

**Virtual teaching of the concept of number in
primary school children in an interactive
mixed media system**

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**PONTIFICIA UNIVERSIDAD JAVERIANA CALI
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media system

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Dissertation

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Ghina Alexandra Garcés Rojas
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Abstract

This dissertation explores the design, development and evaluation of an interactive mixed media system designed to teach numerical concepts to primary school children. The project aimed to create an engaging educational tool using multimedia elements to enhance understanding and retention of mathematical concepts. Iterative testing with primary school children and feedback from educators ensured the tool's effectiveness and usability. Results indicated significant improvements in student engagement and comprehension. The findings suggest the potential of such systems to enhance traditional teaching methods, with future research needed on curriculum integration, scalability, and advanced features.

Keywords: Numeracy, learning environment, mixed media, digital learning tools, physical manipulatives, educational technology

Summary

This document proposes a solution through the development and implementation of an interactive mixed media system that combines digital learning tools, such as educational software and games, with physical manipulatives like counting items and number cards. The methodology involves a multi-phase approach. Initially, the mixed media system was designed with input from educational experts, ensuring it aligned with curriculum standards and pedagogical best practices. Following this, the system was deployed in a real classroom setting over a defined period. To measure its effectiveness, pre- and post-intervention assessments were conducted, including observational studies, and qualitative feedback from both users.

The results of the study demonstrate significant improvements in the numerical skills and overall understanding of mathematics among students who used the interactive system compared to those who were taught using traditional methods. The data shows higher engagement levels, increased motivation, and better retention of numerical concepts.

The conclusions drawn from this study highlight the effectiveness of the interactive mixed media system in enhancing primary education. It provides evidence that integrating digital and physical learning tools can create a more engaging and effective learning environment, leading to better educational outcomes for young learners. This approach can be considered a valuable addition to current teaching practices, offering a modern solution to the persistent challenge of teaching numerical concepts to children.

CHAPTER 1

Introduction

In contemporary educational landscapes, the integration of technology represents a pivotal advancement in teaching and learning paradigms. Nonetheless, it is imperative to recognize that despite these advancements, the incorporation of technology into education remains in its initial stages, indicating that significant advancements must still be made to realize its full potential. Virtual teaching has consistently posed challenges in both pedagogy and technology, particularly when it comes to young children in primary school. These children typically have short attention spans and need continuous stimulation to stay engaged in structured activities. The task becomes even more daunting when teaching abstract concepts essential for understanding fundamental mathematics.

One of the critical hurdles in remote learning environments is maintaining young children's focus and motivation. The absence of a physical classroom and direct interaction with teachers and peers often leads to diminished engagement. Additionally, the abstract nature of math concepts such as numeracy—understanding numbers and their relationships—adds another layer of complexity. Teaching these concepts requires not only capturing the children's interest but also providing concrete experiences that can make abstract ideas more tangible.

The objective is to develop a more engaging and effective learning experience for young children. This approach aims to bridge the gap between the abstract nature of mathematics and the concrete experiences that are essential for young learners to comprehend these fundamental concepts. By integrating interactive digital tools with hands-on activities, we seek to create a more engaging and effective learning experience for young children. This approach hopes to bridge the gap between the abstract nature of mathematics and the concrete experiences necessary for young learners to grasp these essential concepts.

1.1. MOTIVATION

The Covid-19 pandemic and corresponding quarantine tested the limits of transferring classroom teaching to a digital format. From preschool to college, both students and teachers struggled to replicate the dynamics of traditional classes through screens at home. Contrary to initial expectations, this forced experiment largely proved unsuccessful, with educational outcomes declining worldwide. This has led to a reevaluation of the notion that screens alone can provide the comprehensive learning experience necessary for effective education.

During the pandemic, UNESCO reported (Team, 2021) that over 1.370 billion stu-

dents from schools and universities were enrolled in remote education models. To cope with these unprecedented circumstances, various technological resources were extensively utilized to support learning. However, despite these initial measures, research studies have identified significant learning gaps in core subjects such as mathematics and language.

Now, three years post-lockdown, the repercussions of these adaptations are becoming apparent. While schools managed to survive the pandemic, the current educational landscape is fraught with challenges. The heavy reliance on technology in classrooms has not yielded the expected improvements in learning outcomes. Despite advanced technological tools, many students have not achieved satisfactory educational progress, indicating that current technology fails to meet critical learning needs. There is a pressing need to support teachers in integrating technology effectively by providing necessary resources and training. Enhancing the meaningful use of technology is essential to address deficiencies in student learning and to give technology a genuine opportunity to contribute positively to education.

In response to these challenges, this project aims to develop a human-machine interactive digital device that integrates both hardware and software. The goal is to create an educational tool that surpasses the limitations of screen-only teaching methods. By combining existing technologies into a cohesive and interactive experience, this device seeks to enhance student engagement and improve learning outcomes. This project will explore the specific learning needs that are not being met by current technological solutions and offer a more effective alternative for modern education.

1.2. GOAL

This project is aimed at developing a software application that integrates various physical interaction technologies to teach basic math concepts, with a particular focus on numeracy, to children aged 6 to 10. This software will be designed to create an engaging and interactive learning experience that goes beyond traditional screen-based methods. Both the source code and the hardware setup will be open source, allowing for full replication and adaptation by educators, researchers, and developers interested in enhancing early math education.

1.3. WORK DONE

A thorough software application has been developed utilizing Python and its various libraries. The project also includes a hardware setup comprising a projector, a camera, speakers, and physical interactive objects such as augmented reality (AR) markers to optimize the software's functionality. Several mathematical activities have been incorporated into the application, leveraging three primary modes of interaction to facilitate effective learning.

1.4. OUT OF SCOPE

This project is designed as a prototype to demonstrate the potential of integrating various interaction technologies in early mathematics education. It is not intended to be a fully-functional, market-ready product. Consequently, the implementation assumes ideal conditions for the utilization of these technologies.

1.5. STRUCTURE OF THE DOCUMENT

This documents consists of the following sections:

1. **Introduction.** Where the motivation and justification of this project is discussed. Also includes the purpose of the information in a concise way.
2. **Background.** Includes the main and secondary objectives and their scope are listed. Includes limitations of the project and evaluation criteria for the finished product.
3. **Methodology.** Describes the thought process that lead to the design of the application and the factors taken into account for the development of the application, from the hardware to the software setup and tools used.
4. **Delivery.** Explains what ended up being developed for the application based on the design and how each part helps complete the objectives established.
5. **Evaluation.** Describes the process of evaluation of the application with real users and the results obtained from this process.
6. **Conclusions.** Discusses if the objectives were achieved during the project and how the results could be used for derived works.
7. **References.** List of bibliographic sources used for the research and design of the project.

CHAPTER 2

Background

2.1. OBJECTIVES

2.1.1. General objective

Create an interactive learning environment with interactive systems that involves interrelationships between physical and virtual media for teaching the concept of numbers to children.

2.1.2. Specific objectives

1. Leverage different types of interactions for didactic activities in a mixed-media learning environment.
2. Create a teaching environment with interactive systems that fosters a reflective process for concept construction for children.
3. Develop didactic activities from a systemic perspective on the concept of numbers that permanently include the four basic operations.
4. Implement a perspective of physical and digital interrelationships in the environment that allows the user to materialize high levels of attention and motivation through active participation in the surroundings.
5. Evaluate the level of comprehension of a child regarding the concept of numbers after having learned through the interactive system.

2.2. REQUIREMENTS AND LIMITATIONS

2.2.1. Solution requirements

1. Operating System: The software will be developed for use on Windows OS, given its prevalence among average users.
2. Independence: The software should be operable by students with or without a mentor present.
3. Hardware: The hardware should consist of commonly used, affordable devices.
4. Space: The hardware setup should be usable within a space no larger than 1m².
5. Didactic Elements: The didactic components should be easily created or replaced.

2.2.2. Solution characteristics

1. User-friendly interface suitable for children of different ages.
2. Integration of multimedia elements such as audio, video, and interactive components.
3. Easy setup and calibration of hardware elements.

2.2.3. Scope restrictions

1. Dependence on specific hardware to run the application.
2. Compatibility constraints with older hardware or software versions.
3. Requirement of a space that accommodates the hardware setup.
4. Dependency on ideal sound and light conditions for proper application use.

2.2.4. Functional Requirements

1. Utilization of physical elements for activities provided by the software.
2. Software recognition of the physical elements.
3. Application recognition of handwritten numbers.

2.2.5. Non-functional requirements

1. The software interface should be intuitive and easy to understand for users.
2. The application should provide easy-to-follow instructions to guide the user.
3. The interface should be visually appealing to engage users.
4. The interaction between physical elements and the software should be seamless.

2.3. EVALUATION REQUISITES

2.3.1. Methodology for evaluation

1. Conduct observations to ensure that users engage with physical elements as intended, such as number cards or manipulative tools.
2. Evaluate the accuracy of the software's recognition of physical elements by comparing the system's responses to the expected outcomes.
3. Use controlled experiments where participants interact with known physical elements to assess the software's ability to recognize and respond appropriately.
4. Assess the software's accuracy in recognizing handwritten numbers by comparing its interpretation of handwritten inputs to the correct values.
5. Conduct usability testing sessions to evaluate users' ability to navigate the software interface independently.
6. Observe user's interactions to identify any instances of friction or difficulty in the interaction between physical elements and the software.

2.3.2. Data collection methods

1. Use video recordings and screen capture software during usability testing sessions to capture user interactions and behaviors.
2. Collect qualitative data through post-task interviews to gather insights into participants' perceptions of the software's learning experience and engagement
3. Document instances where the software successfully promotes reflection and concept construction among users.

2.3.3. Metrics and Criteria for Assessment

1. Accuracy rates on math exercises embedded within the software. Time spent engaging with interactive elements related to number concepts.
2. Frequency of interactions with reflective prompts or activities within the software.
3. Participant feedback on the software's ability to foster meaningful interactions between physical and virtual elements.
4. Observations of instances where the software supports the integration of the four basic mathematical operations into interactive learning activities.
5. Identification of features within the software that enhance user motivation and engagement with number concepts.

2.3.4. Participant selection criteria

1. Age range: Children between 6 and 10 years old.
2. Educational background: Bilingual students enrolled in elementary school mathematics classes.
3. Informed consent: Obtain permission from parents or guardians before involving children in the evaluation process.
4. Privacy: Safeguard personal information collected during the evaluation and ensure compliance with data protection regulations.

2.4. STATE OF THE ART

2.4.1. Concept of number

The concept of number, also referred to as "Number Sense" or "numerical awareness", constitutes a foundational skill necessary for mathematical understanding. It encompasses a well-organized conceptual framework enabling individuals to comprehend numbers and their interrelationships, facilitating problem-solving beyond traditional algorithms(Way, 2005).

The National Council of Teachers of Mathematics in the United States has delineated five key components characterizing number sense: numerical meaning, numerical relationships, numerical magnitude, operations between numbers, and benchmarks for numbers and quantities. In essence, number sense denotes a student's capacity to flexibly employ numbers as tools and interpret them across various contexts(Way, 2005). Evaluation of the concept of number typically considers parameters such as (Hornigold, 2021):

1. Awareness of the relationship between number and quantity.

2. Understanding of numerical symbols, vocabulary, and their meanings.
3. Proficiency in systematic counting, encompassing cardinality and ordinality concepts.
4. Understanding of magnitude and comparisons between differing magnitudes.
5. Familiarity with diverse representations of numbers.
6. Competence in basic mathematical operations.
7. Recognition of numerical patterns, including identification of missing numbers.
8. Comprehension of place value and the conceptualization of numbers as sums of units.

2.4.2. Semiotic representations of Duval

Semiotic representations of mathematics, as proposed by French theorist Raymond Duval, pertain to the various modes through which mathematical concepts can be conveyed, including symbols, natural language, graphics, diagrams, and other communication tools. These representations serve to construct meaning and facilitate understanding of mathematical concepts, categorized as iconic, discursive, or symbolic.

Duval asserts that each semiotic representation possesses unique characteristics and potentials, suggesting that mathematical understanding evolves through their combination and interrelation. Transitioning between diverse representations fosters a deeper comprehension of mathematical concepts and enables problem-solving from varied perspectives. Duval advocates for teaching mathematics to young children by coordinating concrete actions with visual representations and symbolic operations.

A significant pedagogical challenge lies in transitioning from visual to symbolic representation systems, with oral language serving as a crucial transitional medium. Given that children may struggle to independently establish connections between these representations, simultaneous teaching approaches are essential to ensure the formation of necessary associations for mastering mathematical knowledge.

2.4.3. Screen inferiority

There is ample evidence that much of the virtual education available today suffers from "screen inferiority," the concept that students retain less information in memory when reading on a screen compared to printed media. Students typically score lower after reading a text on screen compared to paper and tend to be overly confident in their knowledge, studying for shorter periods and achieving worse results than those who read in print. Multiple psychology studies (Van der Weel y Van der Meer, 2024) suggest that there are cognitive and behavioral differences associated with the medium through which information is presented, and it has been observed that the way content is typically presented on screen leads to faster and shallower reading, and therefore, less comprehension. It has been found that screen reading is more suitable for review reading because behavior becomes more scanning and searching, and non-linear reading with less attention to content and more to keywords. These studies (Van der Weel y Van der Meer, 2024) suggest that the medium in which the text is presented provides contextual cues for the information retrieval process, so fewer resources are used for comprehension and metacomprehension processes when reading on screen.

The *Frontiers in Psychology* journal has made studies that show that using movement and physical mediums stimulate the brain more than interacting with a screen, in a way that brain connectivity patterns are more elaborate and widespread between different areas of the brain, which creates connectivity patterns and frequencies that are crucial to memory formation and encoding of new information and, thus, beneficial for learning (Van der Weel y Van der Meer, 2024). This appears to be related to what a study in infant degeneracy on neural patterns conclude about how “the spatiotemporal pattern from visual and proprioceptive information obtained through the precisely controlled hand movements, contribute extensively to the brain’s connectivity patterns that promote learning” (F. R. (Ruud) van der Weel y van der Meer, 2019). Though the study focuses on writing with a pen versus on a keyboard, the conclusion was that the involvement of intricate hand movements in contrast to key pressing that requires the same simple movement creates brain patterns that are more elaborate, “as shown by widespread theta/alpha connectivity coherence patterns between network hubs and nodes in parietal and central brain regions” (F. R. (Ruud) van der Weel y van der Meer, 2019).

Though screen inferiority has been researched to affect the most when reading long texts, new studies (Ackerman, sidi, y ophir, 2016) have focused on brief tasks and shown similar results of lower comprehension on screen than on paper. Studies have proposed that electronic devices offer a contextual cue that prompts individuals to engage in less profound processing, leading to diminished cognitive performance. Many other studies (Wang y cols., 2023) have suggested that this inferiority is independent of the format of the question to solve, with shallow processing and inferior reasoning being present in multi-choice as well as open ended questions. It appears that there is even an unconscious understanding of screen inferiority and its relation to lessened reasoning when it pertains to solving math problems, as even those who had a preference for digital mediums resorted to paper when faced with the task of solving simple math problems. The same studies (Ackerman y cols., 2016) have shown that “while on paper in-depth text processing is the default, on screen an external trigger is needed”.

2.4.4. Multisensorial math teaching

Mathematics requires abstract thinking and problem-solving skills, which can be overwhelming for many children, often leading to disinterest or anxiety. Multisensory learning, however, offers a solution by engaging different learning modalities. When children interact with math through multiple senses, they can form stronger neural connections, allowing them to approach problems from various angles and perspectives, which leads to a more comprehensive understanding of the subject (Luigi F, 2022). Furthermore, multisensory learning fosters a positive attitude towards math. By incorporating multisensory activities, children can perceive math as enjoyable and engaging rather than dull and difficult, significantly enhancing their motivation and willingness to learn.

Effective educational settings leverage manipulatives, cards, games, counters, and scaled models to facilitate the mental representation of abstract concepts. These tools help visualize contexts that foster various types of mathematical thinking, including numerical thinking and number systems, spatial thinking and geometric systems, probabilistic thinking and data systems, and variational thinking and algebraic systems (Luigi F, 2022). It is crucial to address these types of thinking from the early grades, focusing on understanding mathematical concepts, relationships, and opera-

tions through problem-solving in meaningful contexts.

Nevertheless, according to Rojas (D., 2024), most educational software in mathematics promotes mechanical drilling, lacks scaffolding, and restricts engagement and autonomy by predominantly fostering keyboard-based input, thereby displacing multisensory responses. Therefore, advancing towards pedagogically centered technology is crucial for enhancing educational experiences for both students and educators. There is a clear need for digital contexts that integrate higher cognitive functions and sensory involvement. Hardware and software solutions should facilitate processes conducive to what Mishra, Henriksen, and The Deep-Play Research Group (Henriksen, Creely, Henderson, y Mishra, 2021) proposed: technology for transdisciplinary, transferrable construction of knowledge, and more inclusive, interactive, and cross-disciplinary project-based learning.

Traditional learning strategies tend to be unisensory: whiteboards, textbooks, etc, all tend to exploit mainly the sense of vision in the classroom. However, since humans process the world through all of the senses at the time, it has been shown by studies that the integration of more sensory learning modalities improves processing of concepts. This process is known as sensory integration and occurs when the brain processes the same information through different channels (Luigi F, 2022). Studies by Luigi F. Cuturi have also shown that multisensory integration usually occurs late in early development mainly because of the lack of inclusion of multisensory in school which is why starting from an early age might help them develop it earlier. Research on mathematics education has shown that multisensory teaching approaches play a critical role in the conceptualization of mathematical concepts and in many other studies, multisensory education has been suggested for improving classroom learning (Luigi F, 2022).

The role of mathematical knowledge is undeniable in shaping our mental representations of the world and our future expectations. It is essential for the advancement of humanity, supporting global changes, and creating sustainable options. As Nelson Mandela stated, "Mathematics is a tool for development." Therefore, it is imperative to improve the technology-mathematics connection, aiming for more comprehensive physical responses and interactivity that lead to better attention, engagement, and deeper thinking processes.

2.4.5. Manipulatives in math teaching

There has been a long tradition of using manipulatives (physical elements) in mathematics. Educators have long perceived an intensity and insight when engaging with mathematics through manipulatives that is not present when observing a visual display (Nemirovsky y cols., 2004). Although just the use of manipulatives is not enough to learn automatically, they offer a learning experience that can not be easily simulated through a screen. One of the main differences is how manipulatives allow the inclusion of touch and proprioception (kinesthesia) into math learning.

There is a new perspective known as "Exploratory vision" (Nemirovsky y cols., 2004) that argues that vision is fully integrated with the other senses and actions and that showing static images does not fully exploit this, and that information that can not be captured solely by the eyes can be completed through other senses. This perspective, however, is not new and had been previously explored by Poincare, who argued that the movements of the body provide more information than thought of and

that “the localization of objects in space is conceived through muscular sensations that accompany real or imaginary movements around said space”(Poincaré, 1963).

Studies have shown that kids that use manipulatives in math problem solving not only identified more solutions but that their use fostered more conceptually developed strategies, “relating consecutive solutions to each other systematically in exploring the space of permutations”(Manches y O’Malley, 2016).

2.4.6. Proprioception in learning

Proprioception, otherwise known as kinesthesia, is the body’s ability to sense movement, action, and location. It is referred to as a sense though really it is a cumulative effect of the senses that uses kinesthetic, auditory, and visual input(Kasterko, s.f.). The brain processes the contraction and relaxation of every muscle, its distance from the body and its relative location in the space and uses visual and auditory cues to understand the distribution of the space around it and the objects in it.

It has been argued that developing proprioception is one of the most important skills for learning and that “When proprioception is not fully developed and an attempt at teaching academics is made, this will always lead to attention difficulties”(Kasterko, s.f.). This is because proprioception includes the ability to control the body and until this is done, the brain can’t properly focus on anything else because “if there are even tiny momentary unnoticed balance problems the hard wiring of the brain will put all mental function towards correcting this”(Kasterko, s.f.).

Developing proprioception, therefore, is a necessary skill, especially for kids who are just starting their academic journey. As such, since proprioception is a multisensory skill, activities that engage the body in a way that improves understanding through movement and the senses at the same time could help them develop a greater understanding of difficult subjects.

2.4.7. Mixed media

The concept of mixed media can be defined as the use of both physical and digital media to interact with an application. Screen-only applications which use only the screen as a means of interaction are considered digital media. In order to have a mixed media application, physical items other than the screen must be used to interact directly with the application. This project includes physical media easy to produce/replicate to interact with the activities. Through this, not only does it try to overcome screen inferiority but also make use of multi sensorial activities to enhance the comprehension of a concept by enabling multiple pathways in the brain for knowledge to be processed through.

CHAPTER 3

Methodology

In the quest for educational transformation, it's not solely technological advancements that will drive progress but rather the harmonious integration of human ingenuity and digital innovation. This synergy is essential for crafting new digital learning environments that truly enhance educational outcomes and societal development. Key to this integration are creativity, sensitivity, and a steadfast human commitment to pedagogical excellence. Thus, the future of digital learning lies in the delicate balance between technological innovation and human-centered design. Only through a thoughtful integration of creativity, sensitivity, and pedagogical expertise can we unlock the full potential of digital learning to shape a more inclusive, dynamic, and intellectually vibrant society.

The design path of this project has adhered to the human-centered design principles, aiming at creating a solution that is not only innovative and technologically advanced but also deeply resonate with users, enhancing their lives and experiences in meaningful ways. Thus, the Double Diamond Model and design thinking methods have been combined along the design process. Figure 3.1 show the four steps of the Double Diamond methodology which have been followed along this project: Discover, Define, Develop, and Deliver.

3.1. DISCOVER: IDENTIFY USERS' NEEDS

The inspiration for this project was the post-pandemic educational challenges and opportunities in technology integration. Following the return to school campuses after the pandemic, there were high expectations among students, parents, teachers, and ad-

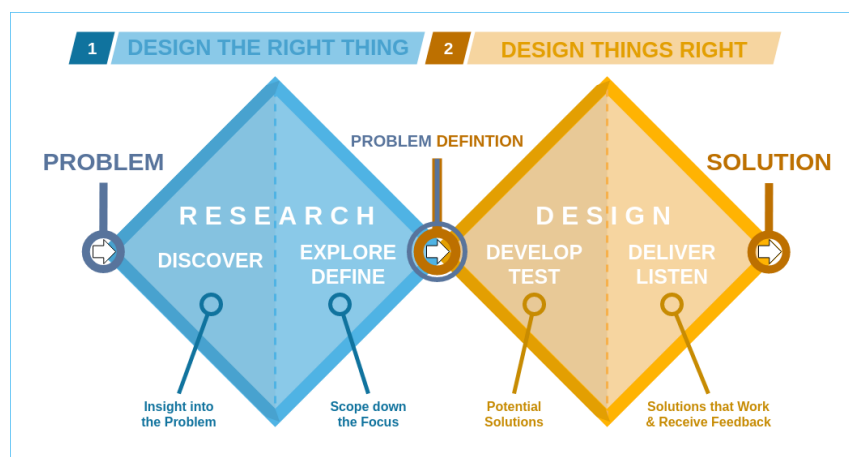


Figure 3.1: Double Diamond design methodology

ministrators for innovative and disruptive learning opportunities. However, a crisis soon became evident. The use of technology as merely a repository of information, excessive reliance on adaptive systems to teach math concepts, and the digitization of traditional worksheets led to student disengagement. The school's ambitious post-pandemic adoption of extensive technology integration raised concerns among teachers, administrators, and parents about negative changes in teaching methodologies and declining academic standards. Misconceptions about students being inherently tech-savvy and overestimated expectations of technology's impact may have contributed to the current situation.

As stated by Rojas(D., 2022) The view on the actual context of education provided by teachers, psychologists and Pedagogical Consultants allows the understanding of the struggle the education system deals with when considering the insertion of technology in school settings. We need to close the global and local perspectives to give an opportunity for technology to be inserted purposely and efficiently. Meanwhile, there is friction about the role of technology that affects both; the future of technology in classrooms as well as the possibility of educational systems to transform positively by profiting the diverse ways technology offers of displaying content which might allow a powerful trans-disciplinary experience

Amidst this concerning scenario, a valuable opportunity arose to work directly with students from 3rd to 7th grades. This close collaboration provided sufficient data to identify pain points in the current learning scenarios mediated by Information and Communication Technology. Additionally, first-hand access to teachers' planning and the tasks they assigned offered significant insights into their conceptions of technology use, knowledge of digital media, and perceptions of students' roles. Equally important was the opportunity to interview experts in math curriculum design and teachers who were struggling with the implementation of digital tools in their classes. The collected data on current practices was then cleaned and analyzed to characterize the audiences, align the goals, and frame the design challenge.

During the inspiration process, insights from users highlighted the need to assess the types of interactivity that current hardware and software fostered or failed to foster in digitally mediated learning experiences. Challenges related to interfaces, data processing difficulties, and issues with attention and memory when working on screens, along with the passive roles often observed in students, shaped initial ideas for potential solutions.

3.2. DEFINE: SYNTHESIZE FINDINGS AND DEFINE THE PROBLEM STATEMENTS

Once sufficient surveys, insights and ideas have been gathered, the focus shifts to synthesizing and analyzing the collected information. This involves identifying patterns, themes, and opportunities that emerge from the research phase. Defining and outlining the desired features, architecture, application architecture, and technology involved was the key objective of this design phase.

- Data analysis and Insight synthesis
- Point of view statement
- Problem statement framework
- Stakeholders mapping

The defining and outlining the application was enriched by a series of reflections on pedagogy, didactics, and the evolutionary conditions required for effective human interaction with the environment in learning experiences.

3.2.1. Identifying the limitations of screen-only applications

Traditional screen applications engage mostly the sight and hearing senses and some even go as far as to include tactile interactions with the screen. Due to the phenomenon of screen inferiority, however, it has been noted that the brain finds it harder to process difficult information when interacting with it just through a screen. Lower reasoning and shallow processing are common effects of screen inferiority, also often accompanied by inferior information retention as a byproduct. For kids who are just starting to understand the concepts, screen-only teaching has led to shallow, temporary understanding of the topics. In a field such as mathematics, where each new concept builds on the ones before it, these early difficulties have translated into comprehension vacuums in later years.

Screen-only applications rely on easy, repetitive movements and dynamics that create shallow neurological pathways and a harder time engaging with the content. As studies have suggested, one of the ways to overcome this is to include external triggers and stimuli that improve retention. Meaning, one way to improve educational screen applications is to not only include more complex movements with less repetition, but also to include external elements that provide stimuli and or different kinds of interactions.

Apart from the external stimuli, educational applications can benefit from multisensory interactions. New technologies, especially in the field of gaming, have led to the development of different kinds of interactions that engage the different senses as a way to stimulate different parts of the brain and activate multiple neurological pathways in a single activity.

3.2.2. Interactions and the senses

One of the main focuses of the project is to include a wide variety of interactions that engage as many senses as possible so as to guarantee as many semiotic representations of numbers as possible. The more a child interacts with a piece of information, the more neurological associations are created that allow the comprehension of said information. Including different senses in the learning process allows the brain to process the same information through different stimuli, expanding the associations made between them.

This application aims to create more interactions than a traditional screen has to engage the same senses in different ways and also include other senses that have not been made use of through everyday devices, specifically, touch and proprioception. Therefore, aside from traditional audiovisual interactions, kinetic and tactile interactions were included.

The following types of interactions, along with the senses they engage, have been taken into account for the development of this application. For each of them, technologies that could be used to provide said type of interaction and how they can be used for this purpose have been included:

1. Visual interactions are those that rely on visual perception, such as seeing images, colors, shapes, and text on a screen or through other visual mediums.
 - a) Graphical User Interface (GUI): Interacting with digital interfaces through visual elements like icons, buttons, and menus.
 - b) Augmented Reality (AR): Overlays digital images onto the physical world, engaging users visually.
2. Auditory interactions engage hearing and involve the perception of sound, including spoken language, music, tones, and other auditory cues.
 - a) Voice Interaction: Interacting with technology using spoken commands.
 - b) Sound Feedback: Providing auditory cues or feedback to users in response to their actions, such as notification sounds or confirmation tones.
 - c) Sonification: Representing data or information through sound, allowing users to perceive patterns or trends auditorily.
3. Kinesthetic interaction involves physical movement or manipulation of objects to interact with technology. It encompasses gestures, motion, and other physical actions. Kinesthetic interactions involve the sense of proprioception, or the perception of one's own body parts in relation to other elements and the world.
 - a) Physical Controllers: Using physical elements such as controllers or objects to navigate through the digital interfaces by moving or manipulating said elements.
 - b) Augmented Reality (AR): Allows movement of digital images through physical mediums.
4. Tactile interaction involves physical contact with objects or surfaces, providing sensory feedback through the sense of touch. It encompasses the feel of different textures, pressures, and temperatures.
 - a) Handwriting: Feeling the texture of the writing surface, the pressure exerted by the writing instrument, and the movement of your hand as you form letters and shapes.

3.2.3. Concept of number

The concept of numbers is the basis of mathematics. There are a number of abilities that must be taken into account when teaching the concept of numbers to a kid just starting their journey into mathematics. After a profound analysis of what abilities encompass the concept of "numeracy", a detailed breakdown of skills was carried out into the following achievement markers, which formed the basis for the development of pedagogical activities.

1. Identifying different representations of numbers: Identifying and being able to switch from one representation of a number to another. The representations of numbers
 - a) Numerals: Identifying the indo arabic numerals used in modern mathematics as a visual and semiotic representation of the concept of each number
 - b) Words: Identifying the English word used to identify each number as an auditory representation of the number.

- c) Magnitudes: Identifying the magnitude of elements that each number refers to in different contexts (real-world representation of two elements, for example)
- 2. Representing quantity: Being able to see or hear a number and representing it as a quantity of items.
- 3. Understanding ordinality: Understanding the order of the numbers and the logic behind the ordering both in ascending and descending order. Counting is a part of this ability.
- 4. Reading numbers: Pronouncing the words for the numbers correctly and tying it to its corresponding representations
- 5. Writing numbers: Writing by hand the numerals in a way that is recognizable
- 6. Comparing number magnitudes: Being able to identify which number is greater than, less than or equal to another by their magnitudes and their representations
- 7. Basic operations: Being able to use the numbers to do the basic four operations with them. Understanding the concepts of each operation, how the magnitude of the answer changes with each one and what kinds of action each operation represents in the real world.
 - a) Addition: Understanding addition as the result of taking two quantities into one by making a single group.
 - b) Division: Understanding division as the result of taking a quantity of items and making equal-sized groups with it.
 - c) Subtraction and Multiplication: These two were not directly represented in this version of the application but being the opposite operation to the ones that were included is meant to show that they could be easily implemented as well.

3.2.4. Problem statement

Teachers and students need access to a interactive and reflective digital experience to foster deeper learning through the proper use of technology in the classroom. Thus, a more responsive learning environment with interactive systems that involve interrelationships between physical and virtual media for teaching the concept of numbers to children will be designated. The following table 3.2 exhibits some of the main aspects that accompany this problem statement along with some possible solutions that will be tackled in the application development.

3.2.5. Defining the audiences

Understanding the target audiences and potential stakeholders is crucial for the success of our application. By identifying these groups, we aim to ensure that the application meets the diverse needs and expectations of its users. This includes students, educators, parents, and administrators, as well as developers and policymakers, who each play a crucial role in the successful implementation and adoption of the application in various educational settings.

- **Students (kinder to 4th grade):** My primary audiences are students in the first years of primary from bilingual, private schools where different subjects are

PROBLEM	DESCRIPTION	SOLUTION
Passivity	Overcome passive math concept drilling	Design a learning environment with interactive systems that fosters a reflective process for concept construction in math.
Innumeracy	Foster problem-solving and mental math	Include tasks that involve making decisions and using mixed media: digital resources and manipulatives.
Repetitiveness	Avoid mechanic practice and automatic responses	Involve a systemic and reflective approach where the basic operations are involved
Disengagement	Enhance attention, engagement, and motivation, therefore, better concept encoding.	Promote a higher level of physical response in a multisensory hand-mind-machine cooperation.

Figure 3.2: Problems and possible solutions accompanying the problem statement

taught in English as a second language. Students are struggling with math platforms that rely heavily on mechanical drilling of concepts. These platforms lack adequate scaffolding and fail to connect concepts to real-life situations, making it difficult for students to sustain attention and derive meaningful learning. The current hardware and software dynamics offer poor learning outcomes and do not engage students effectively. They need more engaging and interactive learning experiences, better instructional support, high-quality learning materials, and formative assessment practices that promote learning from mistakes. Classes are mixed; boys and girls, 50% each gender average. They belong to well-cultured families, whose parents are professionals with good access to technology.

- **Teachers (kinder to 4th grade)** Teachers face significant challenges in integrating technology into their classrooms. The primary issues include a lack of technological skills and the absence of apps, platforms, and digital tools that foster interactive, body-responsive learning dynamics. Adapting existing digital products is time-consuming, and many of these tools do not align with mandatory curricular standards, making it difficult for teachers to provide meaningful instructional support. Teachers need professional development, high-quality digital resources, and data-driven insights to better support student learning.
- **Parents (kinder to 4th grade)** Parents are worried about their children’s over-exposure to screens, poor learning outcomes, and the risks of unsafe virtual environments. Although many parents are well-educated, their own math education was often traditional, focusing on mechanical, repetitive, and isolated concepts. They understand the importance of math knowledge for their children’s future success and value effective math education.
- **School Administrators** School administrators are concerned about the decline in performance indicators and the effectiveness of the technology program. They need comprehensive data to inform improvement strategies, effective technology integration, and measures to enhance math knowledge, which is crucial for their ranking and community status.
- **Educational Technologists and Researchers** Educational technologists and researchers focus on the validity of data collected through learning analytics and the effective implementation of data driven decisions. They require detailed and

accurate data, collaboration with educators, and insights to enhance learning technologies.

- **Policymakers and Educational Authorities** Policymakers and educational authorities need evidence-based data to inform decisions and seek successful models of technology integration to ensure quality education across schools. Understanding these diverse perspectives and needs is crucial for developing a holistic and effective solution to the school's current learning challenges. The findings of this research may extend to students, parents, teachers, ICT leaders, administrators, and leaders of other institutions.
- **Technology Developers** Technology developers are deeply interested in the designs of interactive math hardware and software that are robust in pedagogical principles. They recognize the market demand for engaging, effective educational tools and are driven by the potential to make a meaningful impact on learning outcomes. By collaborating with educators and leveraging data analytics, developers aim to design products that not only enhance student engagement and understanding but also integrate seamlessly into classroom instruction. Their goal is to promote innovative, user-friendly tools that support critical thinking, real-life connections, and long-term adoption in educational settings.

3.3. DEVELOP: GENERATE AND TEST POTENTIAL SOLUTIONS

The "Develop" phase of the double diamond design methodology is a critical stage where ideas are transformed into tangible solutions. This phase involves generating a wide range of potential solutions and rigorously testing them to identify the most effective and feasible options. Through a mix of investigation, brainstorming and testing, a possible configuration for the development of the application was reached. In this section, the specifics of the development are outlined. Further description of the resulting product plus the Deliver stage of the methodology are included in the following chapter.

3.3.1. Application interactions

The following types of interactions were designed for the application to be used in different math activities:

1. Markers as magnitudes: Using ARuco markers as physical representations of elements. Each marker represents a single element which makes it so that magnitudes can be represented using different numbers of markers
2. Handwriting recognition: Students write, by hand, using a marker, whether on a piece of paper or a white surface the numbers and the computer should identify them as the correct representation. Once identified, they can be used in operations and comparisons
3. Beat recognition: Following a beat rhythm pattern by counting the beats and replicating it through the pressing of physical buttons
4. Speech recognition: Recognizing words spoken by the user. Used for checking the pronunciation of the number words.
5. Card recognition: Students use physical cards with the numbers or operators to complete activities by choosing the right one and placing it in a designated

space.

3.3.2. Manipulatives

The following are the manipulatives (or physical media) used in the interactions as forms of input for the application:

1. Markers: ARuco printed markers are used to represent individual, countable elements in different activities. Markers are the main element in the kinetic interactions included in this application. They could be interpreted as fruits or flowers to represent magnitudes in operations and number identification.
2. Cards: Physical paper cards that have a number or special operator printed on them that can be identified by the application.
3. Button: A single button, separate from the keyboard and mouse will be used for operation of the software as a way to create an application-only mouse and providing a physical and auditory feedback to selected events.
4. Pencil and paper: Regular pencil and paper will be used for activities that include handwritten digit recognition. A white surface with a thick black marker is preferred to make the written number prediction more accurate.

3.3.3. Software toolbox

The software toolbox for our application is a carefully selected suite of tools designed to maximize functionality and user experience. This toolbox includes libraries and frameworks chosen for their specific strengths in handling graphical interfaces, video processing, machine learning, marker recognition, speech recognition, and text-to-speech conversion.

The application is developed in Python not only because of its versatility and ease-of-use but also because of the numerous libraries available for interaction and artificial intelligence.

Different libraries were used to cover different functionalities in the application as follows:

1. GUI: Pygame was used as the backbone of the application due to its integrated sound mixer and the compatibility of its running loop with the sound and video loops.
2. Sound feedback: Pygame mixer was used to manage different audio channels all running independently and at the same time and for its ability to manage different file types.
3. Video Capture: OpenCV is the library used for any video-related uses such as video capture, isolation of regions of interest, screenshots, ARuco marker recognition and displaying the video capture window.
4. Handwritten digits recognition: AI was used to identify the digits written by hand by the users on the physical screen. For this, Tensorflow was used to train a model that, using the MNIST -a publicly-available database with handwritten characters-, would predict which number was written in each of the designated handwriting areas. Tensorflow also runs the model to recognize the numbers.

5. Marker recognition: The ARuco library was used to generate and recognize the physical markers used by the user to represent items.
6. Speech recognition: The Speechrecognition library is used to manage any audio capture and speech recognition needed in the spoken activities.
7. gTTS: gTTS (Google Text-to-Speech) was used for any spoken commands needed to instruct the player and give auditory feedback.

3.3.4. Hardware design

A big factor in the design of the project is accessibility. Ensuring that the hardware is user-friendly and can be easily utilized by all intended users, including children, educators, and individuals with disabilities, is paramount. By prioritizing accessibility in the hardware design, the project aims to create an inclusive educational tool that enhances learning experiences for all users, regardless of their physical abilities or economic backgrounds. This commitment to accessibility ensures that the hardware can be widely adopted and effectively used in diverse educational settings.

3.3.4.1. Devices and resources

1. Projector: The projector will transfer the GUI visual elements onto the target surface, be it a table or any other horizontal surface to be used as one.
2. USB Camera: The camera will capture in real time the user's interactions on the designed surface.
3. Speakers: Speakers will be used for sound feedback, be it music, sound effects, or relaying instructions and results to the user.
4. Microphone: The microphone will be used to capture user auditory interactions like speech in set activities.

3.3.4.2. Device specifications

Device	Model	Specifications
Projector	AuKing Mini-Projector	Minimum throw distance: 3.7 feet
		Maximum throw distance: 23.6 feet
		Native resolution: 800x600
Web camera	Logitech c930	Resolution: 1080p/30fps (up to 1920 x 1080 pixels)
		Camera mega pixel: 3
		Digital zoom: 4x
		RightLight™ 2 technology
Headphones	SteelSeries Arctis 5	Frequency Response: 20Hz - 22kHz
		Impedance: 32-Ohms
Microphone	SteelSeries Arctis 5	Polar Pattern: Bi-directional
		Frequency Response: 100Hz - 10kHz
		Sensitivity: -48dB

3.3.4.3. Environment setup

The project is named "Mixed media learning environment" and not just "Mixed media learning application" since a great emphasis is placed on developing a very limited

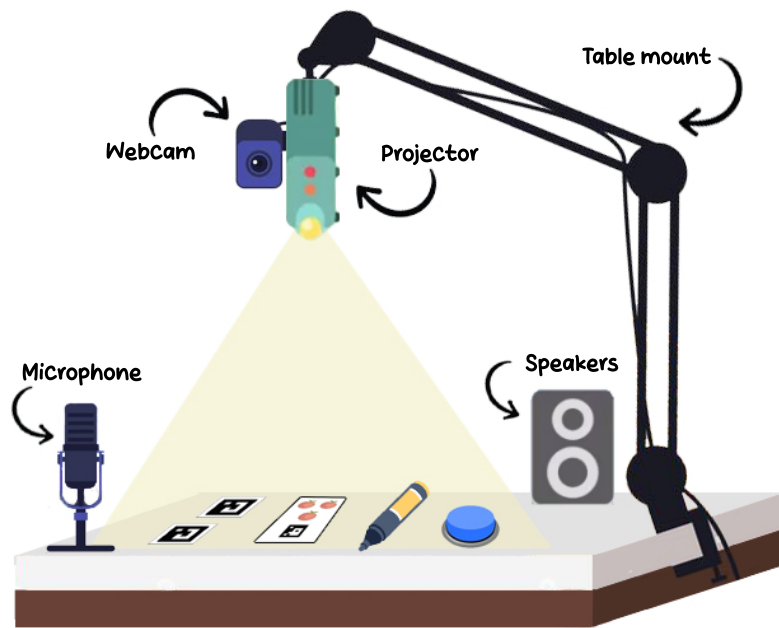


Figure 3.3: Diagram of the setup

space comprised of hardware, software, and physical elements that work together to provide the user a unique, somewhat immersive, math learning experience. Just as the project expects to make do with digital screens, it aims to provide an innovative way to interact, in this case, with a projected screen.

Diagram 3.3 shows the setup used to create the learning space that complies with the requisites. The computer on which the application will be run is not portrayed, as it is expected that the user will not have any screens in their proximity that can take away from the experience; however, its inclusion in this setup is implied.

3.4. DELIVER

The final step in the process will be specified in depth in the following chapter.

CHAPTER 4

Delivery

The subsequent chapter provides a detailed account of the implementation phase of the application, outlining how the design concepts were translated into the final structure. It elucidates the organization of the various components within the software and their interrelationships, as well as the interactions between the software, hardware, and manipulatives. Furthermore, this chapter discusses how the implemented features contribute to achieving the application's interaction objectives.

4.1. CODE STANDARIZATION

From the beginning of the development phase, it was established that the application would be coded following an object-oriented approach. As a sort of demonstration of the applicability of the established interactions, the code was written to be easy to understand and implement.

4.1.1. SOLID principles

The SOLID programming principles are a set of five foundational guidelines introduced by Robert C. Martin that aim to make software design more comprehensible, flexible, and maintainable. These principles are widely-used in the realm of Object-oriented programming.

Throughout our project, we diligently endeavored to adhere to these SOLID principles as much as possible. By doing so, we aimed to create a software system that is not only robust and scalable but also easier to maintain and extend in the future. Our commitment to these principles has guided our design decisions and implementation strategies, ensuring a high standard of code quality and architectural soundness.

4.1.2. Scalability

At the same time, as a first approach the development endeavored to create a base code which could be expanded and improved upon in future projects. For such a purpose, the code structure was designed in a way that makes it easy to implement new interactions or use the existing ones to create even more complex activities by just adding or removing GameRects, also known as class instances that handle each type of interaction.

This scalability can be appreciated in the Level definition class, which handles the contents of each possible level of an activity (each time the uses plays an activity, a random level will be chosen from the level list). A new level can be defined by specifying the the images (Image objects just for display, not for interaction), GameRects, an

optional prompt (to be read by the narrator when the level loads), and even a custom answer check method in the following way:

```

1 level = Level(
2     [list of Image objects],
3     [list of GameRect objects],
4     prompt string
5 )

```

The following are examples of Level instances defined in the application, though more advanced customization can be achieved as well:

```

1 Level([[ "images/numbers/image/0.png" , (200,220) ]], ←
      ↪ [Speech([800,340,200,200], 'zero')], "0")

```

4.2. CLASSES

4.2.1. Class diagram

The following 4.1 is a simplified class diagram that shows the relationships between the classes in the application. The diagram does not include the attributes and methods of each class to make the diagram easier to visualize. Each class will be further specified in subsequent sections.

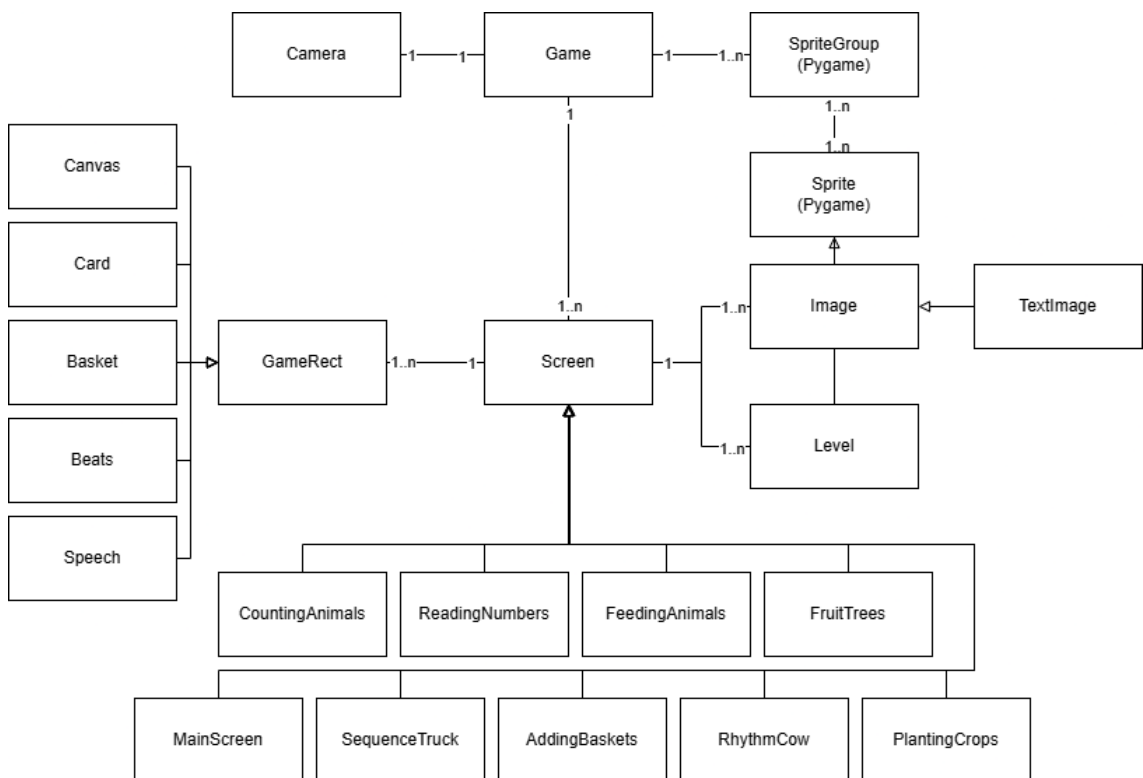


Figure 4.1: Class diagram

4.2.1.1. Game

Figure 4.2 shows the Game class, which handles the integration of all the interactions and screens. It handles the graphic interface, the sounds, the camera, and all events related to them. The Game class used Pygame as a backbone to show the graphics

on the screen and its mixer to handle music and sound. The Game class runs the main application loop that refreshes the screen and captures the camera frames and events.

The images to be loaded on screen are contained inside Screen type objects and it is the Game class which determines which screen is being shown currently, as well as providing the method to change the selected screen. The Game class, on each game loop, calls on the draw() function of each screen to refresh only those areas that have presented any changes. This feature of Pygame reduces the load on the processor by not having to reload the whole screen at once. The Pygame clock is used to limit the framerate of the loop in order to have a reasonable refresh rate that is pleasant to the eye without overloading the computer.

The Pygame mixer allows the use of different sound channels so that sound files can be played one on top of another, allowing the application to run background music and sound effects without having to wait for the other one to finish. The mixer allows up to 12 sound channels but for the application 3 are used: 0 (background music), 1 (sound effects) and 2 (narrator).

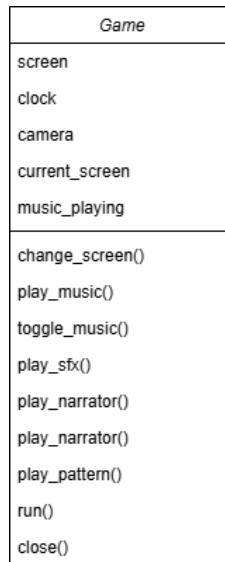


Figure 4.2: Game class diagram

4.2.1.2. Camera

The Camera class [4.3](#) handles the camera loop and all processes that require this loop such as video capture and ARuco marker detection. The camera loop refreshes each time the Game loop does and on each iteration, it captures the image on the selected camera and uses the ARuco library to detect markers in its frame. If any markers are detected and the current screen of the game has ARuco interactions on, the markers are processed inside the process_markers(), a method that analyzes the GameRects on the screen to assign values to each depending on its type.

The Camera class also generates a second window apart from the GUI window where the video capture is shown in real time. This screen is meant to serve as a control interface to check how the game and the GameRects values are interacting in real time (which is not necessarily reflected on the GUI window). To make this possible, the method draw_game_rects() is in charge of drawing and updating the rects with their values on real time in the control window.

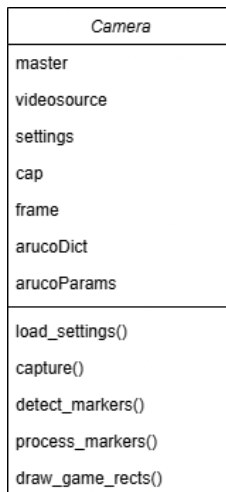


Figure 4.3: Camera class diagram

4.2.1.3. Screen

The Screen class handles all of the items shown on the interface at a time. The parent class Screen handles global GUI interactions, loading of images into sprite groups, level loading, and changing and the showing of modal windows (instructions and results). It also includes all of the activity attributes needed to activate the game mechanics (according to each child Screen) and keep track of the progress. Each activity inherits these components as a different child Screen class, with the ability to override or add methods and attributes specific to each activity. Child screens can also override the methods to have custom interactions and increases the ways in which they can be used.

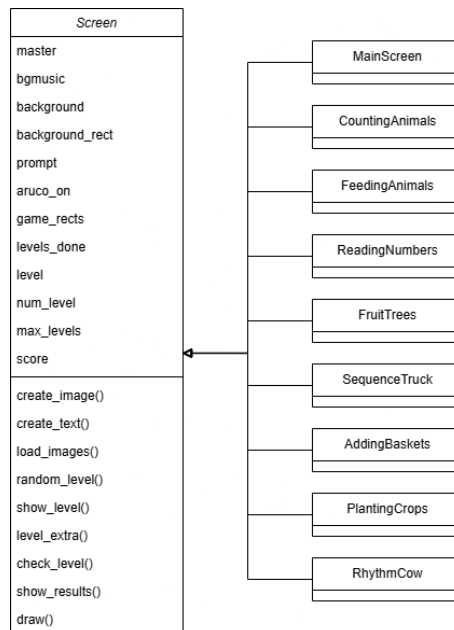


Figure 4.4: Screen class diagram

4.2.1.4. Level

The Level class shown in figure 4.5 handles the levels of a particular activity. The class consists of the images to be shown on the screen with its positions, the spoken prompts particular to the level, if any, and a list of the GameRects to hold values. This class encapsulates all elements to be evaluated in each level instance of the same activity making it so that when a new level starts, only the elements related to the level, not to the activity as a whole, are reloaded.

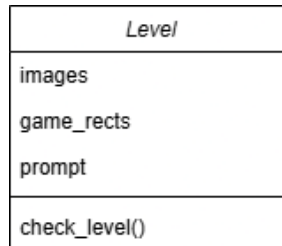


Figure 4.5: Level class diagram

4.2.2. Image

The Image class inherits from the Pygame Sprite class. It loads images and creates from them a sprite to add to a designated sprite_group for handling by pygame. It can also receive a function as an argument to create an onClick bind event to that function on the image rect. This class also allows the creation of temporary images that disappear after a while by making use of the pygame clock, calculating its end time and having the image removed from the sprite group when the end time has passed. Figure 4.6 show the class diagrams for both the Image and TextImage classes (the latter which inherits from the former).

4.2.2.1. TextImage

TextImage creates an Image class object from text it receives as an argument. It uses Pygame's render function to turn this text into a text image on call. With this, text can be created anytime and be handled as a sprite by PyGame.

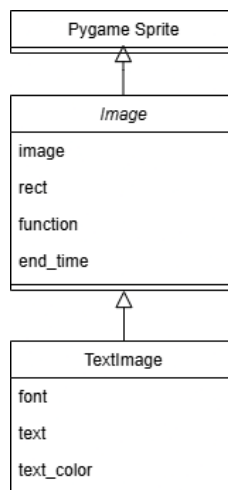


Figure 4.6: Image and TextImage class diagrams

4.2.2.2. GameRect

GameRect consists of the interactive rectangle spaces for the activities. In order to guide the user in the correct way to interact with the activities using the physical elements, GameRects creates visible rectangles that can be seen both in the Game window as well as the Capture Video window where item recognition is limited to these spaces only. This is to prevent the users from getting distracted trying to use the interactions on parts of the screen that do not serve the purpose of the activity and to make sure it is easy for the user to do the physical activities in the right place and decrease guessing. This also has the added advantage of decreasing load for the camera capture aspect of the application by only activating when it detects items within these bounds. Each GameRect signifies a different number which can be accessed through its value attribute and the class handles identification of the value according to the type selected. There are 5 kinds of GameRects which pertain to the interactions which use camera capture: basket, canvas, card, beat and speech. These types are implemented as subclasses that inherit from the GameRect in order to manage them all under the parent class. Figure 4.7 show the relationship between the parent and the child classes.

- **Basket:** The basket type GameRect is a rectangle with ARuco marker detection activated that identifies each marker as a separate item. The focus of a basket is to count how many items are within the bounds in order to use the physical markers to represent items and be able to count them manually. The marker detection is done automatically and on the screen a picture representing an item is shown in place of the marker. The value of this GameRect corresponds to the number of markers inside its bounds.
- **Canvas:** The canvas type GameRect is a ROI (region of interest) which will be captured by the camera to read a handwritten digit. The rectangle will show the user exactly where they should write the number and also serve as a guide for how much space the number should occupy (helping them develop a sense of proportion when writing). This GameRect gets its value by capturing the image on the physical surface through the camera, processing and using the handwriting recognition model to try to predict the value written in the designated space. Correct identification of the number mostly has to do with the accuracy with which the number was written by the user which helps them learn to write readable numbers.
- **Card:** The card type GameRect uses ARuco to identify only one marker at a time. The cards each come with an included marker which will be read by the application when placing the card inside the GameRect bounds. The value will be obtained by getting the first marker id in the list; if there are more than one marker, the first one will be chosen regardless of which it is. The value is equal to the id on the card for digit cards and, for operator cards, each operator will be tied to an id.
- **Beats:** The Beats class is a GameRect used for counting events. The value of this GameRect increases for each event which could be a click, a button press, etc. When it reaches its max value it stops going up. The user must interact with a physical object, in this case the button-mouse and click inside the rect to make the value go up by one each time. The main use for this is to use

sonification to represent number quantities as beats and have the user translate these magnitudes into a visual representation.

- **Speech:** The Speech type GameRect is a class that records sound from the microphone and uses gTTS to translate the spoken words into text. The transcribed words get set as the value of the rect. This type is valuable for speech recognition interactions that seek to improve the user's pronunciation of the language.

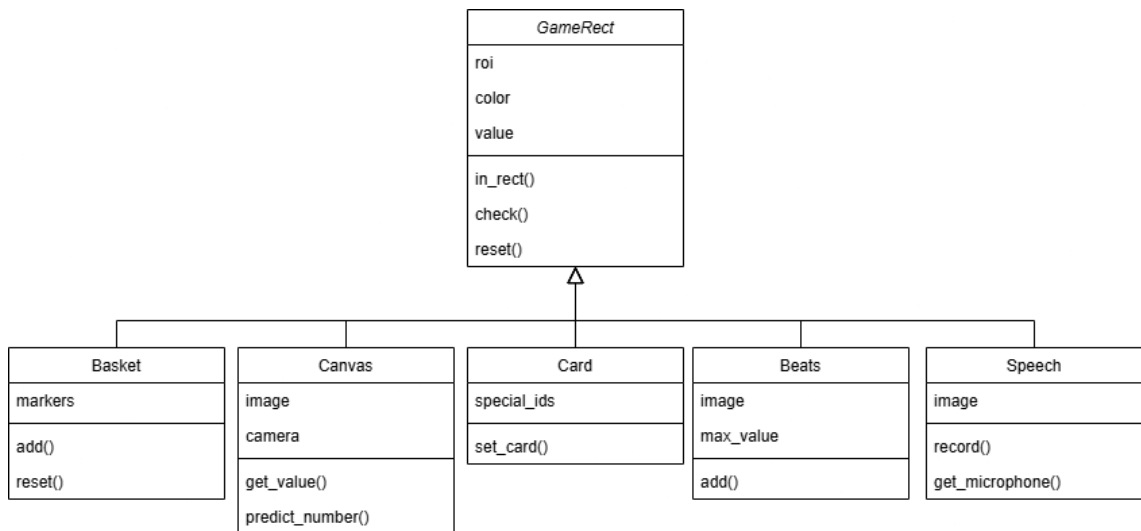


Figure 4.7: GameRect class diagram

4.3. INTERACTIONS AND MANIPULATIVES

Manipulatives are tangible objects that students can interact with physically, facilitating the integration of digital interactions within the application. These physical elements act as conduits through which the implemented digital features are operationalized.

The developed interactions are tied to the GameRect class, with each one reflecting a different type even if the medium used is the same. This way, the application can be expanded to include more interactions using the same physical media.

4.3.1. ARuco markers

ARuco markers are visual markers used in augmented reality applications to identify and track physical objects or locations. These markers consist of black and white patterns arranged in a specific configuration, which can be easily detected and recognized by computer vision systems. In our application, ARuco markers serve as tangible representations of elements in various educational activities, enabling interactive experiences such as counting, sorting, and identifying objects. ARuco markers are one of our most powerful means to turn physical objects into mixed media. By attaching them to any object, we can use their different characteristics: be it their id, their position in space, the angle of inclination, their bounds or their center, or anything else, to turn movement information into digital data.

The figure above 4.8 shows some ARuco markers being recognized by the camera with their ids showing. In this application, we have developed two distinctive interactions using these markers, but more could be implemented.

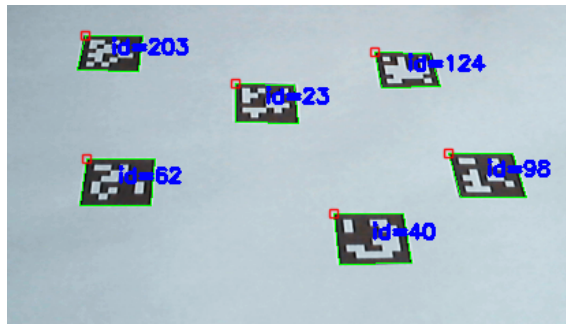


Figure 4.8: Aruco markers being identified by the camera

4.3.1.1. Markers as quantity

ArUco markers are a type of fiducial marker system widely used in computer vision applications. They are square black-and-white patterns that can be detected by cameras and identified by the application. Each shape has an id attached to it which can be used to attach functionalities to each one. The library recognizes not only the id but also the bounds of the markers and it's this function that is used for this type of interaction. More than caring about the singular id of each marker, this interaction focuses on how many markers are inside a GameRect and assigns this number as its value. Markers whose bounds are not completely inside the rectangle are ignored.

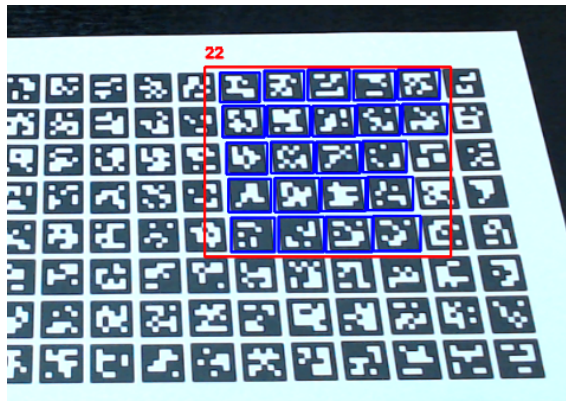


Figure 4.9: Camera recognizing the markers inside the specified rectangle. The value of the rect is shown on the top left.

Representing numbers as physical elements aids in the understanding that numbers are a representation of the real world and helps ground abstract concepts like mathematics to concrete concepts which kids are more receptive to in this cognitive level. Moving around the elements allows the child to add, subtract and even group elements as would be done with the four basic operations, associating the operations with actions done daily.

Figure 4.9 shows a GameRect of type Basket using this interaction. The markers inside the GameRect are counted and saved as the rect value while the markers outside the bounds are ignored.

4.3.1.2. Markers as cards

Another use for the ARuco library and its markers is to make use of their unique ids to create special cards. In this case, the markers are not used for their quantities but the

specific ids. We designate an interaction rectangle (GameRect) where a single card will be placed. More cards could be placed inside these bounds but this interaction is programmed to only recognize one at a time.

For this application, the cards from 0 to 10 have been kept as digit cards and recognized as such; however, special cards have been made for the comparison operators (less than, more than and equal to) in order to introduce kids to mathematical notation and operators, in this case, used when comparing quantities which is one of the main targeted abilities. Figure 4.10 shows a special operator being recognized while inside a GameRect.



Figure 4.10: Card special operator being recognized by the application

The cards offer a traditional, well-documented approach to establishing relationships between concepts. On one side they contain one representation of the concept and on the other side another one. Digit cards have the numeral on one side and an image representing its quantity on the other while operator cards have the mathematical notation on one side and its reading on the other. This physical relationship allows the students to identify them as representations of the same idea and be able to practice while the application is offline, which extends the time they are interacting with the concept to that outside of the runtime of the application.

4.3.2. Mouse button

A physical button has been used to replace the mouse for use in this application. The purpose of changing the shape of the mouse while retaining its function is to have an object that requires a greater movement and greater effort to function. The greater effort needed to press than to click the mouse engages more muscles not only in the finger but in the hand and arm which engages more neuronal pathways with a single movement. Compare the movement needed to click a mouse button to the movement shown in the following figure 4.11 to press a button. The increased area of contact and effort needed for this button engages more muscles in the body and, therefore, more neuronal pathways.

This manipulative has been included in the development to serve as a physical means through which digital interactions can be carried out. For this application, this mouse button has been included into two interactions: speech recognition and beat recognition. As for speech recognition, it serves as the trigger to activate the microphone capture feature. It serves a more involved purpose on the beat recognition



Figure 4.11: Movement needed to press the mouse button

interaction, where each press of the button increases a counter to match a specific sound pattern. Both of these interactions are described below.

4.3.2.1. Speech recognition

Speech recognition has been widely used in applications already, especially in language-learning applications, to check the user's pronunciation of a word. This technology has proven effective in providing immediate feedback and enhancing the learning experience. In the context of a math teaching application, integrating speech recognition allows the user to learn the verbal representation of the number, which pertains to the ability to identify and change between representations.

The technology behind speech recognition has been widely-worked on and its accuracy is fairly high, even accounting for different speaking accents. This proves to be especially useful when taking into account both native speakers who are just learning their words and bilingual students who may have some difficulty adapting to the sound of another language. In this way, speech recognition focuses on the pronunciation of the word regardless of the language, which helps the user focus on producing the sounds of the language properly. For the application, speech recognition is used only for the pronunciation of the reading of the numbers, however, this could be extended to verbalizing mathematical problems which would encourage users to articulate their thought processes, fostering deeper understanding and improving their ability to reason logically.

The Speech recognition interaction is implemented as a GameRect that on click activates the microphone in order to record the words of the user and then transcribe them into text that will be saved as a variable. This transcribed text is what will be compared to the answer to make sure the user pronounced the words correctly after listening to the application model it (through the use of gttts). If a user mispronounces a number or mathematical term, the system prompts them to try again, reinforcing correct pronunciation and understanding.

4.3.2.2. Beat recognition

Sonification is the act of transforming information into sound. Numbers can be translated into sounds be it through the volume, frequency, or, as in this case, beats. For this interaction, numbers have been converted to beats which the user must count be

it mentally or manually and then interpret into movement or visual representations on the screen.

A certain pattern of beats is played to the user. The beats are separated by short intervals of silence and then distributed into groups separated by large intervals of silence. The user must listen carefully and decipher when one group starts and ends and how many beats there are per group. This whole mental process includes more than one cognitive process: transforming auditory information into numerical one, differentiating between short and long intervals of time, and holding different and related numbers in memory all at once.

The GameRect for this interaction consists of a rectangle with an image that has a function attached. This function, on click, adds 1 to the value of the rect. This may or may not be visually represented though in the case of the developed activity it does not in order to force the user to mentally count how many beats he has input into each rect. The images can be clicked both with a mouse or with the button mouse but using the latter gives an added benefit of increasing the effort needed to produce the clicks and, with it, greater conscience of each event.

4.3.3. Handwriting recognition

One of the most important aspects of mathematics is mathematical notation. In order to represent the abstract concepts of the field, a detailed order of symbols and characters have been created. Mathematics is, in reality, a written endeavor. Even just the concepts of quantity have a symbolic representation known as indo-arabic numerals that every student must learn to not only identify but write as well. The act of writing the numerals may seem intuitive and a byproduct of learning to write but, just as when writing characters, if the required care is not taken into account, could lead to hard-to-decipher numerals at the least and problems in the resolution of problems at worst.

Writing by hand has been shown to be more effective at knowledge retention than typing or writing on a tablet because of the way the hand muscles increase the number of neuronal connections established while doing the writing. These neuronal connections help create more pathways to associate knowledge with. Learning to write by hand also helps kids learn how to distribute characters in space, which is helpful when learning the concept of place value and its importance in mathematics and its operations. Practicing numbers through handwriting (instead of, for example tracing with the finger on a screen), therefore, will be helpful not only to make clean, organized numerals but also to teach them how number distribution is important in problem solving. The following figure indicates how a user would interact with this type of GameRect when using the application.

For this application, a handwritten digit recognition has been developed using a Tensorflow model. As for the training data, the MNIST (a public, open-source handwritten characters database) has been used to train the model to recognize different types of handwriting although in this case only the digits have been taken into account. In order for this interaction to work, the user must write the character on a physical medium (be it paper or a whiteboard) inside a specified rectangle. Each rectangle identifies a single digit which means that if we want to work with numbers 10 or above, two or more rectangles will be needed. The scope of this particular project includes only single-digit numbers which is why the feature to connect the rectangles to form a single number is not implemented. The GameRect that reflects this interaction is known as a canvas.

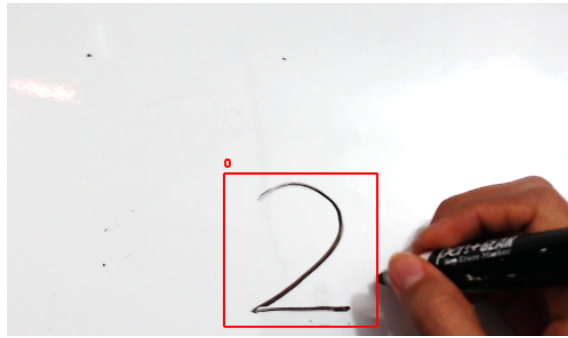


Figure 4.12: User writing a number inside the bounds of a Canvas GameRect.

In the case of this interaction, no manipulatives have been developed, as any white surface can serve as the medium. However, for OpenCV to recognize the number, the user must write the numeral in as clear a way as possible, centered and polished. This results in a good training for the user's writing in that numbers that are not well-written will be misread as something different and forces the user to improve their writing. To get the best results in the recognition, the numbers should be written on a matte white background (which is why the rectangles projected are white) with a bold black marker; the bigger the contrast between the background and the number, the more accurate the reading. This model, however, as every AI model, has a certain accuracy rate where some numerals will be misidentified regardless of how well-written they are. Figure 4.12 shows the preferred distribution of the number in the rect to optimize recognition.

4.4. STRUCTURE OF THE APPLICATION

This section offers a comprehensive view of the user experience flowchart and the software flowchart, crucial for understanding the systematic interaction between hardware and software components within the application.

4.4.1. Application flow diagram

In the development of an application designed to analyze user body movements, it is imperative that the audio, video, and interface dimensions operate continuously. These components must remain active to monitor user interactions effectively. To achieve this, it was determined that they would be integrated within a single main loop, ensuring synchronization among them.

This integrated system allows for seamless communication between the audio, video, and interface modules, enabling them to activate various functions managed by each component. The accompanying diagram illustrates the responsibilities of each dimension and the interdependencies triggered by user actions. The flow diagram 4.13 delineates the interaction dynamics among the different dimensions of the application in response to user interactions.

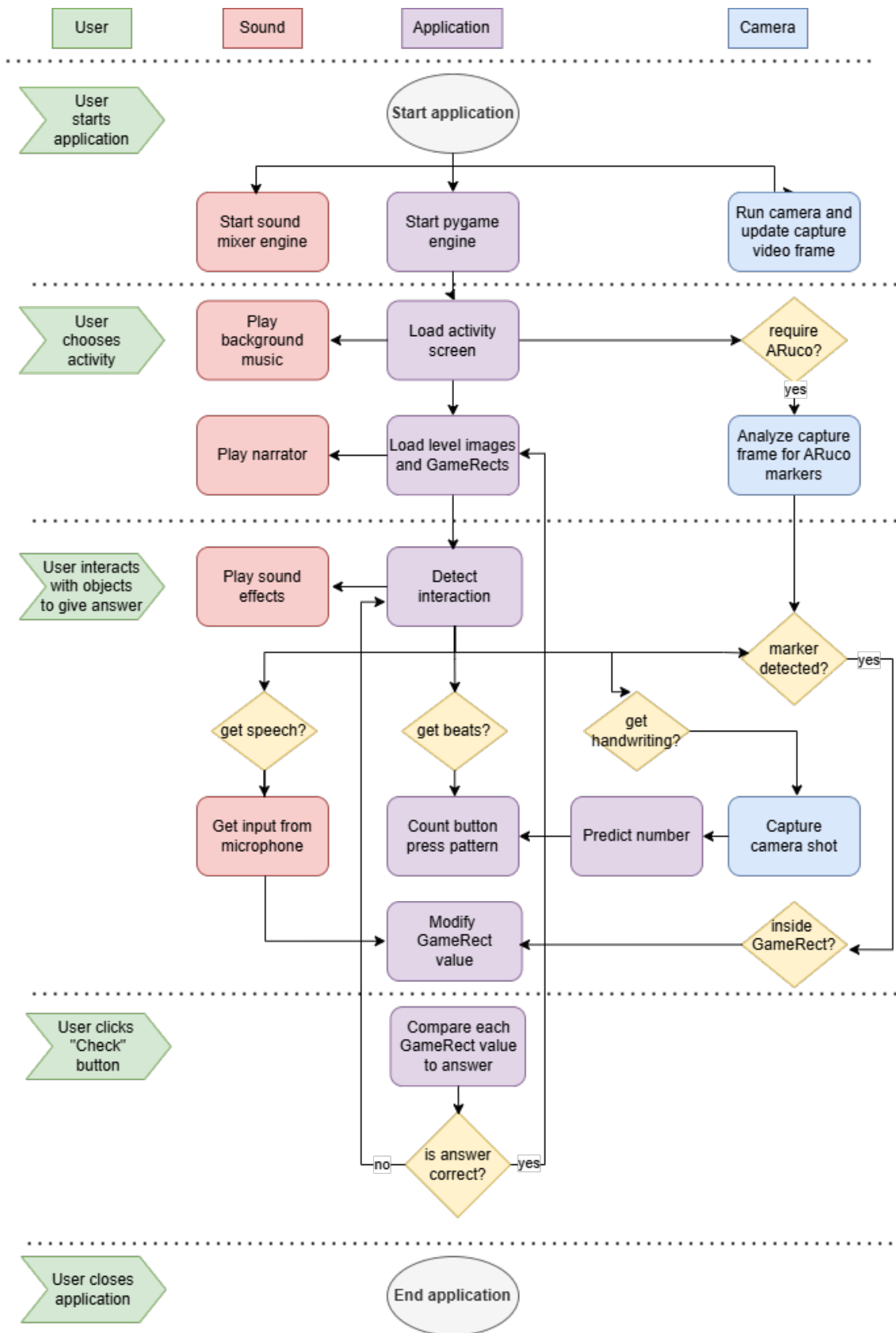


Figure 4.13: Software elements flow diagram

4.4.2. User flow diagram

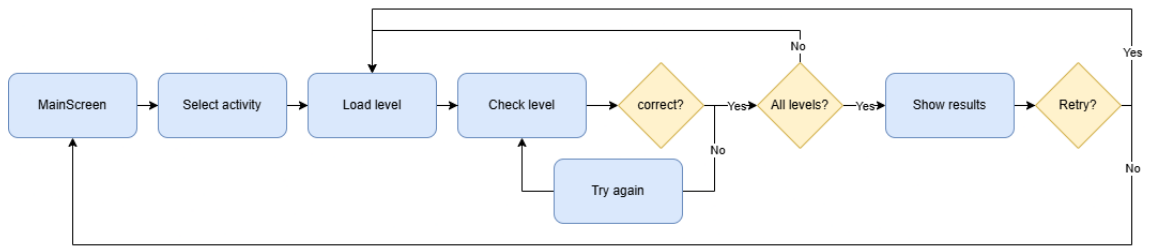


Figure 4.14: Flow diagram of the user experience of the application

This iteration of the application functions as a demonstration of the activities and interactions, with all activities being accessible from the outset. While the pedagogical development of academic skills and knowledge typically follows a specific sequence, this application does not adhere to such a sequence. The primary focus of this project is the development of the application itself, rather than the pedagogical methodology, which falls outside the scope of this work.

Consequently, the flow diagram represented in figure 4.14, exhibiting the user's experience within the application, is straightforward. Users can select an activity from the MainScreen, complete all levels within each activity, and then choose to either repeat the same activity or return to the MainScreen to select a different one. Between each level, users' answers are evaluated, and progression is contingent upon providing the correct response. The application calculates a score for each level based on the number of attempts required to obtain the correct answer. At the conclusion of each activity, the user is presented with their results before being given the option to retry the activity.

4.5. SCREENS

The application was developed in two iterations. The first iteration included the implementation of the designated interactions and a screen for each kind of interaction as a means of testing its usage. This iteration included the main screen and the first six activity screens in the following list.

The second iteration included the last three activities, which serve to exhibit different ways in which the main interactions can be used by expanding the number of GameRects to create more complex activities.

4.5.1. Main screen

The main screen of the application is where the user will select the activity they want to try.

Each item surrounded by a white border on the MainScreen is a button that leads to a corresponding activity where the idea of the button image is used as the basis of the minigame, all related to farm activities. Great care was taken to make sure the GUI is appealing to kids of the target age.

4.5.2. Reading numbers

This activity consists of the user looking at the visual representations of the number, both numerals and magnitude representations, on the screen and learning how to



Figure 4.15: Main screen where the user selects the activity

pronounce it. This is one of the introductory activities to introduce the number representations all at once before reinforcing each one in different activities. On each level, the screen shows both quantity and numeral representation. When a button is clicked, the user can listen to the pronunciation of said number and then they can click the other button to activate the microphone to speak into it. The program then decodes the audio to see if it matches the reading of the number.

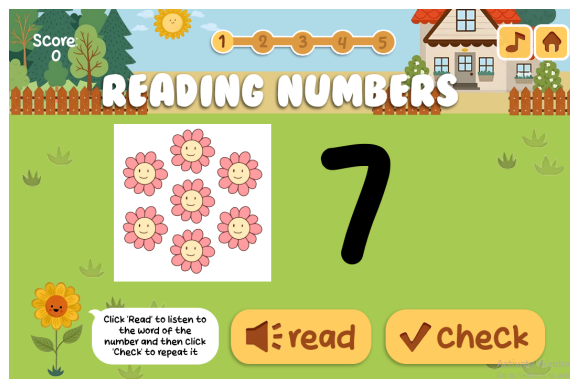


Figure 4.16: Reading numbers activity

4.5.3. Counting animals

The user must write by hand on the surface the screen is projected on the numeral corresponding to the number of animals on the screen. This activity targets the ability of “Identifying representations of numbers” and “writing numbers” in the way that the student must first identify the magnitude through the number of items on the screen and then associate it to the corresponding numeral representation.

4.5.4. Feeding Animals

The user must feed the adequate number of food items to the animals on the screen. The food items are represented by the ARuco markers and the user must manually move the markers into the designated rect until the markers inside the rect correspond to the number signaled by the screen. This activity targets the “identifying representations of numbers”, “representation of quantity” and “counting” abilities by making the user mentally or manually count the items to match the numeral on screen and represent the correct magnitude.



Figure 4.17: Counting animals activity



Figure 4.18: Feeding animals screen

4.5.5. Rhythm Cows

The user must follow a sequence of beats divided into 1-3 groups with 1-5 beats each. The application plays the beats and then asks the user to input the sequence by pressing a button. This activity helps develop the ability to count through sonification of the information, count both the beats as well as the time between them to differentiate them from the groups. The visual cues also help with the transformation of representations from visual to conceptual and to the identification of the quantity.



Figure 4.19: Rhythm cows screen

4.5.6. Sequence Truck

The user must identify the numbers in each of the truck wagons and complete the pattern according to the correct sequential order of the numbers. The user must use the

cards with the numbers to put the missing number by placing the card in the designated rectangle. This activity helps the user understand the concept of ordinality to know the order in which the numbers go according to their magnitude. The understanding of magnitude through the number of items is intuitive, however, the activity focuses on understanding ordinality of the numerals, which at the same time helps with the identification of different representations.



Figure 4.20: Sequence truck screen

4.5.7. Fruit Quantities

The student must identify which of the two shown quantities is greater than, equal to or less than the other. According to the prompt both written on the screen and said out loud by the narrator, the user must choose the right card from the comparison operator cards (more than, less than or equal to) and place it inside the designated rectangle. The application identifies the card and checks if it is the correct relationship. This activity is geared towards understanding magnitudes and the concepts of comparison (more, less, equal) which are usually intuitive. This also helps the students tie the concepts of comparison to the mathematical representation of the operators.



Figure 4.21: Fruit quantities screen

4.5.8. Adding baskets

The user must identify the quantities in each basket and write the number corresponding to said quantity in the canvases attached to each basket. After that, the user must add the two values to get the answer to the addition and write the numeral in the "total" canvas. On check, the application makes sure the values written are correct, both the

operands and the sum. This activity is an extension of the Counting Animals activity in that it shows how canvas type GameRects can be used for operations as well.

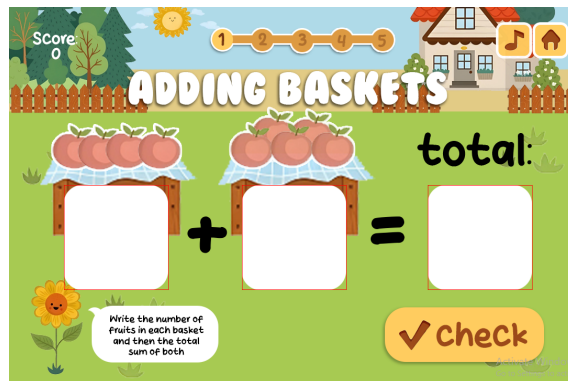


Figure 4.22: Adding baskets activity

4.5.9. Planting crops

The user must take the specified number of markers (called seeds in this instance) and place them in the GameRects in equal quantities so that the sum of both equals the number written on the screen. This is the principle of division from a real-life perspective. Basket type GameRects allow the user to understand the concept of division, which is usually referred to as “sharing” in early-age mathematics, through proprioception by mimicking the act of physically dividing the number of items into equal groups.

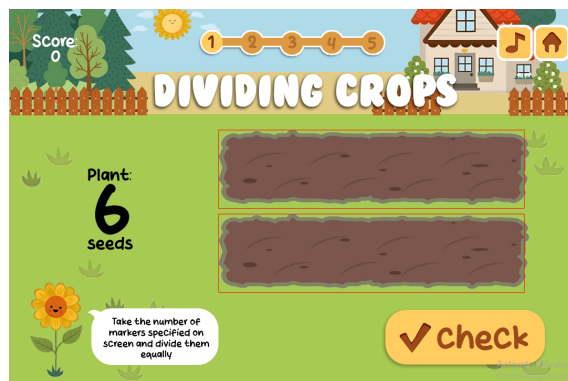


Figure 4.23: Planting crops activity

CHAPTER 5

Evaluation

This chapter outlines the evaluation methodology employed to assess the performance and usability of the software project. The evaluation was conducted based on four main criteria: the usage of physical elements, the recognition of physical elements, the recognition of handwritten numbers, and the intuitiveness of the interface. Each criterion was systematically evaluated using specific methods designed to yield comprehensive insights into the software's functionality and user experience.

5.1. PARTICIPANT SELECTION

The participants selected for the study were children aged 6 to 10 years from a bilingual background due to the language of the game being English. These children were chosen based on their ability to understand simple instructions in English and their exposure to or ongoing learning of basic English skills. For these children, the application serves as both an introduction and a reinforcement tool for mathematical learning in English.



Figure 5.1: One of the users interacting with the application

5.2. LOCATION AND EVALUATION CONDITIONS

The evaluations were conducted in the participants' respective homes rather than a single, controlled location. This decentralized approach necessitated that the setup be

adaptable to each user's home conditions, reflecting the real-world environments in which the application would typically be used. While this meant that the assumption of ideal conditions was not always met, it also provided valuable data on how the application performs in diverse settings. Figure 5.2 show how the whole environment was adapted to a user's room space between furniture. This shows how it is possible to adapt the hardware to the designated 1 meter square.

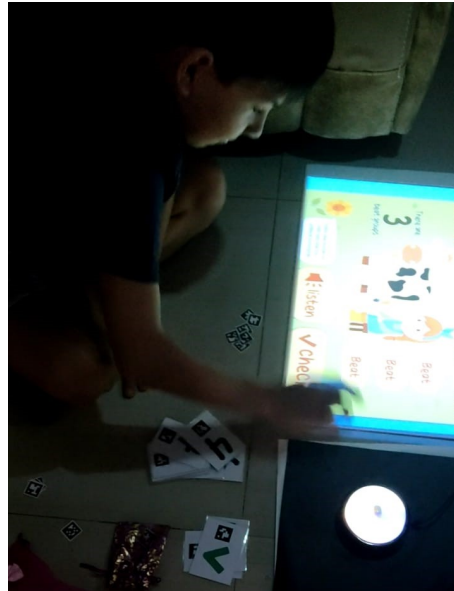


Figure 5.2: Example of the setup adapted to a small space in a user's house.

One significant finding was the impact of hardware constraints, particularly the camera resolution and projector potency, on the recognition of physical elements. The need to balance light conditions—ensuring the projector worked effectively while maintaining sufficient light for items to be visible—was crucial for an optimal user experience. This aspect highlighted the importance of considering environmental factors in the design and deployment of educational technology. It is also important to highlight that most, if not all, of the tests were carried out on the floor and not on a table as expected due to the projection distance of the projector at hand, which needed about a meter and a half to project an adequate size. This can be, however, shortened by using a projector with a shorter projection distance.

5.3. EVALUATION ITERATIONS

The evaluations were carried out in two distinct iterations to refine and improve the application based on initial findings.

The first iteration was carried out with three users at the same time. The tests were conducted in a somewhat open space where ambient light was hard to control which resulted in less than ideal conditions for the software to run: the projected image was not properly visible and this made the interaction with the application as the mouse pointer disappeared. The kids expressed a lot of frustration trying to properly navigate the interface and even when the interaction was managed by the developer, the camera recognition not working properly meant that the test had to be cancelled until proper conditions were met. After this iteration, changes were made to the software such as increasing the the pointer size and color to make it more visible and the setup was

adjusted to improve the camera recognition in the conditions expected for the next tests.

For the second iteration, the tests were translated from this initial space to each user's house in order to have more control over the space. However, this meant that the setup had to be adaptable to the different conditions in each user's location. Two of the users that had participated in the first iteration could not participate in the second but one of them plus other seven users participated in these tests.

In each test, the kids were made to play each activity once and the way they interacted with the activity and the manipulatives was observed. The whole session with each kid lasted around 30 minutes plus the time needed for the interview, which was around 10 minutes. All of the process was captured on video and further notes were taken whenever they showed a positive or negative reaction during the activity. The observation process focused strongly in three moments: the comprehension of the activity's instructions, the learning curve of each activity and the difficulties, if any, when trying to make the application work as intended through the manipulatives and hardware.

5.3.1. First iteration

In the initial round of tests, several issues were identified with the recognition of manipulatives. The software struggled to accurately identify correct answers, leading to frustration among the children as they had to repeatedly attempt to have their responses recognized. This challenge was largely attributed to sub-optimal hardware conditions, such as improper lighting and the distance between the camera/projector and the work surface.

During these initial trials, the spaces where the demonstrations were conducted were too open, making it difficult to control surrounding light. This affected both projection and video-capture recognition. Consequently, a few of these tests had to be rescheduled until a more suitable closed space was available. This does not imply that the software is completely unusable in open spaces; however, the light intensity must meet certain requirements for proper functioning. Figure 5.3 illustrates an example of a setup under natural light that meets these requirements.



Figure 5.3: Example of the setup under natural light

Due to hardware calibration errors and a lack of control over variables such as light and sound, some of these early tests resulted in frustration among the children when

the application did not produce the expected results.

5.3.2. Second iteration

Based on feedback from the first iteration, significant recalibrations were made to the hardware setup and software parameters. The distance between the camera/projector and the work surface was reduced, resulting in enhanced recognition of the manipulatives, including both markers and cards. These adjustments led to a noticeable improvement in the application's ability to accurately capture user interactions, thereby reducing user frustration and improving overall satisfaction.

During this iteration of tests, interactions still occasionally had trouble recognizing the physical elements, with a failure rate of approximately 10%. This can be attributed to hardware restrictions and, in some cases, environmental limitations. For example, users with pets found that the microphone would capture their movements during recordings, complicating speech recognition. Others found that the lighting in their rooms was not optimal for handwritten character recognition, leading to incorrect digit predictions. Figure 5.4 illustrates a non-optimal light configuration for handwritten digit recognition.

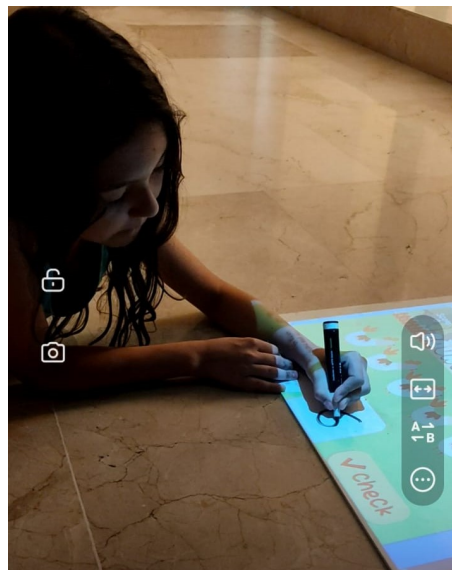


Figure 5.4: User writing the answer by hand as instructed by the activity

5.3.3. Interview

At the end of session, when they had gone through all of the activities, a spoken interview, also recorded, was made with each user. During the interview, the interviewer would go back through each activity with the interviewee and ask the user their opinion on the usability, the intuitiveness, and the difficulty of comprehension of both the interactions and the math concept being studied. After going through all the activities, a set of questions on the overall experience and enjoyability of the application was also included. The user would answer most of these questions on a scale from 1 to 5 translated into spoken words to take into account the users who still had trouble with the comparison of number magnitudes.

The first part of the interview focused on four aspects of each activity: ease-of-use, intuitiveness, enjoyability and comprehension. Ease-of use refers to how easy it is

to manipulate both physical and digital media to work with the application; intuitiveness refers to the relation between the physical media and the math concepts being addressed; enjoyability measures how much fun the felt during the activity; and comprehension if they felt the activity helped them understand the math concept, including what they had to solve, why the answer was wrong if it was and what they needed to do to correct their answer. The user would then answer questions like "How hard was it to get the cards to work well?" or "Did you understand how to solve the problem using the cards?" using a scaled appreciation system: not much (1), a little (2), more or less (3), good (4), very good (5).

The following table shows the average value awarded to each aspect of each activity:

Activities	Interaction	Ease-of-use	Intuitiveness	Enjoyability	Comprehension
Reading numbers	Speech	4	5	4	5
Counting animals	Writing	5	5	4	5
Feeding animals	Counters	5	5	5	5
Rhythm cows	Button	3	3	5	3
Sequence truck	Cards	5	5	5	5
Fruit quantities	Cards	4	4	4	3
Adding baskets	Counters	5	5	5	5
Dividing crops	Counters	5	4	5	4

Figure 5.5: Average qualification of the four evaluated aspects of each activity and its corresponding interaction according to the users.

The second part of the interview focused on general appreciations of the system and its application. This included appreciations about the design elements, the interface, and the possible uses of the system. The users would then answer Yes or No to each question.

The results of these appreciations are shown in the following diagrams:

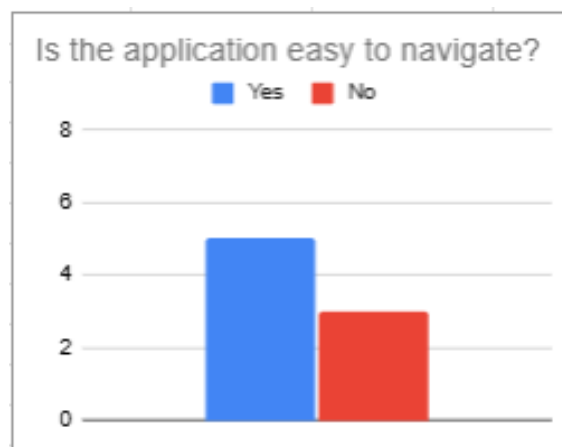


Figure 5.6: Answers to the question "Do you think the application is easy to use/navigate?"

The last part of the interview was a space for the users to give any kind of comment about the application. During this space, a lot of the users gave comments like "I really liked this game", "I wish instead of a farm it was about soccer" or "I want to have a

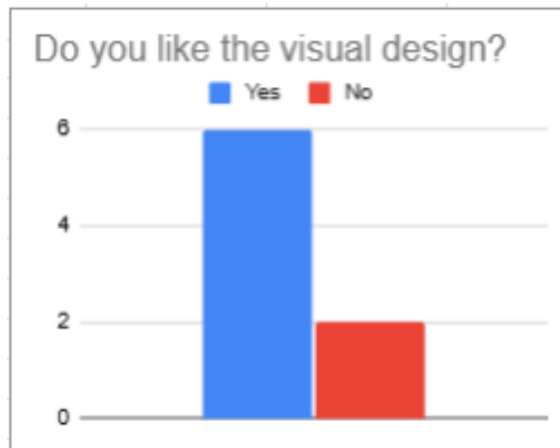


Figure 5.7: Answers to the question "Do you like the visuals and pictures of the application?"

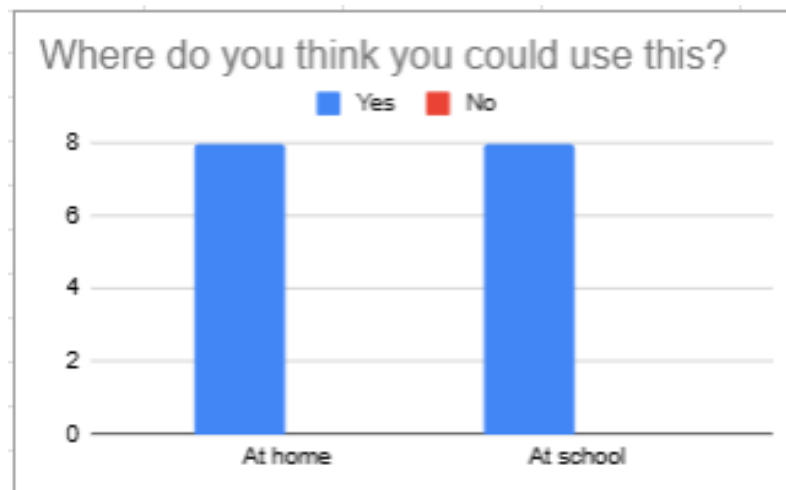


Figure 5.8: Answers to the question "Would you like to use a system like this at school/home?"

button like this for my computer". Overall, the comments portray that the users had a positive experience with the system.

5.4. OBSERVATIONS

The users thoroughly enjoyed the range of activities, engaging with each level and eagerly awaiting their results. They were particularly enthusiastic about using the manipulatives to solve problems and continued to use them during their spare time, outside of designated study periods. This behavior supports the idea that physical elements help students transfer knowledge from the lesson to other contexts. Figure 5.10 showcases users actively using the manipulatives to solve activities.

Although there was a learning curve for properly using the manipulatives, users quickly adapted after their initial use, making subsequent activities easier to manage.

The most challenging activities for users were the beat detection and quantity comparison tasks. The difficulty with the quantity comparison activity stemmed from the introduction of comparison operators, which were unfamiliar even to older children. This included both the symbols and the grammatical structure of expressions such

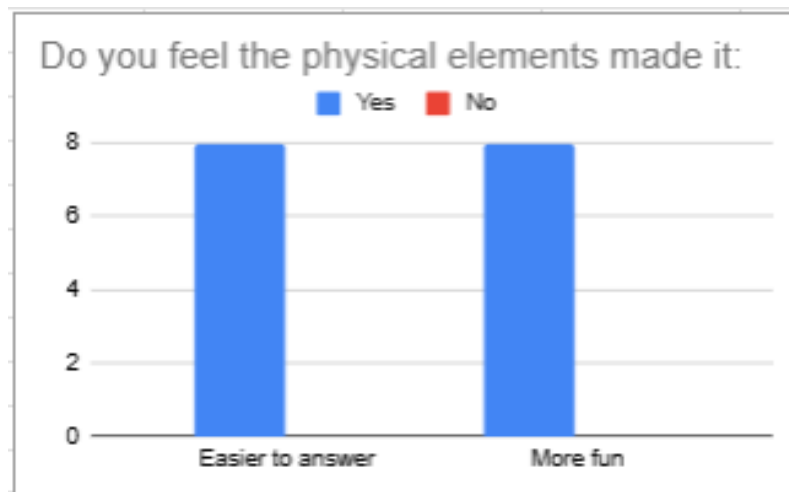


Figure 5.9: Answers to the question "Do you think the physical elements makes math more fun/easier to answer?"

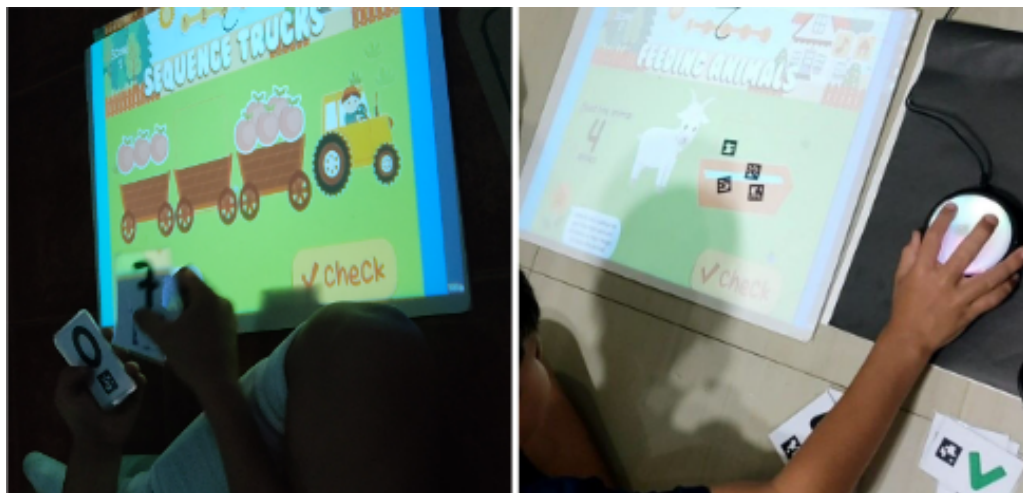


Figure 5.10: Users interacting with the manipulatives while looking for the answer

as "less than" and "greater than," making it difficult for users to identify the correct number despite understanding the logic of the operator symbol. Beat detection proved challenging because some children had difficulty distinguishing between short and long intervals or felt that the beats were too fast to count. These difficulties appeared to be more related to individual abilities rather than age, suggesting variability in personal aptitude.

Interestingly, the mouse button received a significant amount of attention. Despite being a minor change in the interaction method for a typical computer application, it had a notably positive effect on users. The colorful lights were appealing in the darkness required for the application, and the tactile feedback from pressing the button was enjoyable for the children. Some users even engaged their whole body in pressing the button, turning simple actions such as checking answers into an engaging experience. Figure 5.11 depicts a student excitedly pressing the button to check their answer.

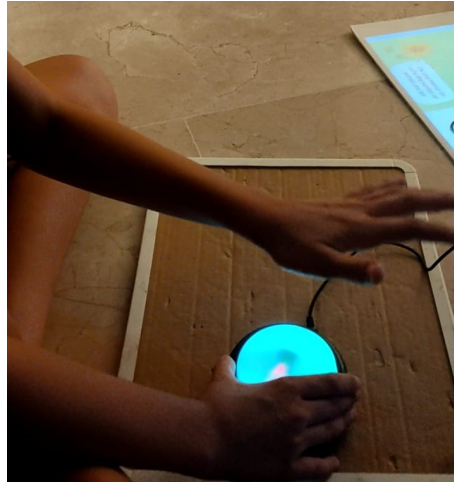


Figure 5.11: User enthusiastically using the mouse button

5.5. USER FEEDBACK AND RECOMMENDATIONS

Throughout the evaluation process, user feedback played a critical role in identifying areas for improvement. One recurring suggestion was the need for additional visual cues within the application to enhance user understanding of their interactions. Specifically, the application could benefit from more explicit visual indicators regarding the value of the GameRects, as users sometimes believed they were answering correctly but received negative feedback due to the application not capturing their actions accurately.

As of now, it appears the application needs to be developed more profoundly on the user guidance aspect. As of now, the application is easy to use for users of the target ages as long as they have an adult knowledgeable in the use of the application to answer their questions where the application comes short. However, it appears that the interactions are easy to understand for the users. The learning curve of each interaction is only difficult in the same level as it is difficult to get the software recognition aspects to work.

By integrating more intuitive visual cues and refining the feedback mechanisms, the application can better align with users' expectations and improve their learning experience. This iterative process of evaluation and adjustment underscores the importance of user-centered design in developing educational technology that is both effective and engaging.

5.6. RESULTS

The results show a clear improvement in the user engagement and enjoyment of the math activities when compared to similar traditional paper-only activities.

The need to improve learning through digital media has motivated this journey. The proper use of technology for learning must align with the principles humans apply in any learning experience. One of the fundamental principles of pedagogical design is to create learning scenarios that direct students' attention, balancing the minimization of distractions with the enhancement of active participation and choice.

In the classroom, attention can be oriented through various means, making it crucial to evaluate teaching strategies, the level of cognitive engagement, the educational setting, task adjustment, and the type of interaction with the learner. Modulating the

learner's attention to different features can lead to varied learning approaches and subsequently elicit different patterns of neural activity.

The combination of physical movement, hands-on activities, and interactive digital tools described in this project has fostered a dynamic learning environment that enhances attention, engagement, and retention in the learning of number sense. Tailoring the different games and activities to students' ages and grades was a key factor in strengthening their effectiveness. The designed learning scenarios leverage optimal conditions to ensure a more efficient process of encoding and retrieving knowledge. However, evaluating and concluding on the level of conceptual transformation and long-term encoding of number sense would require a study focused solely on that topic.

Additionally, the following benefits were evident:

- Provides good scaffolding: Interactive systems provided step-by-step guidance and support to students as they progressed through more complex concepts.
- Integrates error as part of learning: The system embraced error as a critical component of the learning process.
- Offers an adaptive learning systems These systems adapt to the individual student's pace and level of understanding, keeping students challenged but not overwhelmed.
- Contextual learning: Embedding mathematical problems within stories or real-life scenarios made abstract concepts more concrete and engaging.
- Interactive narratives: Interactive stories, where students made decisions or solved problems influencing the outcome, increased engagement and motivation.

In conclusion, integrating human-machine interactive systems in education offers substantial didactic and pedagogical benefits. These systems enhance conceptual understanding, engagement, and retention while providing personalized, differentiated instruction. They also foster collaborative learning, improve teacher efficiency, and build student motivation and confidence. Overall, such interactive systems contribute to a more effective and enjoyable learning experience.

CHAPTER 6

Conclusions

6.1. GOALS ACHIEVED

It could be said that the initial goals, which included developing an interactive application for enhancing mathematical learning and engagement, were satisfactorily achieved. The project successfully integrated digital tools with physical manipulatives, offering a hybrid learning experience. This combination allowed users to benefit from the tactile engagement of physical objects and the dynamic interaction of digital tools to make learning more enjoyable and effective compared to traditional paper-based methods or screen-only applications.

The interactive nature of the application encouraged active participation, making learning more dynamic and less monotonous. It also demonstrated a positive impact on the encoding of mathematical concepts, providing a more engaging and supportive learning environment. Interactive and multimedia elements helped users, particularly children with attention issues, to better grasp and retain numerical concepts. The interactive elements and multimedia content helped maintain their focus and interest, leading to improved learning outcomes. The use of visual aids, audio prompts, and interactive tasks helped facilitate a deeper understanding of the material.

User feedback indicated a significant increase in engagement and enjoyment while using the application. Metrics such as user engagement, concept retention, and overall satisfaction showed significant improvement when using the application.

Overall, the project achieved its objectives by creating a tool that not only made learning mathematics more enjoyable but also more effective, particularly for children with learning challenges. This success is attributed to the thoughtful design and implementation of interactive and multimedia elements tailored to the needs of young learners.

6.2. FUTURE AND DERIVED WORK

The development of the interactive mixed media system for teaching numerical concepts to primary school children has shown promising results. However, the application primarily served as a demonstration rather than a structured learning sequence. To build on this foundation, several areas warrant further exploration.

Firstly, comprehensive pedagogical studies should assess the long-term impact on student learning, comparing this system with traditional teaching methods. Developing a full curriculum, including lesson plans and assessment tools aligned with educational

standards, would facilitate classroom adoption and provide a structured pathway for students.

Scalability and adaptability are crucial. The system should be tested in diverse educational contexts, ensuring it remains effective across different age groups, cultural settings, and educational needs. Incorporating advanced features like adaptive learning algorithms could personalize the experience and address individual student needs.

Exploring collaborative learning features could foster a more engaging environment, allowing students to work together, share progress, and learn from each other. Longitudinal studies tracking students' progress over several years would provide valuable data on the long-term benefits and areas for improvement.

Finally, continuous feedback and iteration are vital. Engaging with educators, students, and parents to gather feedback will help refine the system, ensuring it evolves to meet users' changing needs.

In summary, while the initial development has demonstrated potential, further research and development are necessary. By focusing on pedagogical studies, curriculum integration, scalability, advanced features, collaborative learning, longitudinal studies, and continuous feedback, future work can enhance this innovative approach to teaching numerical concepts.

6.3. PERSONAL CONSIDERATIONS

Working on this dissertation has been an enriching experience. Developing the interactive mixed media system for teaching numerical concepts to primary school children has significantly shaped my understanding of educational technology.

One of the most rewarding aspects was seeing the enthusiasm of the children using the application. Their positive responses reinforced my belief in the power of technology to enhance learning. This experience has deepened my commitment to innovative educational solutions and inspired me to pursue further research in this field.

Designing an educational tool that is both effective and user-friendly required careful consideration and iterative testing. This taught me the importance of user feedback, patience, and persistence. Collaborating with educators and experts provided invaluable insights and highlighted the importance of interdisciplinary teamwork.

Reflecting on this journey, I am grateful for the support of my mentors, peers, and family, their encouragement kept me motivated. Being able to use my work experience as both a teacher and a software developer to create a product that seeks to help build a new path for education has been an incredibly rewarding experience. I hope this work may serve as inspiration for even greater things from those who share a passion for education and technology.

REFERENCES

- Ackerman, R., Sidi, Y., y Ophir, Y. (2016, 04). Generalizing screen inferiority - does the medium, screen versus paper, affect performance even with brief tasks? *Metacognition and Learning*, 11. doi: 10.1007/s11409-015-9150-6
- D., R. (2022). Education reform: What trends can we expect in 2023. part ii. *MSc SmartEd Tech, Co-Creativity and Digital Tools for Educational Innovation, Université Côte-d'Azur.*
- D., R. (2024). The evolution of hardware and software in education: What is the next step? introduction to research. *MSc SmartEd Tech, Co-Creativity and Digital Tools for Educational Innovation, Université Côte-d'Azur.*
- F. R. (Ruud) van der Weel, S. B. A., y van der Meer, A. L. H. (2019). Infants' brain responses to looming danger: Degeneracy of neural connectivity patterns. *Ecological Psychology*, 31(3), 182–197. Descargado de <https://doi.org/10.1080/10407413.2019.1615210> doi: 10.1080/10407413.2019.1615210
- Henriksen, D., Creely, E., Henderson, M., y Mishra, P. (2021, 01). Creativity and technology in teaching and learning: a literature review of the uneasy space of implementation. *Educational Technology Research and Development*. doi: 10.1007/s11423-020-09912-z
- Hornigold, J. (2021, November). How important is number sense? (turns out, very). *Maths, no problem!*. Descargado de <https://mathsnoproblem.com/blog/teaching-practice/number-sense>
- Kasterko, D. (s.f.). Why developing proprioception might be the most important step to overcoming specific learning disabilities. *Learning Success*. Descargado de <https://www.learningsuccesssystem.com/system/proprioception>
- Luigi F. N. Y. S. P. M. G., Cuturi, Giulia Cappagli. (2022, Oct 21). Informing the design of a multisensory learning environment for elementary mathematics learning. *Springer Link*, 16, 155-177. doi: 10.1007/s12193-021-00382-y
- Manches, A., y O'Malley, C. (2016). The effects of physical manipulatives on children's numerical strategies. *Cognition and Instruction*, 34(1), 27–50. Descargado de <https://doi.org/10.1080/07370008.2015.1124882> doi: 10.1080/07370008.2015.1124882
- Nemirovsky, R., Borba, M., DiMattia, C., Arzarello, F., Robutti, O., Schnepf, M., . . . Scheffer, N. F. (2004). Introduction: Pme special issue: Bodily activity and imagination in mathematics learning. *Educational Studies in Mathematics*, 57(3), 303–321. Descargado 2024-07-01, de <http://www.jstor.org/stable/4150293>
- Poincaré, H. (1963). *Mathematics and science: Last essays (dernieres pensees)* (J. W. Bolduc, Traduc.). New York: Dover Publications, Inc.
- Team, G. E. M. R. (2021). Global education monitoring report summary, 2021/2: non-state actors in education: who chooses? who loses? *UNESCO Report*, 31. Descargado de <https://unesdoc.unesco.org/ark:/48223/pf0000380076> doi: ED-2021/WS/38
- Van der Weel, F. R. R., y Van der Meer, A. L. H. (2024). Handwriting but not typewriting leads to widespread brain connectivity: a high-density eeg study with implications for the classroom. *Frontiers in Psychology*, 14. Descargado de <https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2023.1219945> doi: 10.3389/fpsyg.2023.1219945
- Wang, X., Chen, L., Liu, X., Wang, C., Zhang, Z., y Ye, Q. (2023, Mar 9). The screen inferiority depends on test format in reasoning and meta-reasoning tasks. *Front*

Psychol, 14, 067577. doi: 10.3389/fpsyg.2023.1067577
Way, J. (2005). Number sense series: Developing early number sense. *University of Cambridge, Nrich Mathematics*. Descargado de <https://nrich.maths.org/2477> (Revised 2014)