Exploring New Possibilities: Virtual Reality in Supporting Children with Autism

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***Abstract*—Children with autism spectrum disorder (ASD) often require structured opportunities to practice social interaction, following instructions, and recognizing emotions in safe, controlled environments. This study presents and evaluates a mobile virtual reality (VR) application designed to train these skills through simulated everyday scenarios. An applied quantitative study with an experimental design involving control and experimental groups was conducted with 10 children with ASD from the Sagrada Familia Special Basic Education Center (Trujillo, Peru). The experimental group (n=5) used a Unity 3D/C# VR application featuring four scenarios (park, store, pedestrian crossing, and emotion recognition), while the control group (n=5) followed conventional activities. Outcomes were collected through direct observation (60 records; 30 per group) and analyzed statistically, with findings interpreted cautiously due to the repeated-observation structure of the data. The post-test results showed statistically significant differences between groups, with the experimental group performing better on all evaluated indicators (social interaction, following instructions, emotion recognition, and average time to detect oncoming traffic). However, due to the small sample size and repeated observations, these findings should be interpreted as preliminary evidence. The results suggest that mobile VR may complement traditional interventions to strengthen social and emotional skills in children with ASD.**

Keywords—Autism Spectrum Disorder; virtual reality; mobile application; social skills training; immersive learning; special education

I. Introduction

In Peru, between 2020 and 2023, there has been a sustained increase in diagnoses of autism spectrum disorder, reflected in greater demand for specialized health and education services. National reports indicate that the highest concentration of diagnosed cases corresponds to school-age children, which has created a significant challenge for public institutions responsible for providing educational and therapeutic care, especially in contexts where access to specialized technological resources is still limited [1]. Although advances in diagnosis have enabled earlier detection, significant gaps in access to appropriate interventions and support services remain, highlighting the lack of comprehensive policies to accompany people with autism throughout their lives [2].

In the United States, epidemiological studies conducted by national monitoring networks indicate that autism spectrum disorder affects approximately 1.7% of children, equivalent to 1 in 59 school-age children. This prevalence has been identified from systematic assessments conducted in multiple states, demonstrating a significant impact of ASD on health and education systems, as well as the need for early interventions and specialized support strategies [3]. In Peru, around 1% of the population is on the spectrum, and more than 70% of registered cases correspond to children under the age of eleven, reinforcing the need to strengthen educational and technological support programs in special education [4].

Recent meta-analyses indicate that immersive virtual reality-based interventions can improve cognitive, social, and emotional skills in children and adolescents with ASD, providing structured, safe, and engaging practice opportunities [5]. Furthermore, virtual reality applications designed for high-functioning children with autism can effectively support social skill development, facilitate engagement in controlled, immersive environments, and help mitigate difficulties in social interaction and following structured instructions [6].

These difficulties can affect their participation in daily activities, limit their autonomy, and generate anxiety or discomfort in new situations. In educational and social contexts, many children with autism have problems relating to their peers, following instructions in public spaces, or identifying risky situations, such as when crossing a street. This highlights the need for safe, controlled, and personalized teaching methodologies that allow for the progressive development of social skills in structured environments [7].

In the city of Trujillo, the Sagrada Familia school, a Special Basic Education Center (CEBE), serves children diagnosed with ASD and focuses its work on the development of social and emotional skills. However, it faces challenges due to the limited availability of technological tools adapted to the teaching-learning process, which affects the behavioral progress and autonomy of students [7].

In this scenario, virtual reality (VR) emerges as a technology capable of offering immersive, safe, and personalized environments that facilitate learning through the simulation of everyday experiences. Recent studies show that the use of virtual environments promotes motivation, concentration, and emotional understanding, contributing significantly to the development of social skills in children with autism spectrum disorder [8].

In response to this problem, a mobile virtual reality application based on social environments was designed and developed with Unity 3D and the C# programming language. The application integrates everyday scenarios such as a park, a store, a crosswalk, and emotional recognition activities, aimed at promoting social interaction, decision-making, and understanding of emotions in an educational and therapeutic context [9].

The application was developed using the SUM methodology, which proposes a structured and modular approach to the construction of educational software, allowing iterative adjustments to be made based on observations and the performance of the participating children. This methodology facilitated the progressive adaptation of virtual environments to the needs of the intervention process [10], [11].

The main objective of this research was to improve social skills in children with autism spectrum disorder through the implementation of a virtual reality mobile application. Specifically, the aim was to increase the proportion of social interaction in groups of people, increase the frequency of following instructions in everyday environments such as shops, decrease the average time to detect oncoming traffic before crossing the street, and increase the emotion recognition rate in everyday situations.

Research hypotheses. The general hypothesis states that the implementation of a virtual reality mobile application based on social environments significantly improves social skills in children with autism spectrum disorder. The following specific hypotheses were also proposed: (H1) the use of the application increases the proportion of social interaction; (H2) it increases the frequency of following instructions in everyday environments; (H3) it decreases the average time to detect oncoming traffic before crossing the street; and (H4) it increases the emotion recognition rate in everyday situations.

II. Theoretical Framework

A. Virtual Reality

Virtual reality (VR) is an immersive technology that allows the user to enter a computer-generated three-dimensional environment, in which they can interact with objects, characters, or simulated situations in real time using specialized headsets and controllers. This technology is characterized by immersion, which generates a sense of presence in the virtual environment; interactivity, which allows the user to actively influence the development of the experience; and the ability to simulate controlled and safe contexts, facilitating the repetitive practice of skills without real risks. VR also offers immediate feedback and personalization of the environment, aspects that favor experiential learning and progressive adaptation by the user, especially in educational and therapeutic contexts [12].

B. Social Skills

Social skills are a set of learned behaviors that allow people to interact appropriately with their environment, express emotions, establish interpersonal bonds, and comply with social norms. These skills involve the ability to communicate, cooperate, empathize, and resolve conflicts in different contexts [5].

In the case of children with ASD, limitations in verbal and nonverbal communication hinder the acquisition of these skills, affecting their school and social integration. The development of social skills requires structured environments and methodologies that encourage observation, imitation, and constant practice of appropriate behaviors [6].

C. SUM Methodology

The SUM (Scrum Unified Methodology) methodology is considered an agile software development model that combines the iterative principles of Scrum with a structured approach to software development. This approach prioritizes continuous collaboration between the work team and the end user, encouraging partial deliveries, constant feedback, and adaptability to change [10]. SUM allows for the incremental planning and development of technological products, ensuring quality, flexibility, and control of time and costs. This methodology is suitable for educational projects, as it integrates stages of design, validation, and continuous improvement according to user needs [11].

Together, virtual reality as an immersive technology, the development of social skills as an intervention variable, and the SUM methodology as an agile development approach form the theoretical framework that underpins the design, implementation, and evaluation of the mobile application proposed in this research, aimed at improving social behavior in children with autism spectrum disorder.

III. Materials and Methods

A. Type of Research

This was an applied study, as it focused on the implementation of a social environment-based virtual reality mobile application with the aim of improving the behavior of children diagnosed with autism spectrum disorder (ASD). This type of study seeks to generate practical and tangible solutions using scientific knowledge [13]. Likewise, a quantitative approach was used, since the data obtained were numerical and were analyzed using statistical techniques to verify the validity of the hypotheses proposed [14].

B. Research Design

A true experimental design was used, aimed at determining the effectiveness of the virtual reality mobile application in improving the behavior and social skills of children with ASD. This design is characterized by the deliberate manipulation of an independent variable and the observation of its effects on a dependent variable under controlled conditions. Experimental studies allow causal relationships between variables to be established through the use of control and experimental groups, ensuring the internal validity and reliability of the results [14].

In this parallel-group true experimental design, the Control Group served as the concurrent behavioral reference, reflecting performance under conventional educational conditions without VR exposure. Both groups were matched at allocation by age, educational level, and ASD diagnosis profile, supporting initial group equivalence. Accordingly, between-group post-test comparisons provide the primary evidence of the intervention's effect, consistent with parallel-group experimental designs in which group equivalence is established at allocation [15].

Because detailed pretest values were not reported in the manuscript, full statistical verification of baseline equivalence is limited.

To reduce this limitation, participants were allocated considering similarity in age, educational level, and confirmed ASD diagnosis. The Control Group served as a concurrent behavioral reference under conventional educational conditions. Therefore, the results should be interpreted as preliminary evidence [14].

C. Variables and Operationalization

1) Independent variable: Virtual reality.

2) Conceptual definition: It is a technology that allows the creation of three-dimensional environments with which users can interact in an immersive way [16].

3) Operational definition: The virtual reality application was used by the Experimental Group. A nominal scale was used.

4) Dependent variable: Behavior of children with autism.

5) Conceptual definition: The behavior of children with autism is defined as qualitative alterations in social interaction, communication, and repetitive and restricted behavior patterns [5].

6) Operational definition: The variable Behavior of children with autism was measured using four indicators: proportion of social interaction, frequency of following instructions, average time to detect oncoming traffic before crossing, and emotion recognition rate. All indicators were measured on a ratio scale.

D. Population, Sample, and Sampling

The population consisted of children diagnosed with autism spectrum disorder (ASD) attending the Sagrada Familia Special Basic Education Center in Trujillo, Peru. An intentional sample of ten (10) participants was selected and divided into two groups with similar characteristics: five in the experimental group and five in the control group, maintaining similarity in age, educational level, and behavioral characteristics. The selection was made considering inclusion criteria such as confirmed diagnosis of ASD, regular attendance at the center, and informed consent from parents or guardians [17].

Due to limitations in parental authorization and the small number of participants, the study included a total of 10 children with ASD (5 per group). While inferential statistical tests, including the Mann–Whitney U test, were applied to compare outcomes between groups, it is important to recognize that small sample sizes can produce unstable effect estimates. No formal statistical power analysis was conducted due to the limited sample size; therefore, the results should be interpreted as preliminary evidence rather than definitive conclusions. To strengthen behavioral documentation, 30 observational records per group were collected through repeated observations during the intervention sessions. These repeated measures provide insight into the children's performance but do not increase the statistical power at the participant level.

During data collection, a total of 60 observational records were obtained (30 per group), corresponding to repeated observations of the 10 participants. Although participants constituted the primary sampling unit, the observational records were used to document behavioral performance across intervention sessions. Therefore, the inferential results should be interpreted as exploratory and preliminary evidence rather than definitive participant-level effects [18].

E. Data Collection Techniques and Instruments

Data collection was carried out through direct observation, a technique that allowed for real-time recording of the children's behaviors and responses during the intervention sessions. This method provided accurate and objective information about the participants' actions in their controlled educational environment, ensuring the reliability of the results [18].

The instrument used was an observation form validated by expert review, designed to systematically document the indicators defined in the dependent variable: social interaction, following instructions, traffic identification, and understanding emotions.

The observation instrument underwent a formal content validation process conducted by a qualified expert in autism spectrum disorder and special education. The validator held expertise in behavioral assessment and therapeutic intervention with ASD populations, and evaluated the instrument across multiple dimensions: 1) clarity, assessing whether each item was written in clear, unambiguous language appropriate for the observational context; 2) relevance, confirming that each indicator was directly aligned with the behavioral dimensions targeted by the intervention (social interaction, instruction-following, traffic hazard detection, and emotion recognition); 3) coherence, verifying that the indicators were internally consistent with the theoretical framework underpinning the study; 4) pertinence, ensuring that each item was appropriate and necessary for measuring the behavioral outcomes in children with ASD in educational settings; and 5) sufficiency, confirming that the set of indicators as a whole provided adequate coverage of the dependent variable. Based on the expert's review, minor wording adjustments were made to two items to improve observational objectivity, and the instrument was confirmed as suitable for measuring the target behavioral indicators in this population. The expert's assessment provided evidence of content validity, supporting the use of the observation form for the purposes of this study. However, because the instrument was reviewed by a single expert and no inter-rater reliability or agreement coefficient was calculated, this aspect is acknowledged as a methodological limitation.

The data obtained were processed using Jamovi software version 2.3.28, applying descriptive and inferential statistics. For group comparisons, the Shapiro–Wilk test was used to assess normality; Student's t-test was applied to normally distributed data, and the Mann–Whitney U test was used otherwise [15].

F. Procedures

The study was carried out in three stages following the SUM methodology, which is suitable for the agile and incremental development of educational software. In the first stage, the virtual reality mobile application was designed and programmed using the Unity 3D platform and the C# language, integrating three-dimensional environments focused on improving the social behavior of children with autism spectrum disorder (ASD). Subsequently, functionality, usability, and performance tests were carried out to ensure the stability of the system before its application in the educational environment.

During the second stage, participants in the Experimental Group used the mobile application through Oculus Quest 2 virtual reality headsets in controlled sessions. The activities included interactive scenarios representing everyday situations, such as interacting in a park, shopping, crossing a street, and recognizing emotional expressions. Each session lasted approximately 15 to 20 minutes and was conducted under the supervision of educational staff. To reduce potential sensory burden, participants were allowed to pause or stop the activity if signs of discomfort, fatigue, anxiety, visual overstimulation, or auditory sensitivity appeared. In addition, the virtual scenarios were designed with simple visual elements, guided interactions, and limited exposure time to minimize sensory overload during the intervention. At the same time, the Control Group continued with conventional educational activities without VR exposure.

In the third stage, the observation form was administered to both groups to document behavioral performance across the four indicators: social interaction, following instructions, average time to identify traffic, and emotion recognition. For the Experimental Group, this corresponded to the post-intervention phase; for the Control Group, it captured concurrent performance under conventional educational activities, serving as the parallel behavioral reference. Data were then processed and analyzed to determine the effect of the VR application.

IV. SOFTWARE METHODOLOGY

The virtual reality mobile application was developed using the Scrum Unified Methodology (SUM), an agile approach geared toward the development of interactive systems and immersive applications. This methodology was selected for its iterative and flexible nature and its suitability for the development of virtual reality-based educational applications, allowing for continuous improvements based on feedback and system testing.

The SUM methodology is structured in five phases: Conception, Planning, Initial Development, Beta Version, and Closure, which allowed for the progressive organization of the design, implementation, and validation of the application aimed at improving the social behavior of children with autism spectrum disorder (ASD).

A. Platform and Tools

The virtual reality application was implemented for the Oculus Quest 2 platform, with the aim of providing an autonomous immersive experience for sessions in the educational environment. Development was carried out with Unity 2022.3.16f1 and programming in C#; the environments and characters were integrated using 3D models from asset catalogs. User interaction (selection, button activation, and object manipulation) was implemented with XR Interaction Toolkit under the OpenXR standard. For the recording and consolidation of results per session, a cloud service was integrated using Supabase, consumed from Unity with UnityWebRequest.

To run the application on the headset, the project was configured in Unity for Android, generating an APK package compatible with (Oculus/Meta) Quest 2. The compilation was performed using the Android SDK and OpenJDK, and the APK was then installed and managed on the device using Meta Quest Developer Hub, allowing controlled tests to be run in a real environment. During these tests, the correct loading of scenes, interaction via controllers, and network connectivity for sending records to the database (Supabase) were verified, ensuring the storage of results per session.

B. Software Architecture

The solution was organized in a modular fashion: 1) a navigation module for accessing the objectives/scenarios, 2) an XR interaction module for user selection and control, 3) logic modules per scenario (park, store, intersection, and emotional recognition) with decision and timing controllers, and 4) a logging module that stores user responses/times and manages the sending of results. This structure facilitated iterative adjustments during development and stabilization before the experimental phase. As shown in Fig. 1, the XR application was developed in Unity using C# for deployment on Meta Quest 2, relying on the Android toolchain (Android SDK/OpenJDK) and Supabase as the database backend to store user logs and support result transmission.

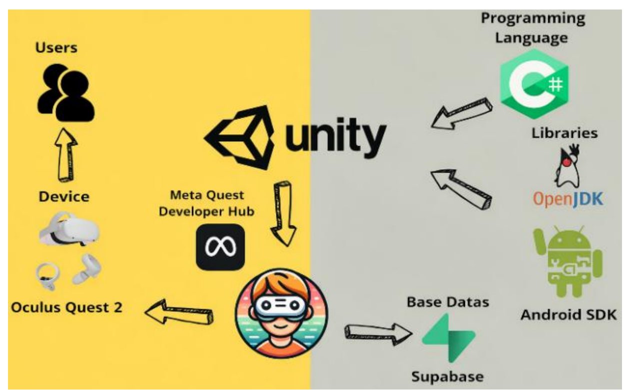

Fig. 1. Software architecture.

C. Scenario Implementation and Recording

The application includes four objectives: 1) social interaction in the park, where the child practices greetings and interaction with groups of people and the system counts successful interactions; 2) interactive store, where the child selects products from a list and the system counts correct selections; 3) pedestrian crossing/risk situation, where the child crosses while avoiding vehicles and attempts and time are recorded; and 4) emotional recognition, where the child identifies emotions on faces and the success rate is recorded. In all cases, the system saves the results at the end of each activity for later analysis.

D. Testing and Debugging

Before the intervention, interaction tests and iterative corrections were performed to ensure system stability. Among the incidents resolved, the interaction of panels/buttons in VR was corrected by adjusting the raycaster, and the sending of results to the database was stabilized by configuration and connection changes in OpenXR.

E. Conception Phase

In the conception phase, an analysis was carried out of the educational context and behavioral needs of children diagnosed with autism spectrum disorder. This stage helped identify the main difficulties to be addressed, such as social interaction, following instructions, recognizing emotions, and identifying risky situations in everyday environments.

Based on this analysis, the overall objective of the application was defined, which was to provide a safe and controlled virtual environment that allows children to practice social skills through immersive experiences. Likewise, the functional scope of the system was established, and the profile of the end users was determined, prioritizing accessibility and ease of use.

Based on the analysis carried out in this phase, the needs and objectives of the application were identified, which are summarized in Table I.

TABLE I. NEEDS ANALYSIS IN THE CONCEPTION PHASE

Aspect Analyzed	*Description*
Context of the problem	Children diagnosed with autism spectrum disorder have difficulties with social interaction, following instructions, recognizing emotions, and understanding risky situations in everyday environments.
Target user	Children with autism spectrum disorder (ASD) attending a special elementary school.
Identified need	To have a technological tool that allows social skills to be practiced in a safe, controlled, and repeatable environment.
Objective of the application	To provide immersive virtual environments that promote the development of social and behavioral skills.
Solution strategy	Implementation of a virtual reality mobile application based on interactive social scenarios.
Proposed environments	Park, store, crosswalk, and emotional recognition activities.

F. Planning Phase

During the planning phase, the functional and non-functional requirements of the application were defined. The general structure of the system was designed, establishing the different interactive virtual environments, which included scenarios such as a park, a store, a pedestrian crossing, and emotional recognition activities.

Likewise, the technological tools for software development were selected, using Unity 3D as the development engine and C# as the programming language. The project activities were organized according to development priorities, and a schedule was established that allowed for the progressive implementation of the functionalities.

As a result of the analysis carried out in the conception phase, the functional requirements of the virtual reality application were defined in the planning phase. These requirements made it possible to establish the functionalities necessary for the development of social scenarios and to guarantee an adequate user experience for children with autism spectrum disorder. Table II presents the functional requirements considered for the design of the system.

TABLE II. FUNCTIONAL REQUIREMENTS OF THE VIRTUAL REALITY APPLICATION

ID	*Requirement*
RF1	The application must provide immersive virtual reality environments geared toward the development of social skills.
RF2	The system must allow the user to interact with virtual objects and characters within each scenario.
RF3	The application must include everyday social scenarios such as a park, a store, and a crosswalk.
RF4	The system must incorporate activities for recognizing and understanding emotions.
RF5	The application must allow for simple and intuitive navigation between the different scenarios.
RF6	The system must record user interactions and responses during usage sessions.
RF7	The application must be suitable for children with autism spectrum disorder, prioritizing visual simplicity and ease of use.

G. Initial Development Phase

In this phase, the main functionalities of the virtual reality application were implemented. Three-dimensional environments were developed and integrated in Unity 3D, programming the interactive elements that allow user navigation, interaction with virtual objects and characters, as well as the execution of guided activities.

In addition, the system logic was implemented to record user responses and behaviors during usage sessions. Iterative testing was performed to verify system stability, usability, and proper interaction between components, allowing for early adjustments to the application's design and operation.

As part of the initial development, the application was structured into different virtual social scenarios, each aimed at reinforcing a specific skill. Table III presents the relationship between the scenarios developed and the social skills addressed in each one.

TABLE III. VIRTUAL SCENARIOS DEVELOPED AND SKILLS ADDRESSED

Virtual Scenario	Social Skill Addressed
Park	Social interaction in public spaces
Store	Following instructions in everyday environments
Crosswalk	Identification of risky situations
Recognition of emotions	Understanding emotions in social situations

H. Beta Version Phase

The beta version phase was aimed at validating the application in a controlled educational environment. The system was implemented using virtual reality headsets, allowing children in experimental groups to interact with the different scenarios during scheduled sessions.

During this stage, feedback was collected from direct observation and support from educational staff, which allowed for the identification of opportunities for improvement related to visual clarity, interaction time, and navigation within the virtual environment. Based on these results, minor adjustments were made to optimize the user experience and reduce possible sensory overload.

To validate the application's performance in a controlled environment, a beta version of the virtual reality system was developed. This version allowed for the evaluation of the correct execution of the virtual scenarios, user interaction with the elements of the environment, and the overall stability of the application before its experimental implementation. As shown in Fig. 2, the beta version enabled verification of scenario execution, user interaction with virtual elements, and overall application stability.

Fig. 2. Virtual scenario of the virtual reality application in execution.

I. Closing Phase

In the closing phase, the final version of the virtual reality mobile application was consolidated. The correct functioning of all modules was verified, and compliance with the objectives established in the initial phases was checked.

Finally, the application was prepared for implementation in the experimental phase of the research, serving as the main tool for data collection and evaluation of the impact of virtual reality on improving the social behavior of children with autism spectrum disorder.

Upon completion of the application's development, the final components of the system were consolidated, ensuring its proper functioning and alignment with the objectives set forth. Table IV summarizes the main components that make up the final version of the virtual reality application.

TABLE IV. FINAL COMPONENTS OF THE VIRTUAL REALITY APPLICATION

Component	Description
Development engine	Unity 3D
Programming language	C#
Virtual scenarios	Park, store, crosswalk, and recognition of emotions
Interaction	Navigation and interaction with virtual objects and characters
Platform	Mobile application with virtual reality viewer
Final status	Functional system ready for experimental implementation

V. RESULTS

A. Descriptive Analysis

The descriptive analysis of the observational results showed differences between the Experimental Group (EG) and the Control Group (CG) across the four evaluated indicators. The CG results reflect behavioral performance under conventional educational activities across the observation period, serving as the parallel baseline reference for this experimental design. Higher values indicate better performance for social interaction, following instructions, and emotion recognition, whereas a lower value indicates better performance for average traffic detection time. The descriptive results are presented in Table V.

TABLE V. DESCRIPTIVE RESULTS OF SOCIAL AND EMOTIONAL INDICATORS IN CONTROL AND EXPERIMENTAL GROUPS

Indicator	Control Group (CG)	Experimental Group (EG)	Interpretation
Proportion of social interaction (%)	35.47 ± 17.25	54.29 ± 23.89	Higher is better
Frequency of following instructions (%)	26.61 ± 21.27	63.29 ± 26.05	Higher is better
Emotion recognition rate (%)	26.67 ± 14.58	73.33 ± 19.62	Higher is better
Average time to detect oncoming traffic (s)	45.71 ± 2.02	24.29 ± 2.46	Lower is better

The Experimental Group obtained higher average values than the Control Group in the proportion of social interaction, frequency of following instructions, and emotion recognition rate. Specifically, the Experimental Group reached 54.29% in social interaction, 63.29% in following instructions, and 73.33% in emotion recognition, whereas the Control Group obtained 35.47%, 26.61%, and 26.67%, respectively. For the average time to detect oncoming traffic before crossing, the Experimental Group recorded a lower mean time of 24.29 seconds compared with 45.71 seconds in the Control Group. Since lower response time indicates better performance in this indicator, this result suggests that the Experimental Group may detect risky traffic situations faster, providing preliminary evidence of the effect of the VR application.

B. Inferential Analysis

Table VI presents the results of the inferential analysis performed for the four indicators evaluated in the research, with the aim of determining whether there are statistically significant differences between the Control Group (CG) and the Experimental Group (EG) after the implementation of the virtual reality mobile application.

According to the normality test results, nonparametric Mann–Whitney U tests were applied to the indicators of proportion of social interaction, frequency of following instructions, and emotion recognition rate, while Student's t-test was used for the indicator of average time to detect oncoming traffic before crossing.

The significance values obtained ($p < 0.05$) show statistically significant differences between the two groups in the four indicators analyzed. In particular, the results suggest that the Experimental Group performed better on indicators related to social and emotional skills, as well as a reduction in average time to identify traffic, providing preliminary evidence of the effect of the VR application.

TABLE VI. INFERENTIAL STATISTICAL TESTS BY INDICATOR

Indicator	Test applied	Statistic	P-value	Interpretation
Proportion of social interaction	Mann–Whitney U	U = 267.50	p = 0.002	Significant difference
Frequency of following instructions	Mann–Whitney U	U = 145.00	p < 0.001	Significant difference
Average time to detect oncoming traffic before crossing	Student's t-test	t(58) = -36.87	p < 0.001	Significant difference
Emotion recognition rate	Mann–Whitney U	U = 37.00	p < 0.001	Significant difference

Inferential tests were calculated using observational records collected during the intervention sessions. Since these records correspond to repeated observations of 10 participants, the results should be interpreted as preliminary evidence rather than definitive participant-level effects.

VI. DISCUSSION

The study employed a parallel-group experimental design in which the Control Group (CG) served as the concurrent behavioral reference, documenting performance levels under conventional educational conditions without VR exposure across the same observation period (October 2–22, 2024). Both groups were matched at allocation by age, educational level, and confirmed ASD diagnosis, supporting comparability between groups before the experimental phase. The post-test results for the CG, therefore, represent the expected behavioral trajectory in the absence of the intervention, against which Experimental Group outcomes are compared. This design follows established practice in parallel-group experimental research, where between-group comparisons at post-test provide the primary evidence of intervention effect [15]. Findings should nonetheless be interpreted as preliminary evidence given the small sample size (n = 5 per group) and the use of repeated observational records.

For the first indicator (proportion of social interaction), the results showed a notable improvement in the experimental group compared to the control group after using the virtual reality mobile application. This increase is attributed to the fact that virtual environments allow social situations to be simulated in controlled contexts, facilitating the repetitive practice of social behaviors without the pressure of the real environment. Immersion and progressive interaction with virtual characters encouraged greater social participation among children with autism spectrum disorder, which is consistent with previous studies reporting improvements in social skills through interactive virtual environments [12]. In this context, social interaction is understood as the ability to initiate, maintain, and respond appropriately to relevant social exchanges [19].

For the second indicator (frequency of following instructions), the results showed a significant increase in the experimental group, which showed an improvement in the understanding and execution of instructions. This behavior can be explained by the structure of the virtual scenarios, which presented clear, sequential, and visually accessible orders, reducing distractions and facilitating sustained attention. Several studies indicate that structured virtual environments contribute to reducing anxiety and disruptive behavior, promoting compliance with instructions in children with autism spectrum disorder [20]. Likewise, difficulties in following instructions are often related to attention and sensory processing challenges, which can be supported through structured virtual reality interventions designed for high-functioning children with autism [6].

For the third indicator (average time to detect oncoming traffic before crossing), the results showed a significant reduction in time in the experimental group. This finding indicates that repeated exposure to simulated road scenarios allowed participants to recognize relevant stimuli more quickly and efficiently, strengthening their ability to respond to risky situations. Virtual reality offers a safe environment for training skills related to decision-making and hazard identification without exposing users to real risks [21]. Likewise, controlled repetition of complex scenarios has been shown to promote learning and anticipation of critical situations [22].

For the fourth indicator (emotion recognition rate), the results showed considerable improvement in the experimental group after the intervention. This result suggests that virtual scenarios aimed at emotional recognition facilitated the identification and interpretation of facial expressions and social contexts. The visual representation of emotions in structured virtual environments reduces cognitive overload and promotes social-emotional learning in children with autism spectrum disorder [23]. In this sense, emotional understanding is defined as the ability to recognize, interpret, and respond appropriately to one's own and others' emotions, constituting a fundamental skill for effective social interaction [19].

Overall, the results suggest that the mobile virtual reality application was associated with improvements in social interaction, following instructions, emotion recognition, and traffic detection skills in children with autism spectrum disorder. These results provide preliminary evidence of the potential of VR interventions. However, the study is limited by the small sample size and repeated observations, which may affect the generalizability of the findings. Additionally, the use of the Oculus Quest 2 headset may impose a potential sensory burden, such as visual or auditory overstimulation, which should be considered in future research.

VII. CONCLUSION

This study provides preliminary evidence that a mobile virtual reality application may contribute to improving social interaction, following instructions, emotion recognition, and traffic detection skills in children with autism spectrum disorder (ASD) within a controlled educational setting. Improvements were observed across all evaluated indicators, suggesting that VR-based interventions may serve as a valuable complement to traditional teaching methods for children with ASD.

These findings should be interpreted with caution due to the small sample size, the use of repeated observations, and the potential sensory overload associated with the Oculus Quest 2 headset, which could influence engagement and performance during the intervention sessions.

Future research should include larger participant pools, explore additional educational contexts, and investigate the potential sensory effects of VR devices such as the Oculus Quest 2 to better understand their influence on engagement and performance.

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