Reinforcing Inclusive Education with Virtual Reality: Strengthening Knowledge with the STEAM Approach for Students with Disabilities

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Abstract

This study explores the development of a virtual reality (VR) application for inclusive education, applying the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach to enhance learning for students with disabilities. Conducted at the Care Centers for Students with Disabilities (CAED) at CBTis 168 in Aguascalientes, Mexico, the research involved 18 students using Oculus Quest 2 devices to evaluate the application. A detailed statistical analysis, including a paired Student's t-test, was conducted to assess the impact of the VR application. Observations and feedback indicated increased motivation and engagement, and statistical results confirmed a significant reduction in task completion times ($p = 0.02416$), demonstrating that the VR application effectively enhanced students' problem-solving efficiency. While the effect size was categorized as small, its significance validates the positive influence of VR on learning outcomes. The iterative development process, guided by continuous user feedback, ensured accessibility and usability improvements. The study highlights the strong potential of VR in inclusive education by fostering engagement and improving task performance. Future research will expand VR content and explore long-term studies to further substantiate its educational benefits and broader applicability.

Keywords
STEAM, Inclusive education, Virtual Reality, Disability, Personalized learning.

1. Introduction

Inclusive education poses a relevant challenge for institutions at the baccalaureate level, which strive to adopt new educational strategies daily [1]. Inclusive education faces significant challenges, such as the need to train teachers and improve infrastructure, but it also offers opportunities to transform barriers into benefits through collaboration between institutions and public policies [2], there are still areas where there is room for improvement, especially in terms of learning and motivation to participate in academic activities. The STEAM [3] (Science, Technology, Engineering, Art, and Mathematics) approach presents itself as an innovative solution to address these challenges.

Educational inclusion aims to ensure that all students have access to quality education, regardless of any disabilities they may have. This has led various groups to develop applications that support educational processes. Despite these efforts, significant barriers remain due to a lack of adequate technological tools to meet the diverse needs of students with disabilities. This limitation hinders their learning and development opportunities, resulting in a noticeable gap in education compared to students without disabilities.

STEAM education combines traditionally separate disciplines into an interdisciplinary approach. This orientation seeks to enhance students' critical thinking, problem-solving skills, and creativity by implementing the areas involved in such an approach: science, technology, engineering, art, and mathematics into a single educational approach [3]. By incorporating artistic and creative elements into the teaching of technical disciplines, STEAM seeks to make learning more engaging and relevant to students.

Inclusive education is greatly benefited by the STEAM approach because it enables the use of teaching strategies to meet the needs of students with disabilities. In the project we present, we try to develop a prototype for the use of virtual reality, using the STEAM framework, to provide academic assistance for specific areas for individuals with disabilities.

The main objective is to solve difficulties, such as the reduction of motivation and the consolidation of knowledge about the previous stages in which the student is studying, so that students can overcome doubts that can hold them back. In theory, this project is beneficial to all students with disabilities, however, those with mental and psychosocial deficiencies will benefit the most.

Specific objectives include identifying challenging subject areas and analyzing the impact of disabilities on equipment usage (e.g., VR headsets and controllers), determining the application's scope by specifying the disabilities and subjects to support, selecting suitable development tools to enhance assistive device usability, designing an accessible and intuitive user experience with creative elements, creating adaptable virtual environments with robust accessibility features (such as voice dictation and captions), planning intervention processes to validate methodology and user experience, and establishing a continuous improvement process using user feedback and practical tests with disabled students, applying Design Thinking for inclusive and effective experiences.

The project will serve as a didactic support for students in the open high school education modality of the Attention Centers for Students with Disabilities (CAED for its Spanish acronyms). By participating in interactive virtual activities, students can improve their motivation, attention, and academic performance. This increases their prospects for success, whether entering the job market or continuing their higher education.

The CAED are classrooms adapted to offer an opportunity to carry out upper secondary education studies to students with visual, motor, cognitive, auditory, and psychosocial disabilities [4]. Currently, these centers have a good amount of teaching resources such as audiobooks, glossaries of Mexican sign language, braille texts, multimedia resources, specialized software, rulers, punches, thermoformed materials for high and low relief, among others.

CAEDs have strived to improve their teaching methods over time, but there are significant limitations when relying solely on conventional strategies that have been used for many years. These barriers arise for various reasons, including a lack of staff trained in diverse teaching methods, sign language, and educational psychology, among others. As a result, there are far fewer teachers compared to the number of students, especially considering that students in CAEDs require much more individualized attention than those in the traditional school system.

The Mexican law "Ley General para la Inclusión de las Personas con Discapacidad" [5] outlines 11 principles in Article 5, page 5, that public policies must adhere to ensure proper inclusion of people with disabilities in any institution, including educational ones. These principles are:

1. Equity.
2. Social Justice.
3. Equal opportunities.
4. Respect for the evolving capacities of children with disabilities and their right to preserve their identity.
5. Respect for inherent dignity, individual autonomy, the freedom to make one’s own decisions, and independence of persons.
6. Full and effective participation and inclusion in society.
7. Respect for difference and acceptance of disabilities as part of human diversity and condition.
8. Accessibility.
9. Non-discrimination.
10. Equality between men and women with disabilities.
11. Mainstreaming.

This chapter is organized as follows: a general description of the content of the chapter is provided, then, the background of the topic is presented, the project objectives and expected results are described based on the STEAM approach applied. Then, related work on the application of emerging technologies in inclusive education is reviewed. The rationale section defines key concepts related to the "design thinking" methodology and the "STEAM" approach and describes adapted procedures. This chapter ends with some results, conclusions, suggestions for future work and thanks to the institutions that supported this research.

2. Related Works

Previously, several works have been developed related to the application of virtual reality technologies to support students with specific disabilities. Two of them will be mentioned below that focused on young people with Attention-Deficit-Hyperactivity-Disorder (ADHD), as well as another that used augmented reality in rehabilitation activities.

Table 1. Related works in learning support for people with ADHD.

Work	Applied technology	Benefits obtained
A Lean UX Process Model for Virtual Reality Environments Considering ADHD in Pupils at Elementary School in COVID-19 Contingency [6]	Project developed to create an application that implements a virtual reality environment on Android devices, allowing elementary school students to interact with activities by following a series of instructions provided by a Non-Player Character (NPC) within the virtual environment.	They identified how many times each student needed to review the instructions to assess their level of attention, while contributing to enjoyable and fun learning in the fields of education, health, and technology.
Development of virtual reality rehabilitation games for children with attention-deficit hyperactivity disorder [7]	Development of an application designed to be used in HTC VIVE viewers, which presented interactions aimed at promoting motor coordination in children with ADHD.	Improved attention, cognitive skills, and abstract reasoning.
Using Augmented Reality and Gamification to Empower Rehabilitation Activities and Elderly Persons. A Study Applying Design Thinking [8]	Combined augmented reality and gamification system in an application to support rehabilitation activities for people with disabilities.	The data collected using the application can be visualized by therapists, who will be able to identify the effectiveness of the support provided and determine what strategies can be applied to improve concentration.

The articles mentioned at table 1 were discovered through a systematic search of various academic sources following the guide provided by J. Vilanova [9], this search was specifically focused on publications that concurred with our research goals. This extensive review process not only advised us on the proper course of action, but also inspired us. Through this analysis, we intended to identify effective methods of designating educational strategies that would facilitate student interaction with modern and pertinent technology, including virtual reality. Notably, the projects examined have a focus on individuals with ADHD, this is a disability that is prevalent among CAED students, as a result, it is pertinent to take inspiration from these projects to create a reference point.

Table 2. Applications developed using the STEAM approach.

Features\Application	Application under development	Tinkercad [10]	Scratch [11]	Minecraft Education Edition [12]	GeoGebra [13]	CoSpaces Edu [14]
Focus on Inclusive Education	X					
Emphasis on empathy with the users.	X		X			
Customization and adaptability	X	X		X		X
Integrated STEAM tools	X	X	X	X	X	X
Active and participatory learning	X	X			X	
Collaboration and communication	X		X			
Evaluation and follow-up	X					
Receives feedback for constant improvement	X			X		
Makes use of Virtual Reality						X
It has constant updates	X	X	X	X	X	X

Some projects where the STEAM approach is used and the characteristics that they include in comparison with the application under development in this work can be observed (Table 2).

3. Theoretical Foundations

This section delves into the essential theoretical underpinnings that form the basis for understanding and applying interconnected concepts in the realms of education and technology. Five key areas are explored: STEAM (Science, Technology, Engineering, Arts, and Mathematics), Educational Applications, Virtual Reality, Design-Based Learning (Design Thinking), and the application of these approaches to students in Centers for Attention to Students with Disabilities (CAED).

3.1. STEAM

The STEAM approach is an interdisciplinary educational method integrating science, technology, engineering, arts, and mathematics [15]. Its primary objective is to cultivate students' creative and problem-solving abilities for real-world applications [16]. Key components and objectives include:

- Science: Focus on natural phenomena, scientific method, and knowledge acquisition in biology, chemistry, physics, fostering observation, investigation, and critical thinking skills.

- Technology: Emphasis on understanding and utilizing digital technology, software, hardware, and digital resources for information collection, analysis, and presentation.

- Engineering: Application of scientific and mathematical principles to design practical solutions, engaging students in problem-solving projects to develop design, logical thinking, and problem-solving skills.

- Art: Integration of creativity and artistic expression into the STEAM process through exploration of various art forms, fostering creativity, aesthetic appreciation, and visual communication.

- Mathematics: Essential for quantitative measurements, aiding in addressing complex problems by developing skills in data analysis, modeling, and informed decision-making.

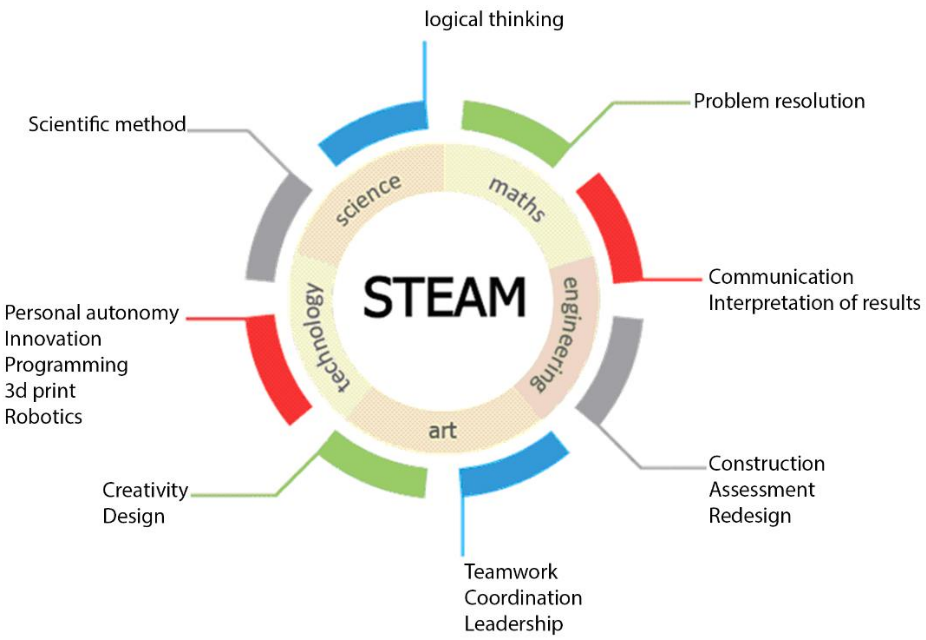

Figure 1: Education outline STEAM [16]

3.2. Inclusion

Inclusion refers to the practice of ensuring equal opportunities, rights, access to the same resources, and social benefits, regardless of individual characteristics. This involves removing obstacles that can marginalize certain individuals based on gender, race, sexual orientation, ethnic origin, disability, religion, etc.

In the academic context, educational inclusion focuses on ensuring that all students, including those with special needs and/or disabilities, could fully participate in the educational process alongside their peers without such conditions. This requires adapting teaching methods, the physical environment, and resources to meet individual needs, such as using the most effective learning methods for each student.

3.3. Educational Applications

Emerging technologies in the educational arena, such as Kahoot, ClassDojo, Khan Academy, and Duolingo, have transformed traditional learning materials. These applications, through interactive activities, provide hands-on experiences, enhancing understanding of the subject matter and complementing traditional learning materials [17].

3.4. Virtual Reality

Virtual Reality (VR) is a technology that generates a three-dimensional digital context in real time, providing immersive experiences through visual, auditory, and sometimes haptic components. It can replicate real-life or fictitious environments, allowing users taking some interactions with different objects in a virtual environment. VR is part of "Extended Reality Technologies" (XR), including Augmented Reality (AR) and Mixed Reality (MR) (see fig. 2) [18].

Virtual reality has numerous areas of application, such as the medical field, architecture, Industry 4.0, tourism, military, education, commerce, marketing, and many others. In these areas, virtual reality plays a crucial role in making processes simpler and more precise, which would otherwise be longer and more time-consuming without these tools. For example, it enables remote medical consultations or even surgeries with the support of remotely controlled robots, three-dimensional modeling overlaid on the real environment with the help of mixed reality, real-time analysis of industrial elements using information overlay on the real environment, and simulators for flight, combat, aquatic vehicles, etc.

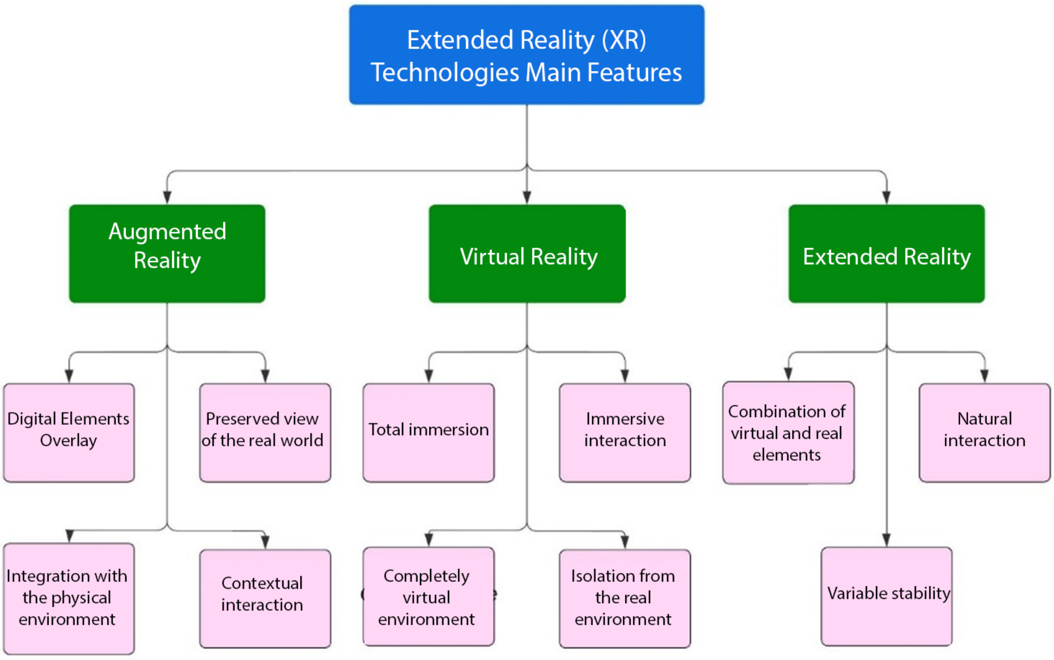

Figure 2: Main features of Extended Reality Technologies

3.5. Disability

Disability is defined as an impairment or difficulty that a person has in performing activities that people typically do with ease [19]. These activities can be classified into various types: cognitive (learning, remembering, or concentrating), motor (walking, climbing, using hands and arms, bathing, dressing, or eating), visual (seeing), psychosocial (performing daily activities due to emotional or mental problems), and auditory (hearing). In the case of speaking or communicating, it overlaps with various types and depends greatly on the individual's symptoms to determine the specific disability.

3.6. CAED

Centers for Attention to Students with Disabilities (CAED for its Spanish initials) address the unique needs of students with disabilities. These centers, distributed across the country, cater to visually, hearing, or mentally impaired students [20]. Educational tools like audio books, sign language dictionaries, and Braille keyboards are provided. The educational program consists of twenty-two modules in communication, social sciences and humanities, experimental sciences, and mathematics (see figure 3).

Figure 3: Educational content modules based on STEAM of the CAED curriculum [20]

3.7. Design Thinking

The approach we will use is based on a fusion of the STEAM together with the Design Thinking methodology [21]. This iterative process is commonly used in various fields, particularly in software engineering. With this model, the needs to be addressed are obtained directly from the users' perspectives, allowing the generation of innovative solutions that meet the required functionalities and address the users' requirements.

The methodology consists of five main phases: empathize, define, ideate, prototype and test [22]. These stages can be performed in a specific order, but it is possible to return to a previous phase or jump to another; they are not performed to obtain a result from the beginning, but with the intention of performing them several times to polish each stage to improve the product in each iteration. The latter is the main objective of the methodology to be employed [23].

4. Integration of the STEAM Approach to the Design Thinking Methodology

Regarding the problem of developing innovative technological applications for the inclusive education of students with disabilities, a development model focused on the creation of inclusive educational content is proposed. This model's main objective is to ensure that educational tools and resources are accessible and effective for all students, regardless of their abilities or limitations.

In the context of the integration of STEAM methods into Design Thinking methods, we are faced with a challenge of great relevance: to develop an inclusive educational application as an important support tool in the educational process of students with disabilities. This situation arises from a widespread need to create innovative and effective educational solutions that address the barriers and challenges faced by students with disabilities when seeking a quality education.

Integrating the STEAM approach into the development of an inclusive education application can provide a few significant advantages that go beyond the simple delivery of educational content. These advantages can positively impact the student experience and the effectiveness of the learning process. Some of the key advantages are described below:

1. Stimulation of creativity and curiosity: Including artistic and design elements in the application can stimulate students' creativity and arouse their curiosity. The incorporation of attractive visual and graphic elements can make the learning process more motivating.
2. Deeper Understanding: By incorporating aspects of Science, Technology, Engineering and Mathematics, the application can provide a solid foundation for understanding educational concepts. The mathematical and scientific aspects can support students in learning to approach topics in a deeper and more analytical way.

3. Interactivity and engagement: Technology can enable active student interaction with educational content. Interactive elements, such as simulations, games, and hands-on activities, can improve student engagement and facilitate a more practical understanding of concepts.
4. Personalization and adaptability: Technology allows the personalization of content, which is essential in inclusive education. The application must be designed with the ability to adapt to the individual needs of each student [24].

One of the limitations of Design Thinking is its tendency to prioritize human-centered design at the expense of technical feasibility and interdisciplinary depth. By integrating the STEAM approach, these gaps are effectively bridged. The inclusion of scientific and mathematical principles ensures a robust analytical foundation, while engineering and technology provide the tools for practical implementation. Art infuses creativity and innovation, making solutions not only functional but also engaging and aesthetically pleasing. This interdisciplinary synergy enhances the overall quality and inclusiveness of educational applications, addressing both the diverse needs of students and the complex technical challenges involved.

It is necessary to make certain modifications within the stages to achieve a good integration of the approach and methodology used, based on both schemes (Fig. 1 and 3):

- Define the challenge and Empathize: Start by clearly defining the challenge that the application seeks to address. What problem is it trying to solve? What is the main purpose of the application? Then, a solid empathy stage is performed, involving the future users of the application, including those who may have disabilities or specific needs. Understand their perspectives, challenges, and needs [25].
- Ideate and Design: In the ideation stage, a multidisciplinary team is assembled that includes experts in Science, Technology, Engineering, Art, and Mathematics. Each participant will bring important perspectives to the design process. encourage the team to creatively come up with innovative ideas to address the primary and secondary challenges that have been defined in advance. Combine artistic creativity with mathematical logic and technological capabilities to design application concepts [26].
- Testing and prototyping: Develop utility models that contain STEAM features. This may include incorporating visual components that are interesting, technology relationships that are advanced, and math considerations that support usability. Conduct testing with credible users, including those with disabilities, to get feedback and ensure that the application is accessible and productive for all.
- Implement and Evaluate: Use engineering and technology skills to create the application effectively and ensure that it adheres to quality parameters. Launch the application and perform constant evaluations to determine its influence and quality in solving its assigned problem [27].
- Improve and Iterate: Continue to improve the utility to make it even more useful and simple.

To perform the integration, it is possible to specify each STEAM approach at different stages of the resulting methodology (Fig. 4), although this is not an absolute projection, since fragments of different approaches can be found in each of the methodology phases.

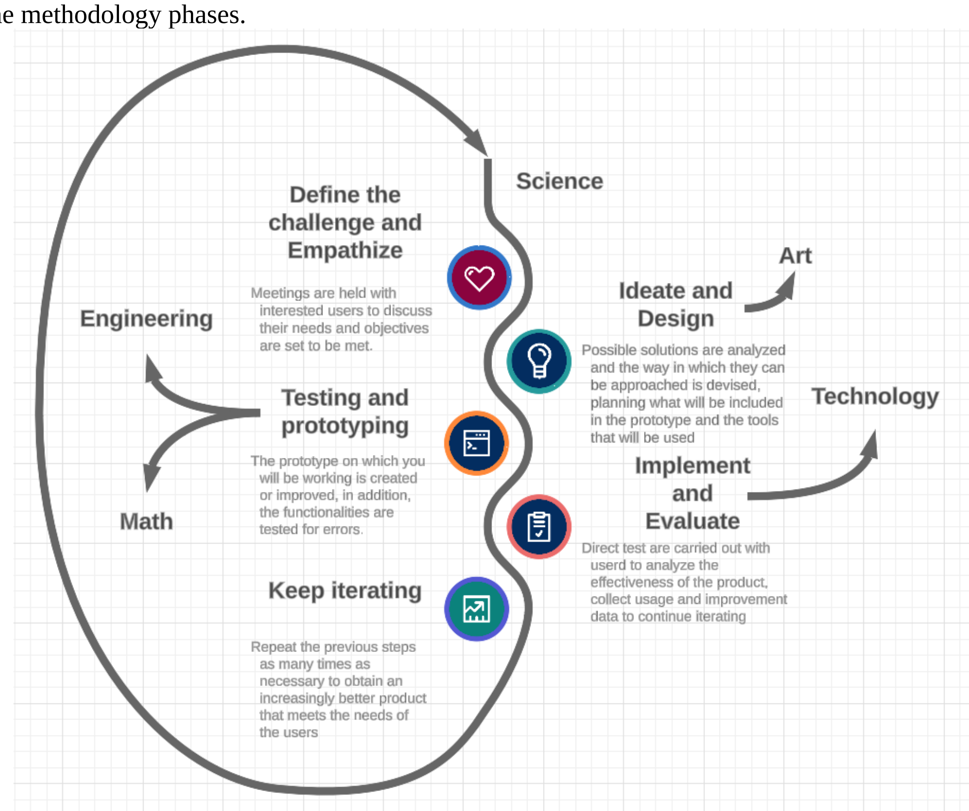

Figure 4: Design Thinking methodology diagram with approach STEAM

Integrating the STEAM point of view into the Design Thinking methodology procedure can lead to more substantial and creative solutions. This involves using art, science, and math to achieve positive effects and using technology to make an object functional. Also, the empathetic perspective ensures that the method is participatory and open to a range of users, including those with disabilities.

5. Implementing the Design Thinking Methodology with the STEAM Approach in Virtual Reality Application.

In the following section, we outline the Design Thinking steps used during the development of the application mentioned in this analysis. We describe the way in which technological tools can support teaching projects that are conceived by teachers who consider the needs of students with disabilities. Then, we defined the proximate requirements they must solve. Next, we established tactics to achieve significant improvements and designed prototypes that worked in accordance with the intended objectives. A complete investigation of these models is done. In addition, this cycle-like procedure enables us to refine and perfect existing features as we go down new routes [28].

5.1. First iteration

5.1.1. Defining the Challenge and Empathizing

In a meeting at the Attention Centers for Students with Disabilities (CAED) within CBTis 168 in Aguascalientes [20], links were established with two teachers and eighteen students, most of them with mental disabilities. The purpose was to investigate the use of virtuality to support regular educational activities. A collaborative network was created, in which the CAED teachers provided the indications, and the specialists were responsible for ensuring that they were complied with. The STEAM point of view was used to devise methods to adapt the activities to the students' needs, highlighting the importance of incorporating motivational steps and discourses to stimulate constant learning.

5.1.2. Ideate and Design

Extensive research was carried out to find the feasible tools to use in virtuality and the available equipment, being the selected option the Unity development engine due to its versatility and the integration of the kit to work with XR. To gather requirements, we started by developing a simple activity to highlight the opportunities and get a first interaction from the users so that they become familiar with the technology. At this stage, we worked with the generation of ideas and creative solutions.

5.1.3. Testing and Prototyping

A program was developed using Unity to visually classify objects in a virtual environment. The activity involves users interacting with colorful characters and placing them on corresponding tables, thus encouraging experimentation, creativity and problem solving (Fig. 5). This initial prototype does not include audio or text instructions.

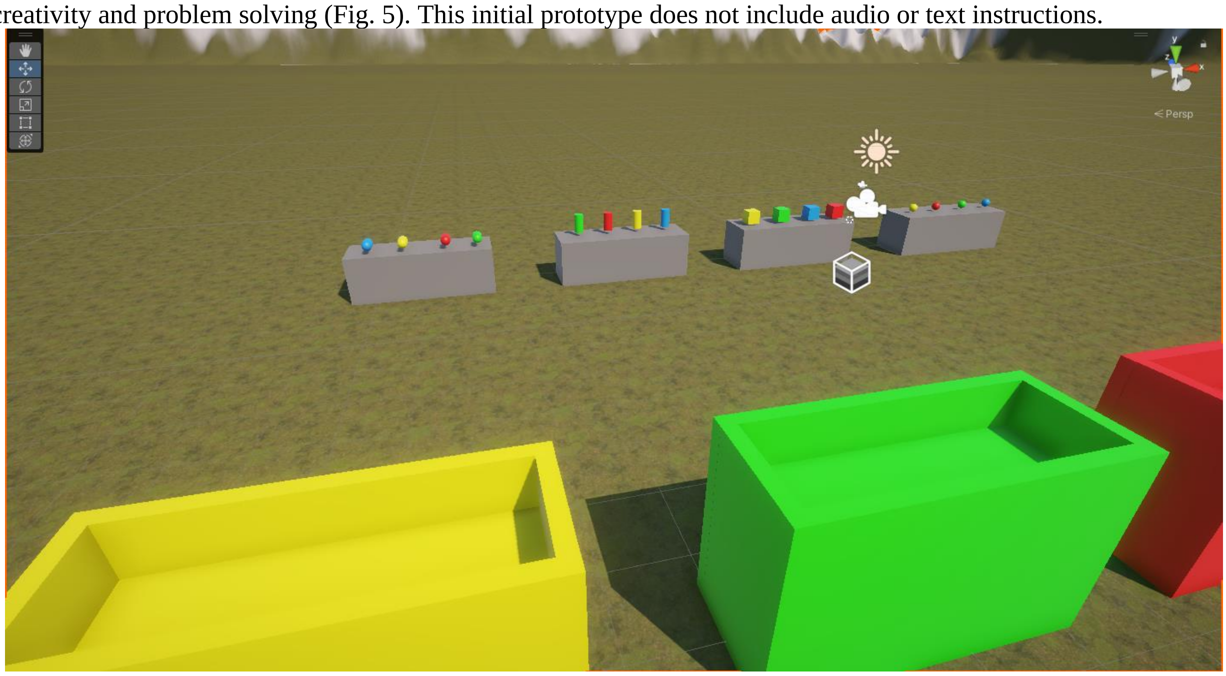

Figure 5: First prototype of the virtual environment

5.1.4. Implement and Evaluate

Demonstrations were given to CAED teachers to highlight possible applications of these techniques in their teaching strategies. Clearly, certain learning modules integrate more effectively with these activities. Intuitive controls require minimal instruction and are easy for teachers to operate in the first instance, which is known from teacher feedback.

5.2. Second iteration

5.2.1. Defining the Challenge and Empathizing

Within CAED, teachers identified two modules: Mathematics and Representation of Natural Systems (Module 8) and Calculus in Natural Phenomena and Social Processes (Module 15) (Fig. 3), as areas where students face significant challenges. We visited the modules, presented the project, and sought student participation. Surveys were conducted to assess teachers' and students' competencies in Information and Communication Technologies (ICT) and an empathy map was created to understand students' needs and perspectives (Fig. 6). Some lectures were planned with the objective of making students aware of new trends in technology (Artificial Intelligence, Extended Reality, Robotics, etc).

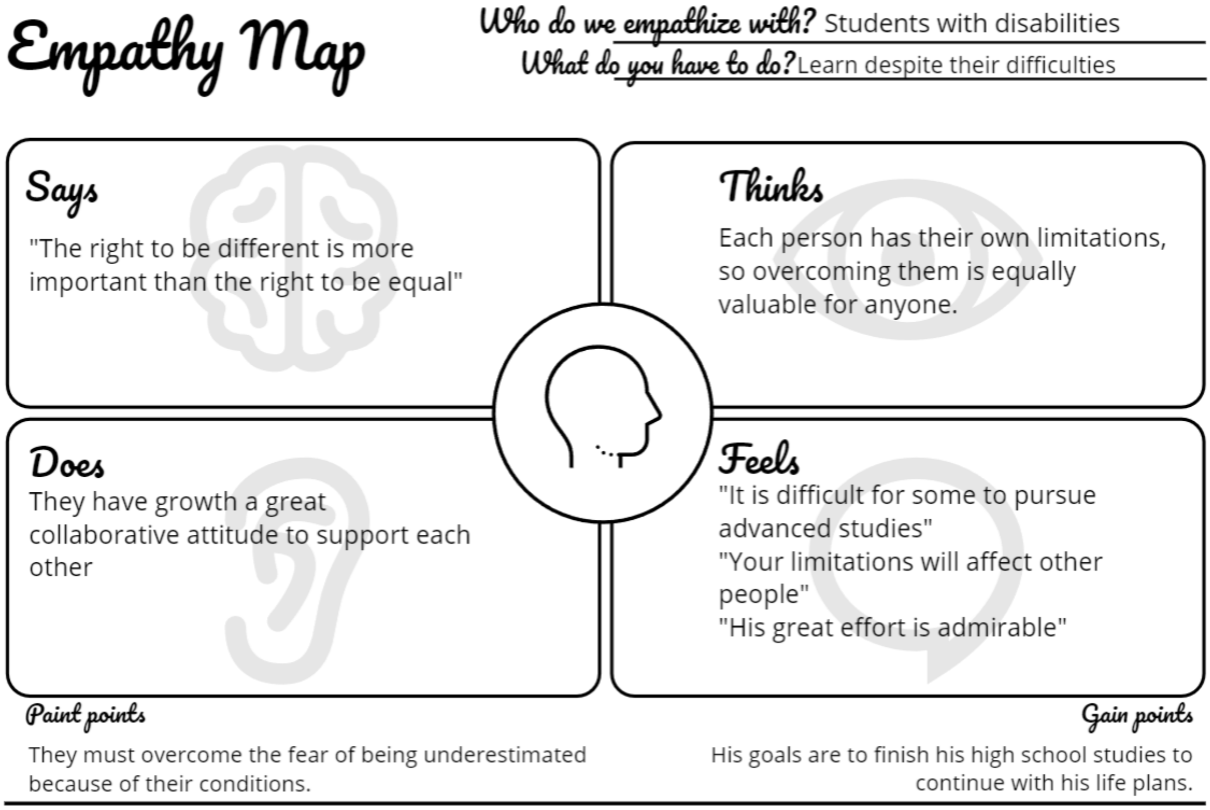

Figure 6: Empathy map of students at CAED CBTis168

To access the content of the proposed study modules, it is necessary to perform a search directly on the CAED page [20], which shows a series of options to reach the material of interest; a Concurrent Task Tree (CTT) was created to show the steps that need to be performed by users who wish to access the content (Fig. 7).

The CTT mentioned (fig. 7) is constituted as follows: as an abstract task you enter the main page of CAED [20], it will direct you to the main menu where a list of options to which it is possible to access is shown, in order to go to the section of the subjects it is necessary to enter the list with the name "CAED" in which more options will be displayed, among them the one called study plan, When selecting it, the user will be automatically redirected to the modular plan where it mentions that it is made up of 22 modules, in addition, it will give the option to choose the area to be searched (communication, mathematics, experimental sciences, social sciences and humanities), selecting any of these, in the case of the example the area of mathematics was selected, after that, it will enable the selection of the subjects/modules related to that field. When accessing each subject individually, it will show a series of didactic materials, among which there are audio books, Mexican Sign Language (LMS) glossaries, Braille printing and intellectual disability booklets. Each of the accesses has its own support content to be able to carry out the activities to be developed in the CAED classrooms.

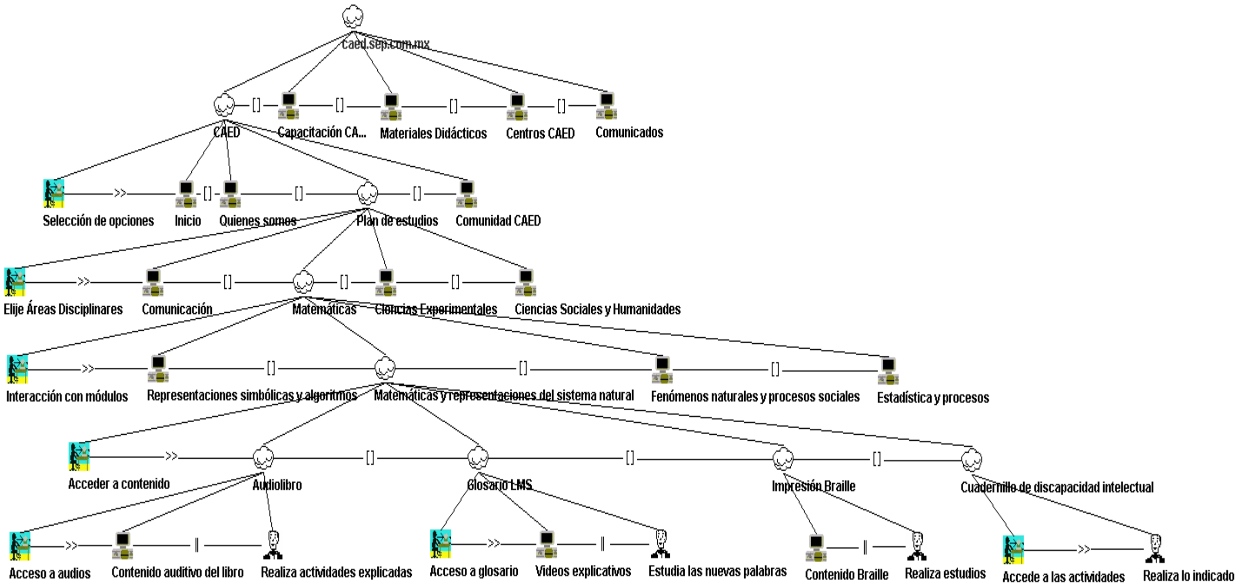

Figure 7: Concurrent Task Tree (CTT) to access the accessibility content of the CAED web page

5.2.2. Ideating and Designing

The students were asked to think and create drawings of characters that they would like to be in the application, encouraging direct artistic participation in the development of the application. The Blender modeling tool was chosen because it allows us to model the students' characters as well as provide structure for their future animations.

5.2.3. Testing and Prototyping

The first character was developed using Blender to test its ability to perform human movements and exhibit natural behavior (Fig. 8). The development of the character was carried out without many complications, the structure and framework of the character behaves mostly as planned. It highlights the experimentation and problem solving of the STEAM approach by deciding to limit these movements until the desired results are obtained so that the final model can be exported to Unity.


Figure 8: Three-dimensional modeling and character structure creation in Blender

5.2.4. Implement and Evaluate

After the initial motion test, it was ensured that the character behaves as expected. However, to ensure the desired performance, adjustments must be made to avoid excessive deformation in the character movements. Technological application and artistic creative need are reflected at this stage to achieve an efficient and realistic result.

5.3. Third iteration

5.3.1. Defining the Challenge and Empathizing

Frustration is a common experience in CAED, especially for students with physical and mental disabilities. It is crucial to address the challenges and find effective solutions to improve their learning experience. To overcome the barriers of frustration, strategies incorporating modern technology must be implemented to increase the concentration and motivation of students in CAED. Attention to students' needs and the search for creative and technological solutions to enhance their learning experiences, promoting interdisciplinarity and innovation within the approach being pursued, is of utmost importance.

Considering what was proposed in the previous stage, the team held a conference (Fig. 9) whose main topics were those mentioned in the previous iteration, the purpose is to familiarize the students with the technologies they will be working on and to make them willing to participate in the project.

Figure 9: Conference given by the researchers

5.3.2. Ideate and Design

One possible solution is to integrate pop-up windows into the application that display motivational messages to help students stay calm and perform activities more efficiently, the selected language was Spanish due to our main users are Mexican students. These messages should also promote long-term learning beyond task completion (Fig. 10).

5.3.3. Testing and Prototyping

The pop-ups were created for students to understand that with patience and perseverance it is possible to overcome most obstacles (Fig. 10).

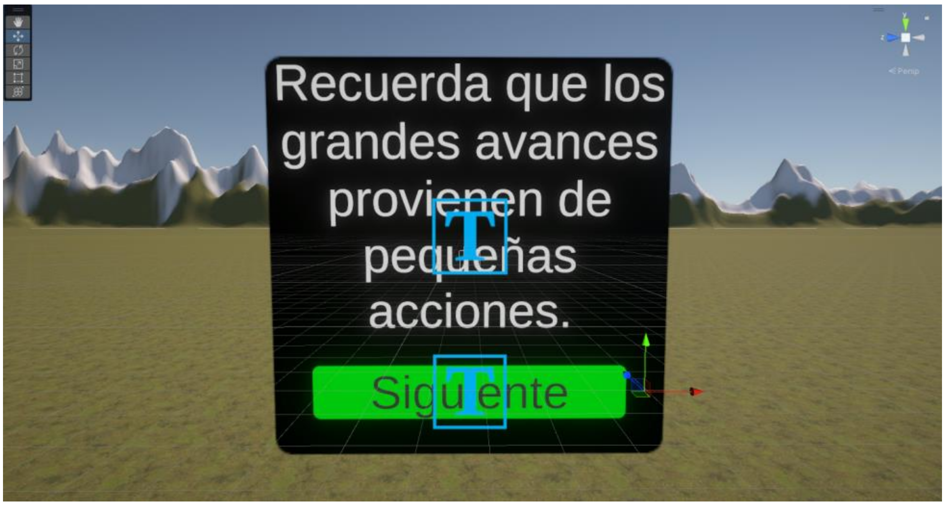

Figure 10: Implementation of motivational messages

5.3.4. Implement and Evaluate

A group of students tested the functionality of the pop-up windows, and the results revealed the challenges faced by visually impaired students who had difficulty identifying text within the boxes.

5.4. Fourth iteration

5.4.1. Defining the Challenge and Empathizing

The designers analyzed whether students had hearing problems that would prevent them from following spoken instructions. Since no hearing issues were identified, consideration was given to implementing an audio system in the application to address additional needs and barriers, particularly for those students with visual impairments. The consideration of in-app audio systems shows a focus on technology to address challenges and barriers.

5.4.2. Ideating and Designing

Using the Audacity audio recording and editing tool, a soundtrack is created for each instruction in the app, giving each student the ability to perform activities in a virtual environment in an accessible way. Within this stage, it is shown how technology is used to adapt and make the application visible to all students, a situation that is essential for inclusion, showing, in turn, a scientific approach when considering individual needs and addressing challenges in a manner creative and effective.

5.4.3. Testing and Prototyping

Visual icons are added so that students press only the box that can be seen and, in this way, they are able to listen to the same instructions that are written, but in a narrated way (as shown in fig. 11).

Figure 11: Motivational message in pop-up window with audio tracks implemented

5.4.4. Implement and Evaluate

Sixteen students had the ability to continue with the activities and access the motivational messages, which brought us closer to our goal; However, two students with severe visual impairment could not even recognize the audio play icon, which prevented them from carrying out any activity. It also demonstrates how constant evaluation is essential to adapt and improve technological solutions, which is aligned with the STEAM approach of experimentation, adaptation, and continuous improvement to address challenges.

5.5. Fifth iteration

5.5.1. Defining the Challenge and Empathizing

To address the challenge of calculating volumes found within module 8 of the CAED curriculum (fig. 3), an appropriate activity that is accessible to all students was sought in collaboration with teachers. Questions were selected that will help remember the formulas to calculate the volume of familiar figures such as the sphere, the cube, the cylinder, the cone, and the prism. It focuses on addressing mathematical and geometric challenges to promote active learning and problem solving, topics that fall into our focus.

5.5.2. Ideating and Designing

To address this challenge, the application of a brief questionnaire that includes three-dimensional models along with the questions is proposed. This allows users to be guided both by their memory and by a small real-time visual aid that they can analyze. With the use of three-dimensional elements, artistic visual understanding and practical application of scientific knowledge are encouraged.

5.5.3. Testing and Prototyping

An environment identical to that of the previous activity was generated, the difference is that it includes new and different elements, having a text box with selectable buttons where a questionnaire related to the selection of formulas for calculating the volume of several three-dimensional figures is displayed. (fig. 12). Creativity and consideration of how different activities can coexist seamlessly is encouraged by managing two distinct environments that can be accessed from the main menu.

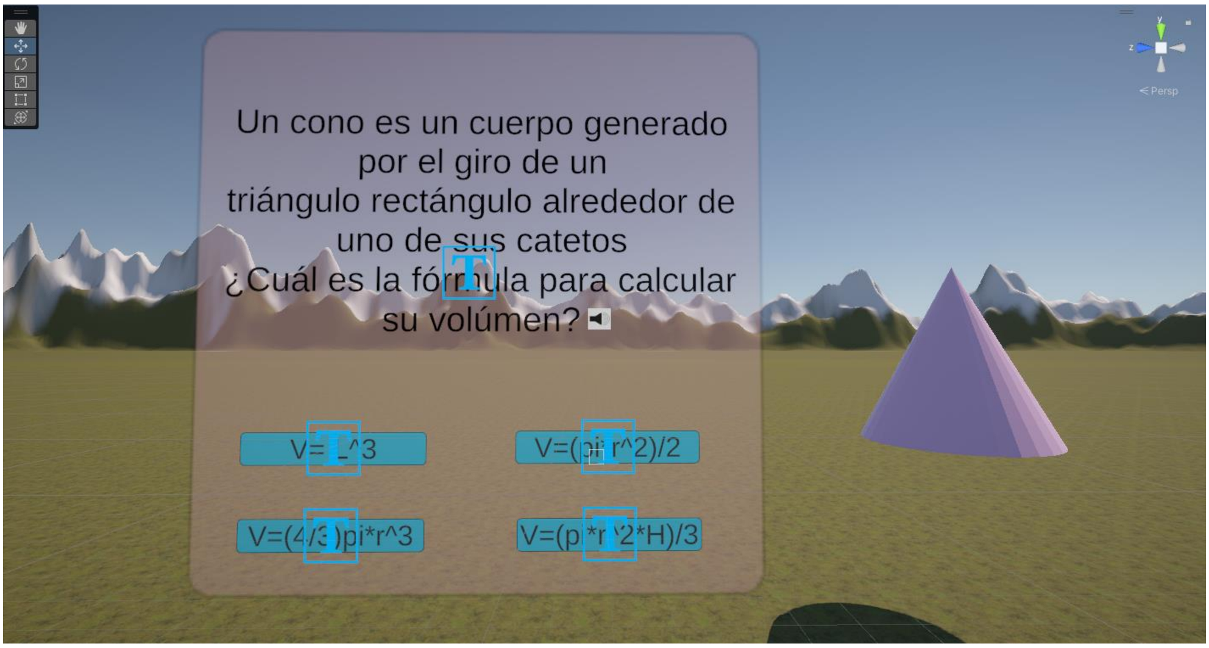

Figure 12: Volume calculation quiz

5.5.4. Implement and Evaluate

Students memorize through trial and error, competing to see who can solve the problem in the shortest time and with the fewest errors. The activity was error-free and student feedback sparked the idea of adding a ranking mode to create healthy and educational competitions. A collaboration is reflected within the scientific and technological approach.

6. Results

The results of this study highlight the potential impact of the virtual reality application, developed with the guidance of the Design Thinking methodology focused on inclusive education. Throughout various development phases, the application continuously improved thanks to constant feedback from the students and teachers involved. Initial evaluation of virtual reality device usage involved introductory sessions with students using Oculus Quest 2 devices. Direct observations and surveys assessed ease of use, and any difficulties experienced, with results showing that students did not encounter significant difficulties, though expanding the sample is recommended for confirmation in a more diverse population. For this test, a group of 11 students (Table 3) out of the 18 participants engaged in a series of two questionnaires to test information retention after using the prototype.

Table 3. Disabilities of students who participated in the quizzes.

Disabilities	Total amount	Males	Females
Intellectual disability	5	3	2
visual disability	2	2	0
hearing impairment	1	1	0
Mixed disability	3	1	2
total	11 of 18	7	4

The prototype's implementation in the educational environment included educational activities within the virtual reality application. Observations during sessions and post-session surveys measured student motivation and participation, revealing notable engagement in both areas. To statistically evaluate the impact of virtual reality on learning, an analysis of variance (ANOVA) was initially considered. However, given the limited sample size (n=11), which falls below the recommended minimum of 15 and ideally over 30 for ANOVA, a paired t-test was conducted instead. The results of the t-test indicated a significant difference ($p = 0.02416$) between pre- and post-use conditions, suggesting that virtual reality had a positive effect on students' learning efficiency. Accessibility and usability of educational content were also evaluated, with surveys and observations gathering feedback from students and teachers on the ease of access and usability of the application. The results demonstrated greater ease in accessing virtual educational content, providing new immersive and personalized learning experiences.

6.1. Data Collection Process

The data collection process to assess the impact of the virtual reality application was conducted over five iterations, adhering to the Design Thinking methodology and incorporating the STEAM approach. A total of 18 students from CAED CBTis 168 participated in the study, with 11 specifically engaging in assessments related to volume calculations. The evaluation involved administering a questionnaire focused on the computation of geometric figure volumes, which was applied at two distinct time points.

- Pre-test: Before using the application
- Post-test: After using the application during several educational sessions

The duration of each test was recorded and documented in a spreadsheet for subsequent analysis. To ensure consistency, the environmental conditions remained identical across all assessments. The tests were conducted using Oculus Quest 2 devices in a specially adapted classroom, with no external modifications that could potentially affect performance.

Initially, an analysis of variance (ANOVA) was considered as a statistical method for evaluating the differences between pre- and post-test results. However, given the sample size of 11 students, which does not meet the recommended minimum of 15 for ANOVA, it was determined that a paired Student's t-test would be more appropriate. The paired t-test allowed for a more accurate analysis given the limited dataset, ultimately providing significant results ($p = 0.02416$) that indicate an improvement in performance after using the virtual reality application.

6.2. Statistical Analysis with Student's t-test

To assess the effectiveness of the virtual reality application, a paired Student's t-test was conducted. This statistical method allows for the comparison of mean resolution times between pre-test and post-test conditions, providing insights into the application's impact on student performance.

Procedure for Conducting the t-test:

- Data Organization: The resolution times for each student were systematically recorded in two columns, corresponding to the pre-test and post-test conditions.

- Assumption Verification: The Shapiro-Wilk test was applied to assess data normality, confirming that the differences between pre-test and post-test times followed a normal distribution (W = 0.94808, p-value = 0.6196), justifying the use of the t-test.
- T-test Calculation: A paired Student's t-test was performed to evaluate whether there was a statistically significant difference in resolution times after using the VR application.
- Effect Size Calculation: Cohen's d was computed to measure the magnitude of the observed effect.

Hypothesis

- H0 (Null Hypothesis): There is no statistically significant difference in resolution times between the pre-test and post-test conditions, indicating that the virtual reality application has no measurable effect.
- Ha (Alternative Hypothesis): There is a statistically significant difference in resolution times, suggesting that the virtual reality application contributes to an improvement in performance.

T-test Results

```
> shapiro.test(datos$Pre - datos$Post)

        Shapiro-Wilk normality test

data:  datos$Pre - datos$Post
W = 0.94808, p-value = 0.6196

> t.test(datos$Pre, datos$Post, paired = TRUE, alternative = "two.sided")

        Paired t-test

data:  datos$Pre and datos$Post
t = 2.6537, df = 10, p-value = 0.02416
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 0.1457936 1.6723882
sample estimates:
mean difference
      0.9090909

> cohen.d(datos$Pre, datos$Post, paired = TRUE)

Cohen's d

d estimate: 0.2268348 (small)
95 percent confidence interval:
     lower      upper
0.04625197 0.40741759
```

Figure 13: Summary of statistics obtained from data processing.

After performing the analysis, the following results were obtained (fig. 13):

- t(10) = 2.6537
- p-value = 0.02416
- 95% Confidence Interval: [0.1458, 1.6724]
- Mean Difference: 0.9091
- Effect Size (Cohen's d) = 0.2268 (small effect size)

Since the p-value is below 0.05, the null hypothesis is rejected, indicating that there is statistically significant evidence to conclude that the virtual reality application had a positive impact on reducing resolution times. However, the effect size suggests that while the difference is significant, the magnitude of the improvement is small. Further studies with larger sample sizes are recommended to validate these findings and better understand the long-term impact of VR-assisted learning.

Table 4. Profiles of students participating in the pre- and post-use test of the prototype with measured solving times.

Student	Disability	Solving time pre usage (minutes)	Solving time post usage (minutes)
Student 1	Autism	18	15
Student 2	Adhd	15	14
Student 3	Down´s Syndrome	20	18
Student 4	Visual	13	13
Student 5	Dyscalculia	12	13
Student 6	Visual	9	19
Student 7	Down´s Syndrome	17	15
Student 8	Autism	12	1
Student 9	Mixed	20	19
Student 10	Mixed	11	10
Student 11	Hearing impairment	19	19

Pre-use and post-use questionnaires on the calculation of the volume of geometric figures were administered to a group of students (Table 4), with a radar chart (Fig. 15) comparing the time taken to complete the questionnaires before and after using the application, where the darkest line represents the solving time after using the prototype and the clearest before it. A reduction in completion time was observed, and statistical analysis using a paired Student's t-test confirmed a significant difference ($p = 0.02416$) between pre-use and post-use conditions. This suggests that the virtual reality application positively impacted students' efficiency in problem-solving.

Overall, the deployment of the prototype received positive feedback, with students demonstrating engagement and enthusiasm in VR activities. Given the statistical significance of the reduction in resolution time, these results indicate a measurable impact of VR on learning efficiency. However, due to the small effect size, further studies with larger samples and extended usage periods may be required to determine the broader applicability of these findings. The iterative development process, guided by continuous communication with users and their teachers, ensures a tailored approach that directly addresses the immediate needs of each student. In conclusion, the adaptation of the methodology and approach proves useful in creating an inclusive education support application, but further investigation is needed to validate its effectiveness in improving task completion efficiency.

6.3. Interpretation of Results

The results of the paired Student's t-test indicate that there is sufficient statistical evidence to conclude that virtual reality contributed to an improvement in solving times for this test. The significant p-value (0.02416) supports this claim, suggesting that the observed reduction in time is not due to random variability but rather to the use of the VR application.

Although the effect size (Cohen's $d = 0.2268$) is categorized as small, it still represents a measurable and meaningful improvement within the context of this study. In educational research, even small effects can be relevant, particularly in emerging technologies such as virtual reality, where engagement and interaction play a key role in learning experiences. The results support the potential of VR as a learning tool, and while further research with larger samples is recommended to explore its full scope, these findings reinforce its validity and applicability in inclusive education settings.

6.4. Graphic Representation

The time distributions are presented below using box plots (fig. 14), which allow the visualization of the median, quartiles, and dispersion of the data before and after the use of the application.

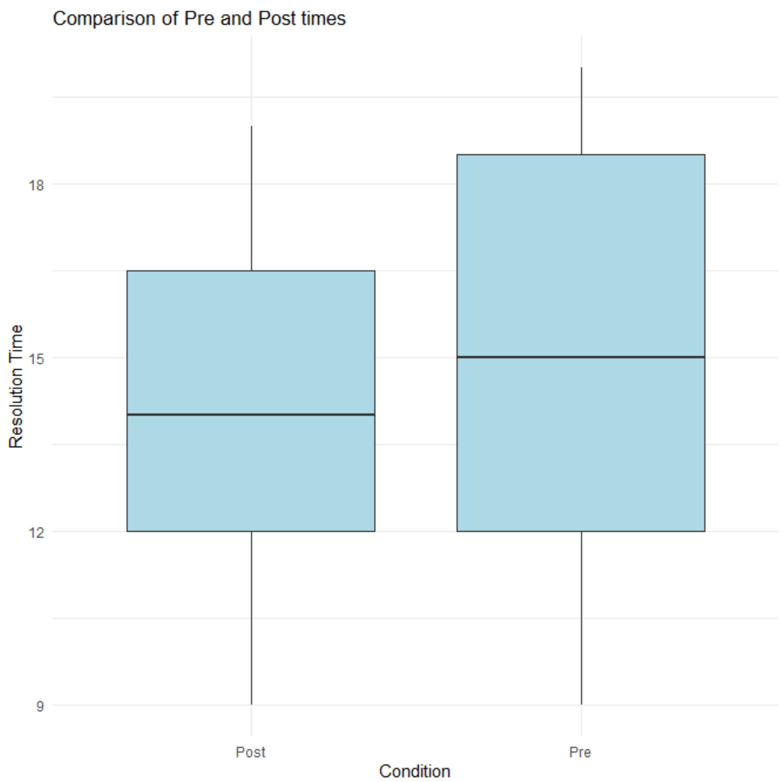

Figure 14: Comparative box plot of pre-use and post-use times.

This analysis confirms that the improvement in resolution times is not due to repeating the test, but rather to the effective use of the virtual reality application. The statistical results support the conclusion that VR positively influences students' ability to complete tasks more efficiently. While the effect size is small, it is still significant in demonstrating the application's effectiveness. Further studies with larger samples and extended usage periods could provide deeper insights into the long-term impact of VR on learning outcomes.

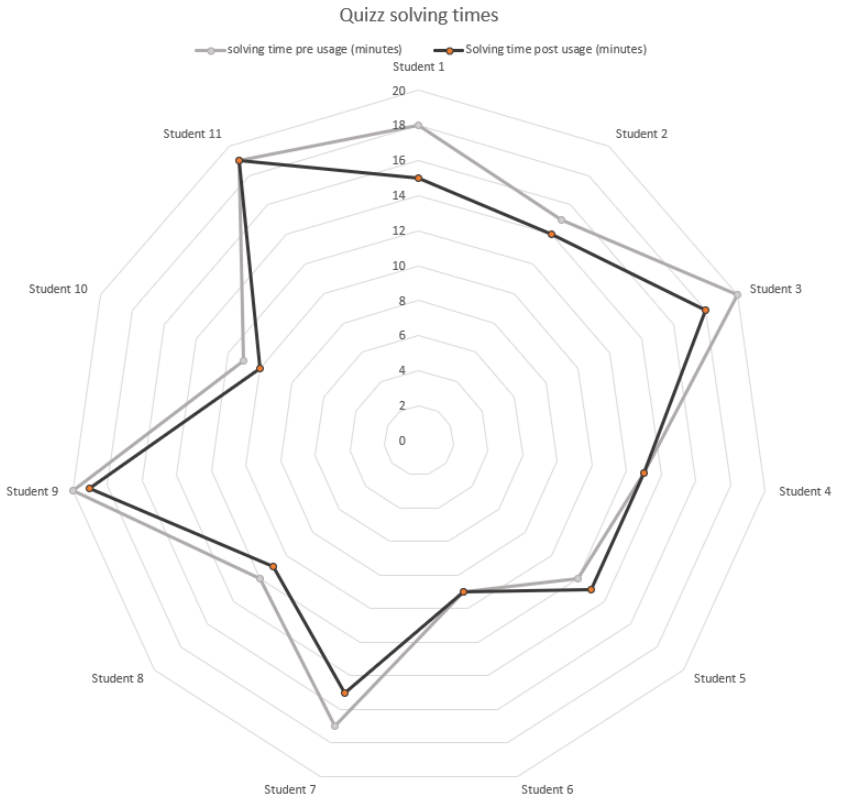

Figure 15: Radar chart of time spent answering the quiz pre-test and post-test

It is possible to identify in another way the dispersion in the resolution times divided by each student (fig. 16) for greater ease in identifying the differences between each test performed.

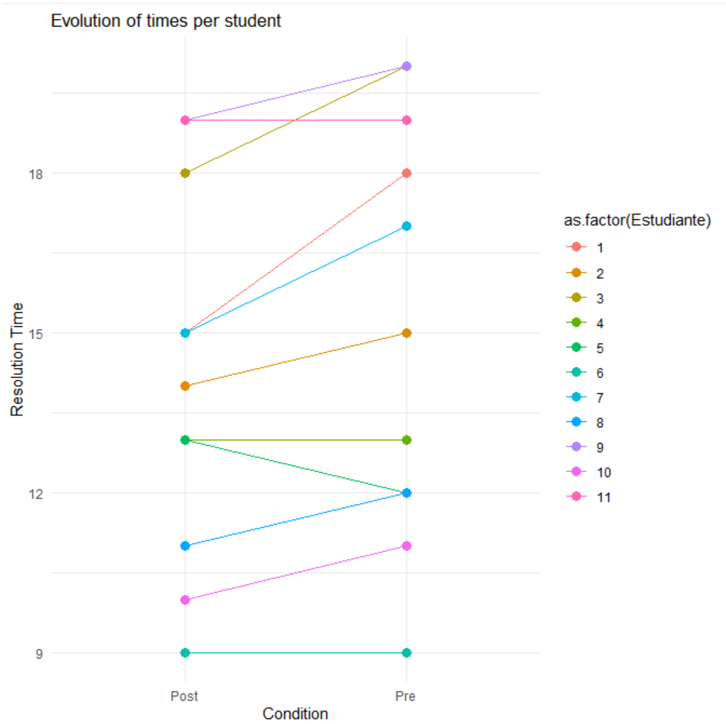

Figure 16: Line graph connecting the values per student

7. Conclusions and Future Works

Employing methodologies that prioritize understanding user needs directly has been shown to be effective in the development of the app created in this study. This impact is especially notable in technologies aimed at inclusive education, as it addresses the unique barriers users encounter.

The research's findings highlight the potential of virtual reality application, developed using the Design Thinking approach with an emphasis on inclusive education. Iterative improvements were made possible through continuous feedback from students and teachers. Implementing the prototype in educational contexts included activities measuring student motivation and participation, which received positive feedback. Surveys and observations indicated that students found accessing virtual educational content engaging, providing immersive and tailored learning experiences. Statistical analysis using a paired Student's t-test revealed a significant difference in task completion times ($p = 0.02416$), suggesting that the VR application contributed to improved performance. While the effect size was small, it still represents meaningful evidence of the application's effectiveness within the sample studied.

The pre-use and post-use questionnaires on calculating the volume of geometric shapes showed a reduction in completion times, supported by statistical significance. Students demonstrated motivation and involvement in VR activities, reinforcing its potential as an educational tool. The Design Thinking methodology remained appropriate for this project, as the stages of empathy and testing helped address user barriers and refine the application based on direct feedback.

Modifications to the methodology focusing on the STEAM approach can be refined and adapted depending on the project context. Integrating new stages clarifies how each STEAM area concentrates in different development phases, with these areas potentially present throughout application and content development.

For future work, ongoing iterations are planned to incorporate more content from CAED's competency and skills modules, as well as exploring activities in other areas. More sessions with collaborating teachers are intended to strategize in communication fields. Additionally, further research with larger sample sizes and extended study durations will be conducted to validate the effects of VR on learning performance through certified statistical data collection methods.

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References

[1] I. de la Cruz Orozco, "Educación inclusiva en el nivel medio-superior: análisis desde la perspectiva de directores," Sinéctica, Revista Electrónica de Educación, 2020. ISSN 2007-7033. doi: 10.31391/S2007-7033(2020)0054-008

[2] G. Maqueira-Caraballo, S. Iglesias, R. Martínez, and L. López, "La educación inclusiva: desafíos y oportunidades para las instituciones escolares," Dialnet, 2023. [Online]. Available: https://dialnet.unirioja.es/servlet/articulo?codigo=9048728

[3] M. Á. V. Martinez, "Desbloquea tu potencial: ¡Aprendiendo con Steam!," LinkedIn, 2023. [Online]. Available: https://es.linkedin.com/pulse/desbloquea-tu-potencialaprendiendo-con-steam-vite-martinez

[4] Secretaría de Educación Pública, "Educación media superior: Centros de Atención para Personas con Discapacidad (CAED)," [Online]. Available: https://educacionmediasuperior.sep.gob.mx/es_mx/sems/bnned_bachillerato_no_escolarizado_personas_discapacidad

[5] Gobierno de México, Ley General para la Inclusión de las Personas con Discapacidad, 2011.

[6] H. Cardona-Reyes, J. Muñoz-Arteaga, K. Villalba-Condori, and M. A. Barba-González, "A Lean UX Process Model for Virtual Reality Environments Considering ADHD in Pupils at Elementary School in COVID-19 Contingency," 2021.

[7] Y.-L. Yang-Kun Ou, "Development of virtual reality rehabilitation games for children with attention-deficit hyperactivity disorder," Journal of Ambient Intelligence and Humanized Computing, vol. 11, pp. 5713–5720, 2020.

[8] O. Korn, L. Buchweitz, A. Rees, G. Bieber, C. Werner, and K. Hauer, "Using Augmented Reality and Gamification to Empower Rehabilitation Activities and Elderly Persons: A Study Applying Design Thinking," in Advances in Intelligent Systems and Computing, vol. 787, 2018, pp. 219–229. DOI: 10.1007/978-3-319-94229-2_21

[9] J. C., "Revisión bibliográfica del tema de estudio de un proyecto de investigación," Radiología, 2011. doi:10.1016/j.rx.2011.05.015

[10] Tinkercad, "Tinkercad | Create 3D digital designs with online CAD," 2023. [Online]. Available: https://www.tinkercad.com/

[11] Scratch, “Scratch - Imagine, Program, Share,” 2023. [Online]. Available: https://scratch.mit.edu/
[12] Minecraft Education Edition, “Exploración Educativa en Minecraft,” 2023. [Online]. Available: https://education.minecraft.net/es-es
[13] GeoGebra, “Mathematics Apps,” 2023. [Online]. Available: https://www.geogebra.org/?lang=es
[14] CoSpaces Edu, “Virtual Reality in Education,” 2023. [Online]. Available: https://www.cospaces.io/
[15] D. Sánchez, “Educación STEAM,” Domingo Sánchez 3D, 2020. [Online]. Available: https://domingosanchez3d.es/educacion-steam/
[16] V. Di-Cristo and J. C. Bonilla Cerón, La Importancia del Uso de Aplicaciones Interactivas y Multimedia en la Educación y Capacitación Actual, 1st ed., 2003.
[17] W. R. Sherman and A. B. Craig, Understanding Virtual Reality: Interface, Application, and Design. Morgan Kaufmann Publishers, 2003. DOI: 10.5555/1055377
[18] INEGI, “Encuesta Nacional de la Dinámica Demográfica ENADID 2018,” México, 2018.
[19] B. A. Medina, “Formación integral, inclusión educativa y responsabilidad social,” DOCERE, 2019, pp. 33–36.
[20] Secretaría de Educación Pública, Gobierno de México, “Planes de estudio. CAED,” 2023, july. [Online]. Available: https://caed.sep.gob.mx/planes-de-estudios
[21] Interaction Design Foundation, “What is Design Thinking?,” 2022. [Online]. Available: https://www.interaction-design.org/literature/topics/design-thinking
[22] S. Karl, “The Design Thinking Process – How does it work?,” MAQE, 2020. [Online]. Available: https://www.maqe.com/insight/the-design-thinking-process-how-does-it-work/
[23] Recla, “El aula digital: las asombrosas ventajas de la tecnología en la educación,” RECLA, 2023. [Online]. Available: https://recla.org/blog/ventajas-de-la-tecnologia-en-la-educacion/
[24] T. D. Dekker, Design Thinking, Routledge eBooks, 2020. DOI: 10.4324/9781003154532
[25] A. Pérez, “3 tipos de equipos de trabajo y un proyecto,” OBS Business School, 2021. [Online]. Available: https://www.obsbusiness.school/blog/3-tipos-de-equipos-de-trabajo-y-un-proyecto
[26] C. Latorre-Cosculluela, S. Vázquez-Toledo, A. Rodríguez-Martínez, and M. Liesa-Orús, “Design Thinking: creatividad y pensamiento crítico en la universidad,” Revista Electrónica de Investigación Educativa (REDIE), vol. 22, 2020. DOI: 10.24320/redie.2020.22.e28.2917
[27] Secretaría de Educación Pública, “Sitio web oficial del CAED,” 2023. [Online]. Available: https://caed.sep.gob.mx/
[28] A. Moreno-Cruz, J. Muñoz-Arteaga, J.C. Ponce-Gallegos, C.A. Collazos-Ordóñez, A.L. Iñiguez-Carrillo, “Inclusive Virtual Reality in Education: Applying the STEAM Approach to Ease the Learning of Students with Disabilities” CEUR Workshop Proceedings, vol. 3691, pp. 294-311, 2023 [Online] Available: https://ceur-ws.org/Vol-3691/paper25.pdf