finances, teamwork, and practical problem solving.
Examples:

- Adjusting ingredient amounts when preparing recipes.
- Organizing school events by estimating materials and expenses.
- Distributing resources fairly in group activities.

Reinforces the idea that arithmetic is a crucial tool for coexistence and shared well-being, as emphasized by Svane et al. (2023).

Another textbook used by primary school students, provided by the SEP, is titled "Nuestros Saberes" (CONALITEG, 2022e, 2022f, 2022g, 2022h). The books for grades 3rd, 4th, 5th, and 6th were reviewed, and mathematics lessons were selected. However, it is important to note that these lessons are integrated into educational exercises rather than being presented as a separate mathematics section. Additionally, both classroom activities and family exercises are included to encourage parental or guardian involvement.

METHODS AND MATERIALS

Methodology for Developing The Matiliztli Web Application

Given the nature of the project, a methodology for designing and developing educational games was selected, as described by Prieto de Lope and Medina (2015). This methodology is mainly based on Scrum, so it follows an iterative and incremental process with four phases:

1) Start
2) Design
3) Production
4) Testing

In the initial phase, educational objectives and skills to be reinforced with each video game were defined, considering the institutional framework described above and suggestions provided by primary school teachers we collaborated with during the 2024-2025 school year. The second phase involved designing the scenes for each video game, including their settings, characters, interactive objects, as well as the challenges, actions, and dialogues they would contain. The four video games feature three settings: an introduction, gameplay and interactive elements, and a closing scene. The production phase included creating 3D models, graphics, animations, and programming.

The application is compatible with various mobile devices, including tablets and smartphones. Each game offers three difficulty levels tailored to different grade levels, which can be 3rd, 4th, 5th, or 6th grade, so the questions vary depending on the selected difficulty. This required that, during the design of the video games, adaptation considerations were applied both to address educational challenges and during their evaluation. During testing, both functional and usability assessments were carried out with technical staff, teachers, and students from a public elementary school. Subsequently, the four video games included in the application were used by 3rd through 6th grade elementary students for one month as part of their school activities. A total of 189 students used the application with prior consent from school administrators, teachers, and parents. Afterwards, they completed a questionnaire to evaluate its usefulness and their level of satisfaction with using it.

Methodology for Data Collection and Analysis

A mixed-method approach was used due to the nature of the variables, which could be quantified and analyzed. The variables measured included fun, ease of use, graphics, level of challenge, and replayability. The study involved 189 students enrolled in 3rd, 4th, 5th, or 6th grade at a public primary school located in the Gustavo A. Madero district of Mexico City.

Ethical Statements

This study adhered to the ethical guidelines established by psychologists and complied with European laws governing research involving children, as well as the principles outlined in the Declaration of Helsinki. All participants received a detailed explanation of the study's goals and methods. To protect anonymity, unique identification codes were assigned to each child before distributing the materials. Prior to the interviews, all parents provided written informed consent, with assurances that the study's content would remain confidential.

Startup and Design Phases

First Video Game: Little Races

Cecilia is the main character. She participates in a race during her physical education class, but this time she also practices arithmetic operations and mental calculations. Fruits with possible answers to the question in the upper left corner will appear above each lane. Cecilia starts in the center lane and can move between lanes by swiping left or right on the screen. To do this, the player must move the character. The goal of the game is to move to the lane that contains the correct answer so Cecilia can grab the fruit and keep moving forward. Cecilia can only move left or right, not forward or backward. However, the answers or fruits will move downward, creating the illusion that Cecilia is running toward them. The more correct answers she collects, the higher the score. If Cecilia achieves a high score, an animation will appear showing she has won first place and recognition in her math class. If she does not score high enough, the player will be encouraged to practice arithmetic and try again with greater focus. Table 1 shows the characteristics of the Little Races video game.

Table 1. Features of the Little Races video game.

Video Game 1 Little Races
Identifier: SG1
Genre: Casual
Gameplay
The main character walks nonstop while simple questions appear, and the player must select the correct answer

from three options. Topics include basic operations, fraction equivalence, and quantity comparison using the symbols >, <, =.
Interactivity
According to the classification outlined in the narrative, standard interaction is offered. The student interacts with the main character by guiding them along the path based on their chosen answer, which is done by tapping the screen to select one of the three possible options. Tapping anywhere other than the answer buttons will not move the character.
General Game Rules
• The video game will have multiple stages, each featuring a monster with different health. • The monster's health, as well as the number and attack of each knight, will be generated at the start of each stage, and these values will depend on each other. • The minimum number of knights that can be placed is 1, and the maximum is 10. • If the knights are not enough to defeat the monster, it will defeat the knights, and the player will lose the game. • If not all knights are placed, the student will receive extra points for each remaining knight.

Second Video Game: Mischievous Spirits

The educational goal is to develop the ability to solve multiplication and division problems involving natural numbers of varying lengths, depending on the grade level (4th, 5th, or 6th). The story of the video game is as follows: We start in a fourth-grade classroom. The teacher, Susana, begins reading a story from the reading book about dungeons and monsters. Miguel, listening to the teacher, begins to imagine the story in his mind, where we are transported to a dungeon setting. Our goal is to defeat the monster with the knights available. When the story concludes, the game also comes to an end.

Table 2. Features of the *Mischievous Spirits* video game.

Video game 2 – Mischievous Spirits
Identifier: SG2
Genre: Logic
Gameplay
We are in a dungeon with a monster at the center of the screen, which also displays its health with a number and a corresponding bar. Additionally, in one corner, there is an icon of a knight displaying the number of knights and each knight's attack. The goal is to place the correct number of knights so that the product of the number of knights and their attack is equal to or greater than the monster's health, allowing them to defeat it. If the student has the option to place more knights than necessary, they must select the required amount. Placing fewer knights than needed results in losing the game, and adding extra knights does not earn extra points for the surplus. Topics: Addition and multiplication.
Interactivity
According to the classification described in the narrative, standard interaction is maintained. The student uses the touchscreen to drag the knights around the monster one by one. Once they have placed the number, they find an appropriate one, and they press a button to move to the next stage to attack; for this, they drag each knight from the center toward the monster, after which the monster's health decreases, and visual and sound effects appear to enhance the action.
General Game Rules
• The character walks forward continuously. • There is a 4-second interval between the moment the question appears and when the player must select an answer. • The player can only swipe right or left to choose one of the three paths/options at the moment the answer is selected. • One second after selecting an answer, a new question appears. • The game contains a good number of questions and ends when the player answers all correctly. • Questions are randomly selected from the entire list. • If the player selects an incorrect answer, the game ends and restarts from the beginning. • Each time the player selects a correct answer, they earn 10 points.

Third Video Game: Chocolaty

The educational goal was defined as follows: to learn and reinforce the method for adding and subtracting fractions at a level commensurate with the student's current grade level. The educational competency was also defined as understanding the equivalence of fractions, which enables students to perform addition and subtraction

with fractions of different denominators, and understanding arithmetic ratios as the comparison of two quantities—the numerator and denominator in a fraction.

Our main character is Roberto, a fifth-grade student at an elementary school. Roberto helps his parents prepare chocolate desserts after school, so he needs to cut chocolate bars into different portions. We aim to help him divide the chocolate bars into equal parts and express the ratio of the numerator to the denominator. This video game also aims to teach the addition of fractions, as outlined in the recipe. Table 3 shows the characteristics of the Chocolaty video game.

Table 3. Features of the *Chocolaty video* game.

Video Game 3 – Chocolaty
Identifier: SG3
Genre: Logic
Gameplay
The main character has two chocolate bars of different sizes, which represent different fractions less than one with different denominators. A basic operation, either addition or subtraction, will be introduced. To operate, the player must use a slider to find a denominator that evenly divides both chocolate bars. Then, they must count the parts in each bar to determine the numerator and find the correct answer, successfully preparing their recipe. Topics: Addition and subtraction, fraction equivalence, proportionality.
Interactivity
According to the classification described in the narrative, standard interaction is supported. The student interacts with the sliders by touching the screen, holding and dragging along the slider, and releasing once a value is set. There is no interaction if the chocolate bars or the main character are touched directly.

Fourth Video Game: Make Your Pizzas

This video game features a narrative explaining how to make a pizza, listing the ingredients needed: 300 grams of dough, 200 grams of tomato sauce, 100 grams of cheese, and 100 grams of pepperoni. The ingredients are shown, then the child is asked to make two pizzas or half a pizza. Table 4 shows the characteristics of this video game.

Table 4. Features of the Make Your Pizzas video game.

Video game 4 – Make Your Pizzas
SG4
Logic
Gameplay
A recipe provides different amounts of ingredients that match specific food portions. The player receives orders with various requested portions, along with the available quantities of ingredients. The goal is to find the proportion of each ingredient based on the recipe's portion size and the customer's requested portions. Topics: Proportionality.
Interactivity
According to the classification described in the narrative, standard interaction is available. The student uses the touchscreen to drag and drop ingredients to create a food item (for example, a pizza). Once they have added the correct amount to match, they are informed whether their solution is correct, and then they proceed to the following order.
General Game Rules
• The video game will have several food orders that the student must fulfill • If the proportions are incorrect, the student will not achieve a high score

Production Phase

At this stage, the four video games were programmed, along with the start interface (Figure 1), the school grade selection interface, the video game selection interface (Figure 2), and the scoring interface (Figure 3). The four video games were integrated with these interfaces, completing the application, which was named Matiliztli.

When the child logs in, they must create a username and password, then select a grade and join a group that matches the one their teacher assigned (Figure 1).

Figure 1. Login Screen Interface.

Figure 2 Displays the interface where users can select from four video games.

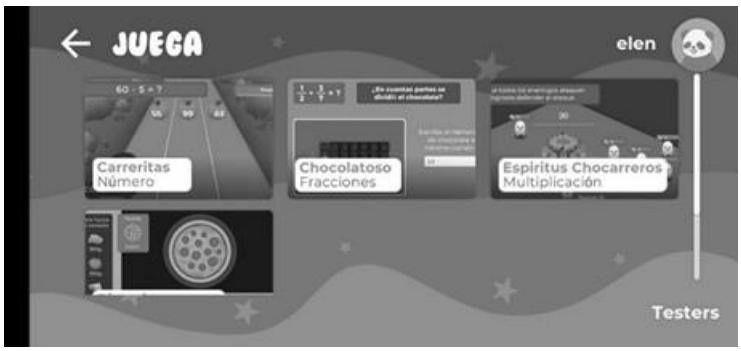

Figure 2. Video Game Selection Interface.

The High Score screen is a universal graphical interface for all video games, displaying the score and providing buttons to access the menu or restart the game (Figure 3).

Figura 3. Interfaz del escenario correspondiente al puntaje.

Each video game consisted of three scenes: an introductory scene, a gameplay and interactivity development stage, and a final closing stage. A brief overview of each game's stages is provided below.

Figure 4 illustrates how the tracks and the child moving along them are shown. The task involves comparing the two quantities given (4000 and 800) and deciding whether 4000 is greater than, equal to, or less than 800. To do this, the child must move between the lanes.

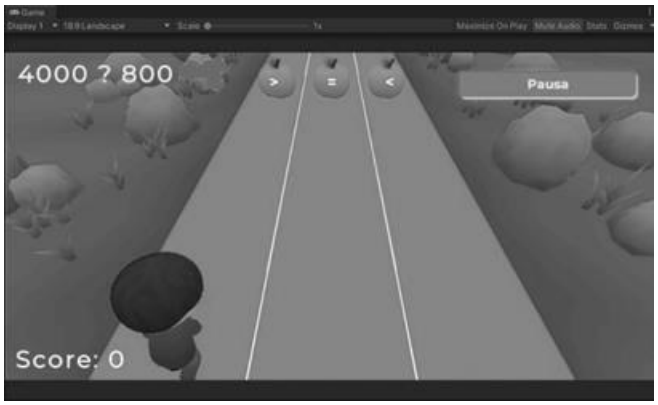

Figure 4. Race Track Interface.

The first scene of the video game Mischievous Spirits takes place in a classroom with Miguel and teacher Susana. The second scene depicts the interior of a stone and brick dungeon, where a monster is located in the center of the room, surrounded by knights that can be moved on the touchscreen (Figure 5).

Figure 5. Dungeon Scene Interface.

In the video game Chocolaty, one scene shows Roberto's kitchen, where he is standing next to a table with utensils. Another scene presents an aerial view of the kitchen table, featuring utensils used as decorative elements around it, with the gameplay area in the center, where the chocolate bar is located. Slide elements can be used to choose the number of cuts to make on the chocolate bar, along with a text field for entering answers, as shown in Figure 6.

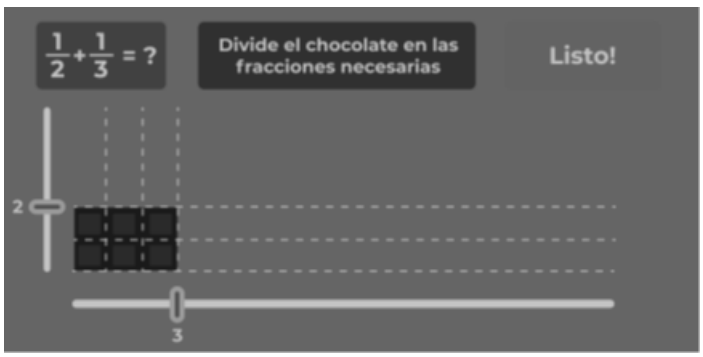

Figure 6. Chocolate Bar Table Scene Interface.

The child must select the correct amount of ingredients by dragging the respective icon, as shown in Figure 7.

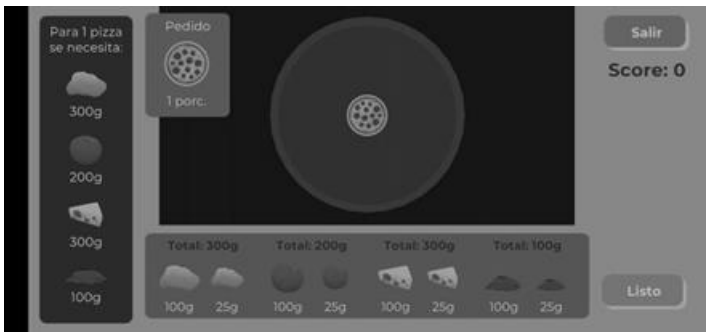

Figure 7. Game Interface: Make Your Pizzas.

Along with hosting the video games through the mobile app, a web platform was developed for teachers, allowing them to create groups and track their students' progress. The interface is shown in Figure 8.

Figure 8. Web application interface showing the teacher's group information.

Testing Phase

After developing the four video games of the application—Little Races, Chocolaty, Mischievous Spirits, and Make Your Pizzas—as well as the webpage for teachers, functionality tests were conducted. These tests included two types: integration tests and alpha tests. The system integration tests ensured the correct operation of the initially defined functional requirements. The use cases were also tested depending on the type of actor interacting with the system. The results of these tests were recorded in Table 5.

Table 5. Verification of Requirements.

Functional Requirement	Test Result
Log In	Correct
Register User Data	Correct
Select Game	Correct
Select Grade	Correct
Show Score	Correct
Show Tutorial	Correct
Pause/Resume Game	Correct
Go to the menu	Correct
Save Score	Correct
View Personalized Progress	Correct
Change Username	Correct
Configure sound	Correct
Log Out	Correct
View Global Leaderboard	Correct
View Group Leaderboard	Correct
Group Search	Correct

During the implementation of the entire system and its integration between the different parts, such as the video games and the teacher monitoring system, alpha testing was conducted by the developers as the system progressed.

RESULTS AND ANALYSIS

Questionnaire Results

The current analysis involves a formal assessment of an educational software consisting of four video games: Little Races, Mischievous Spirits, Chocolaty, and Make Your Pizzas. The goal of these games was to strengthen arithmetic skills in primary school students (grades 3 to 6), using playful activities and engaging stories to support their learning. To evaluate the experience of 189 students, a structured questionnaire with 20 items was administered—five items for each game—using a five-point Likert-type response scale, where options were rated as follows: 1 = Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, and 5 = Strongly agree. For accessibility, facial expressions were incorporated to make the instrument easier for students to understand (Figure 9).

Figure 9. Facial Expression Images.

In Table 6, the questionnaire applied to the students is presented.

Table 6. Questionnaire to Measure the Usability of the 4 Video Games.

Instructions: After playing each video game, indicate your level of agreement with the following statements. Response Scale: 1 = Strongly Disagree 2 = Disagree 3 = Neither Agree nor Disagree 4 = Agree 5 = Strongly Agree
Video game 1: Little Races
1. The Little Races video game was easy to understand and get started with. 2. The visual design (colors, images, animations) was attractive. 3. The difficulty level was just right to keep my interest. 4. I felt motivated to keep playing until I finished. 5. Overall, I found the Little Races video game fun.
Videoj game 2: Mischievous Spirits
1. The *Mischievous Spirits* video game was easy to understand and get started with. 2. The visual design (colors, images, animations) was attractive. 3. The difficulty level was just right to keep my interest. 4. I felt motivated to keep playing until I finished. 5. Overall, I found the Mischievous Spirits video game fun
Video game 3: Chocolaty
6. The Chocolaty video game was easy to understand and get started with. 7. The visual design (colors, images, animations) was attractive. 8. The difficulty level was just right to keep my interest. 9. I felt motivated to keep playing until I finished. 10. Overall, I found the Chocolaty video game fun.

Video game: Make Your Pizzas
1. The Make Your Pizzas video game was simple to understand and get started with. 2. The visual design, including colors, images, and animations, was attractive. 3. The difficulty level was just right to keep my interest. 4. I felt motivated to keep playing until I completed it. 5. Overall, I found this video game fun.
Final Comparative Question
Of the four video games, which one was your favorite? _____ Briefly explain why: _____

Following that, responses were gathered, and descriptive and graphical analyses were performed to identify trends and areas needing improvement.

The internal reliability of the instrument was evaluated by calculating Cronbach's alpha coefficient for each set of items associated with each video game (Table 7). The obtained values ranged from 0.81 to 0.88, surpassing the recommended threshold of 0.70 for opinion questionnaires (Roco-Videla et al., 2024). This indicates that the statements were consistent with one another and that the instrument exhibits high internal reliability.

Table 7. Cronbach's Alpha for Video Game.

Video game	Cronbach's Alpha
Little Races	0.88
Mischievous Spirits	0.85
Chocolaty	0.84
Make Your Pizzas	0.81

The mean scores and standard deviations for each questionnaire item were computed, and the results are presented in Table 8.

Table 8. Means and Standard Deviations by Item and Video Game.

Video game	Ítem	Description	Mean	Standard Deviation
Little Races	1	I found it fun	4.35	0.71
Little Races	2	It was easy to understand and play	4.28	0.74
Little Races	3	The graphics were appealing	4.15	0.8
Little Races	4	The level of challenge was appropriate	4.12	0.83
Little Races	5	I would like to play it again	4.25	0.78
Mischievous Spirits	1	I found it fun	4.2	0.77
Mischievous Spirits	2	It was easy to understand and play	4.05	0.81
Mischievous Spirits	3	The graphics were appealing	4.08	0.79
Mischievous Spirits	4	The level of challenge was appropriate	4.1	0.82
Mischievous Spirits	5	I would like to play it again	3.95	0.88
Chocolaty	1	I found it fun	4.05	0.8
Chocolaty	2	It was easy to understand and play	4.02	0.83
Chocolaty	3	The graphics were appealing	4.1	0.78
Chocolaty	4	The level of challenge was appropriate	3.95	0.85
Chocolaty	5	I would like to play it again	3.98	0.86
Make Your Pizzas	1	I found it fun	3.95	0.84
Make Your Pizzas	2	It was easy to understand and play	3.88	0.87
Make Your Pizzas	3	The graphics were appealing	3.9	0.86
Make Your Pizzas	4	The level of challenge was appropriate	3.82	0.88
Make Your Pizzas	5	I would like to play it again	3.8	0.9

Using the collected data, a bar chart was created (Figure 10).

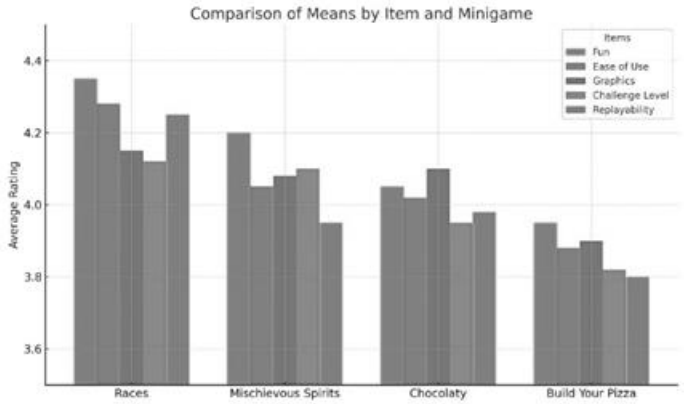

Figure 10. Stacked bar chart.

Interpretation of the Bar Chart by Video Game

Little Races

This video game features a track divided into three lanes where students solve arithmetic operations (addition, subtraction, multiplication, and comparison of quantities) and select the lane with the correct answer. The results show that Little Races received the highest ratings for fun (M = 4.35) and ease of use (M = 4.28), indicating that its mechanics are intuitive and engaging. The challenge level and graphics were also highly rated, suggesting that the combination of mental speed and visual action was effective.

Mischievous Spirits

In this video game, the player defends a castle by solving multiplication or division problems to eliminate ghosts. It received high ratings for fun (M = 4.20) and graphics (M = 4.08), but replayability was slightly lower (M = 3.95). This shows that, although the mechanics are engaging, it could use more variety in challenges or levels.

Chocolaty

This game features visual representations of fractions on a chocolate bar to help solve addition and subtraction problems involving fractions. Its graphics received high ratings (M = 4.10), but the challenge level (M = 3.95) and replayability (M = 3.98) were rated lower, which may be due to the difficulty in accurately manipulating fractions.

Make Your Pizza

The player must calculate the amounts of ingredients for different pizza quantities. It received the lowest ratings across all categories, especially in replayability (M = 3.80). This may be due to the repetitive gameplay and less visual action compared to other games.

A heatmap was generated to identify the items with the highest and lowest values (Figure 11).

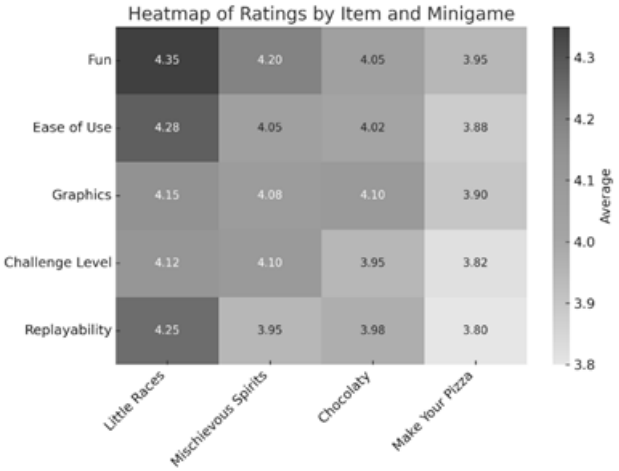

Figure 11. Heatmap of Item and Video Game Ratings.

INTERPRETATION OF RESULTS

Little Races

Item 1 (Fun): The highest average score of about 4.35 indicates that students found the racing mechanics combined with problem-solving highly entertaining, which increased their motivation. Item 2 (Ease of use): Scored roughly 4.28, showing that the controls and mechanics were straightforward. Moving the character and selecting tracks felt intuitive, avoiding confusion. Item 3 (Graphics): With an average of around 4.15, the visuals are functional but could benefit from more dynamism or visual effects to boost their impact. Item 4 (Level of challenge): About 4.12. Students considered it an appropriate challenge. The time limit and variety of actions maintain a balanced difficulty level, though it might become predictable after several rounds for some players. Item 5 (Replayability): High at approximately 4.25. Most students would play again. The competitive aspect and desire to improve times or scores encourage repeated engagement. Little Races is the top-rated game overall, effectively combining math skills with action in an engaging way. Its main strengths are fun and ease of use, with room for graphics enhancements to make it even more immersive.

Mischievous Spirits

Item 1 (Fun): Mean ≈ 4.20. Students enjoyed combining mathematical operations with a castle-defense story, which made the task more engaging and meaningful.

Item 2 (Ease of use): Mean ≈ 4.05. Although the mechanics of responding and eliminating ghosts were straightforward, the use of multiplication and division might be more challenging for younger students, slightly lowering the perception of ease.

Item 3 (Graphics): Mean ≈ 4.08, a stable and positive rating. The ghosts and castle created an engaging, thematic environment; however, the visual effects used to eliminate the ghosts could be more striking to enhance their impact.

Item 4 (Level of challenge): Mean ≈ 4.10. Seen as balanced. The pressure to respond quickly to save the castle created a good balance of tension and fun.

Item 5 (Replayability): Mean ≈ 3.95, the lowest score among the game ratings, indicating that while it is appreciated, it is not the most motivating to play again. Although gameplay is exciting, the repetition of the same pattern (ghost–operation–response) may lessen interest during longer play sessions.

Mischievous Spirits is a narratively engaging video game that strengthens multiplication and division skills under pressure. It excels in fun and challenge, but could boost replayability by adding variations in the number of ghosts, types of operations, or surprise elements.

Chocolaty

Item 1 (Fun): Mean ≈ 4.05, considered positive but not as high as the first two games. The concept of working with chocolate as a visual tool is appealing to children, although manipulating fractions may require more focus than just playful excitement.

Item 2 (Ease of use): Mean ≈ 4.02, viewed as straightforward and easy to play. The action of "cutting" the chocolate is simple, but representing fractions requires more attention and accuracy, which can be difficult for some students.

Item 3 (Graphics): Mean ≈ 4.10, visually attractive. The visual depiction of the chocolate and its cuts is well rated; the elements are recognizable and pleasing.

Item 4 (Level of challenge): Mean ≈ 3.95, the lowest score for this game, indicating it may be too easy or monotonous for some. Solving fractions and manipulating visual objects adds complexity, especially for students with a limited understanding of the topic.

Item 5 (Replayability): Mean ≈ 3.98, acceptable but not exceptional. While engaging, the challenge could become repetitive if there are no variations in the types of fractions or how they are presented.

Chocolaty provides a visually engaging way to learn fractions. It stands out due to its graphics, but the need for precision in cutting might make it less user-friendly. Adding more challenges and surprise elements could increase its replay value.

Make Your Pizza

Item 1 (Fun): Mean ≈ 3.95, the highest score in this game, but still lower than the other games. The culinary theme is appealing, but the mechanics might become repetitive, which could reduce excitement compared to more dynamic games.

Item 2 (Ease of use): Mean ≈ 3.88; some students might find it confusing. Dragging ingredients is simple, but calculating proportional amounts (especially for half-pizzas) can be confusing for some students.

Item 3 (Graphics): Mean ≈ 3.90, not visually outstanding compared to other games. While the ingredients are recognizable, the graphics are more static and less striking than in other video games.

Item 4 (Level of challenge): Mean ≈ 3.82, perceived as less challenging. Proportional calculations can be somewhat complex, but using the same mechanics and ingredients repeatedly may cause boredom.

Item 5 (Replayability): Mean ≈ 3.80, the lowest of all, indicating little motivation to replay. It has the lowest score among all items and games, suggesting that although students enjoy the initial experience, there is not enough variability to encourage repeated play.

Although generally well received, Make Your Pizzas has the lowest scores in nearly all categories, indicating that redesigning its mechanics, graphics, and challenge elements could make it more appealing. It has an educational concept that is useful for working with proportions and quantities. However, its low replayability and graphics scores suggest that adding more ingredients, recipe variations, or surprise features might help sustain interest.

Satisfaction Averages

On a 1-to-5 scale, Little Races achieved the highest average (~4.2), indicating a strong level of satisfaction and perceived playability. Mischievous Spirits and Chocolaty had averages around (~4.0), also demonstrating good acceptance. Make Your Pizzas had a slightly lower average (~3.9), but remained positive.

Table 9 presents the means and standard deviations for each video game.

Table 9. Descriptive results by video game.

Video game	Mean	Standard Deviation
Little Races	4.2	0.65
Mischievous Spirits	4.05	0.7
Chocolaty	4.02	0.72
Make Your Pizzas	3.9	0.75

Statistical Comparison (ANOVA)

A one-way ANOVA was conducted, a statistical test used to compare more than two groups (in this case, the four video games) and determine if their means differ significantly. "One-way" indicates that only one factor is considered, which is the video game. "Independent measures" means that the ratings for each video game are not dependent on the ratings of others (each score is independent). The one-way ANOVA for independent measures revealed significant differences among the video game means, $F(3, 752) \approx 5.2$, $p < 0.05$. This suggests that at least one video game had a rating significantly different from the others. The means indicate that Little Races received the highest score. A repeated-measures ANOVA was also performed, considering that the same 189 students evaluated each video game, to determine if there were significant differences in the average ratings of the four games. The analysis yielded $F(3, 564) = 4.55$, $p < 0.001$, indicating that not all video games received the same ratings.

Tukey's multiple comparison test was used to identify which pairs of video games exhibited these differences. The results are shown in Table 10.

Table 10. Post hoc tests.

Comparison	Difference of Means	P	Significant Difference
Little Races – Chocolaty	0.18 (Little Races- Slightly Better)	0.013	Yes
Little Races – Make Your Pizzas	0.30 (Little Races - Markedly Better	< .001	Yes
Little Races – Mischievous Spirits	0.15 (Little Races - Slightly Better)	0.039	Yes
Chocolaty – Make Your Pizzas	0.12 (Chocolaty - A Little Better)	0.099	No
Mischievous Spirits – Chocolaty	0.03 (Almost the same; -0.2558 in favor of Mischievous Spirits)	0.682	No
Mischievous Spirits – Make Your Pizzas	0.15 (Mischievous Spirits - Slightly Better)	0.039	Yes

Note: A difference was considered significant when $p < 0.05$, adjusted using the Bonferroni correction.

In Table 4, the Bonferroni post hoc test showed statistically significant differences in several comparisons among the video games. Little Races scored significantly higher than Chocolaty ($p = .013$), Make Your Pizzas ($p < .001$), and Mischievous Spirits ($p = .039$), indicating that this game received consistently higher ratings. Similarly, Mischievous Spirits scored significantly higher than Make Your Pizzas ($p = .039$). In contrast, the differences

between Chocolaty and Make Your Pizzas ($p = 0.099$) as well as between Mischievous Spirits and Chocolaty ($p = 0.682$) were not significant, suggesting that students rated these games similarly.

CONCLUSIONS

The results show that Little Races was the video game with the highest overall rating, significantly outperforming Chocolaty, Make Your Pizzas, and Mischievous Spirits. This difference could be attributed to Little Races having a faster-paced dynamic, simple rules, and a level of competitiveness that likely kept students more motivated and engaged. The significant advantage of Mischievous Spirits over Make Your Pizzas suggests that more attractive visual and narrative elements—such as characters and settings—can positively influence the perception of the game.

On the other hand, the lack of significant differences between Chocolaty and Make Your Pizzas, as well as between Mischievous Spirits and Chocolaty, indicates that these games offer similar satisfaction levels. This may be due to shared interaction mechanics or comparable challenge levels, which reduce variability in ratings. Overall, the results suggest that speed, competitiveness, and narrative appeal could be key factors in improving the gaming experience in an educational setting.

The findings show that, although all the video games received good ratings, Make Your Pizzas consistently scored lower than the others. This suggests a need to examine aspects such as game mechanics, visual appeal, and difficulty to enhance its acceptance among students. Conversely, Little Races, Mischievous Spirits, and Chocolaty are the most highly regarded games, with high ratings and no notable differences among them.

The video game with the highest overall rating was Little Races, particularly in terms of fun and ease of use. Mischievous Spirits stands out for challenge and narrative, but its replayability is lower. Chocolaty scores high in graphics, but the precision required may discourage some students. Make Your Pizzas received the lowest ratings, mainly due to repetitive mechanics.

RECOMMENDATIONS

Increase variability in Make Your Pizzas with more ingredients and recipes.
Improve visual effects in Mischievous Spirits and Little Races.
Add new game modes in Chocolaty to keep players interested.
Keep the existing mechanics of Little Races while enhancing its visual appeal.

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