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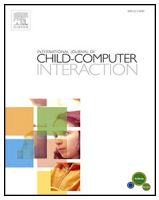

Research Paper

Improved socio-emotional skills in students with autism spectrum disorder (ASD) following an intervention supported by an augmented gamified environment

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ABSTRACT

This study examines the impact of an intervention using an Augmented Gamified Environment (AGE) to stimulate socio-emotional skills in a sample of 54 subjects with Autism Spectrum Disorder (ASD) aged between 3 and 17 years old. The study used a quantitative, exploratory, analytical methodology. Socio-emotional skills were evaluated before and after intervention (pre-posttest) using the *DiagnosticApp* instrument, supported by a fun app. The study specifically analyzed their ability to identify primary and secondary emotions and emotional states, as well as the cause-effect relationship linked to a context. The results show that socio-emotional skills improved after the intervention, regardless of gender, age, degree of ASD, comorbidity, or type of language. Overall, the greatest improvement was in identifying both primary and secondary emotions through recognizing facial expressions. Additionally, as expected, older students, and those with less severe ASD and more functional language exhibited higher scores in their socio-emotional skills. In conclusion, the extrinsic motivation associated with the mix of game mechanics, dynamics, and aesthetics, along with the augmented reality resources making up the AGE, are key contributing elements in improving these students' socio-emotional skills.

1. Introduction

Individuals with Autism Spectrum Disorder (ASD), as generally characterized by the DSM-5™ (American Psychiatric Association, 2013), exhibit persistent deficits in social communication, including difficulties in engaging in socially reciprocal responses, adopting non-verbal communicative behaviors, integrating communication effectively, and displaying anomalies in eye contact and body language, or a deficiency in the appropriateness of gestures. The most significant limitation observed in childhood is the absence of emotional self-regulation, where individuals often struggle to regulate their arousal, express negative emotions more intensely, and exhibit disproportionate emotional reactions (Mazefsky et al., 2012). This presents challenges within educational processes, the workplace, and, in severe cases, the autonomy and independent living of these individuals (Papoutsi et al., 2018). This social conditioning is a predictor for increasing difficulties in adulthood (Anderson et al., 2014). Therefore, interventions to stimulate these skills from an early age are necessary.

Balderas (2020) and Phung and Goldberg (2021) conclude that individuals with ASD may exhibit various types of social alterations: isolation, by rejecting all forms of physical and/or social contact; passive interaction, with no interest in social proximity beyond that necessary to meet basic needs; active yet "odd" interaction, associated with alterations in perception, recognition, and identification of emotions; and also appropriate interaction, that is, very similar to that of their peers. Baron and Bolton (1993) suggest that limitations on an emotional level can be explained by the Theory of Mind, highlighting the lack of social motivation and different information processing. Moreover, according to the Central Coherence Theory (Happé & Frith, 2006), these individuals perceive details before the whole. Moreover, another noteworthy quality is the difficulty in recognizing both primary emotions—such as joy, sadness, anger, fear, or surprise—and secondary emotions, which range gradually from disgust and shame to boredom and nervousness (Vatandoost & Hasanzadeh, 2020); as well as the emotions of others (Andrés-Roqueta et al., 2015).

In this regard, Carrington et al. (2020) advocate for the use of resources that integrate various codes (visual, verbal, auditory) and innovative formulas that enhance motivation, adopting the mechanics and dynamics of play. Recently, interventions with digital applications (apps) have been conducted to adapt to individual learning rhythms and

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capabilities (Aspiranti et al., 2018; Durán, 2021; Ntalindwa et al., 2021). Specifically, Baixaulli et al. (2017) and Papoutsi et al. (2018) use apps that stimulate social reciprocity, emotional recognition, or social norms. Furthermore, the findings of Doulah et al. (2023) reflect those emerging technologies, such as Augmented Reality (AR), incorporated in these interventions, integrate activities in 3D that simulate scenarios close to reality, promoting social interaction (Li et al., 2023), emotional recognition (Talaat, 2023; Lin et al., 2023), and cooperation with peers and autonomy (Bauer et al., 2023).

In this vein, innovative methodologies such as gamification supported by digital resources are being implemented, demonstrating positive results in identifying primary emotions (Dantas & Nascimento, 2022), enhancing interpersonal relationships in gaming contexts (Nabie & Gharebaghlou, 2022), cognitive skills, and solving problems associated with social norms (Hernández et al., 2022). Specifically, Lee (2021) highlights the importance of incorporating 3D virtual characters within these environments, noting that this teaching method can effectively improve the social skills of students with ASD by reducing the fear and anxiety they typically experience when interacting with real people. Furthermore, Lee et al. (2021) and El Shemy et al. (2024) confirm that the use of augmented reality captures the attention of children within this group, proving to be highly effective in teaching social responses.

Thus, considering the results observed in interventions using AR and those based on gamification, this research leverages the potential of both. Specifically, it analyses the impact of an intervention supported by an Augmented Gamified Environment (AGE) in digital format, designed from a playful narrative featuring fictional characters that engage the user, aiming to enhance the involvement of students with ASD and stimulate their socio-emotional skills.

In the following section, the methods for assessing socio-emotional skills in students with ASD are discussed, along with other interventions supported by gamification and augmented reality. Subsequently, the serious game *"From Deckhand to Captain: In Search of the Lost Treasure"*, specifically designed for this intervention, is described. Following this, the methodology employed, the sample, the designed instrument, and the procedure undertaken are detailed to facilitate future extrapolations to other contexts. Finally, the results obtained are presented, followed by a discussion and the conclusions drawn from the study's findings.

2. Socio-emotional skills of students with ASD: assessment and intervention

2.1. Assessment of socio-emotional skills

One of the most widely used scales internationally for assessing socio-emotional skills in this group is the Childhood Autism Rating Scale (CARS) (Schopler et al., 1980). Moon et al. (2019) and Randall et al. (2018) note that it has solid psychometric properties as it allows the evaluation of aspects of communication, social interaction, stereotyped behaviours, sensory anomalies, and emotional regulation. Additionally, McConachie et al. (2015) designed and used a scale to measure these skills based on the observation of joint attention, pretend play, social communication, stereotyped behaviours, sensory deficits, and language development. Similarly, Floyd et al. (2015) implemented standardised tests such as the Vineland-II to assess the adaptive behaviour of individuals with ASD in their interpersonal communication, daily life, socialisation process, and to identify their behavioural problems. Furthermore, the Social Responsiveness Scale (SRS) (Bruni, 2014) measures the severity of ASD symptoms using five subscales: receptive (social awareness), cognitive (social cognition), expressive (social communication), and motivational subdomains (social motivation).

Other research utilises digital tools, as in the case of Muller et al. (2016), who measured social skills by showing a 15-min short film and recording the process of social cognition in adolescents (MASC) (Dziobek et al., 2006). Specifically, subjects had to infer the mental states, thoughts, and intentions of two women and two men interacting during a dinner, thus detecting their limitations. Other studies take advantage of the potential of apps as contextual assessment instruments for these skills, as done by Andrés-Roqueta et al. (2017) to evaluate the emotional understanding of these students. And their emotional competence (Andrés-Roqueta et al., 2015; García-Arnanz et al., 2018). In this vein, López-Bouzas and Del Moral (2022) point out that using apps to assess socio-emotional skills provides a friendly and motivating context, fostering student involvement by displaying information with various codes –visual, verbal, and auditory– and presenting multiple options for accessing content, both perceptually and comprehensively. Hence, in this research, a collection of interactive activities presented through an app is chosen to record the students' skills.

2.2. Interventions with gamification and augmented reality to stimulate the socio-emotional skills of students with ASD

Gamification allows the integration of game mechanics and dynamics within playful scenarios, constituting an innovative formula to enhance the motivation and competency performance of these students (Carrington et al., 2020). Specifically, various studies take advantage of this methodology to stimulate the socio-emotional skills of individuals with ASD. Most studies focus on *emotional identification*, with Dantas and Nascimento (2022) developing a gamified environment that facilitates the recognition and expression of basic emotions. Pires et al. (2022) create an interface that eases facial recognition through neurofeedback.

Wang et al. (2022) design software that aids emotional recognition during therapeutic sessions. Similarly, Chien et al. (2022) build a social interaction platform based on games that encourages gaze following and emotional recognition. Griffin et al. (2021) use *Social Games for Autistic Adolescents (SAGA)* to increase sensitivity to gaze signals through an immersive story that encourages interaction with characters and reveals the usefulness of observing gaze signals to guide behaviour. Similarly, Scherf et al. (2018) design a gamified environment that enables individuals in this group to understand gaze shifts to facilitate their interpersonal relationships.

Others implement gamified digital resources to activate socio-emotional skills through *peer play*. Terlouw et al. (2021) use a gamified environment based on Escape Room techniques and facilitate direct communication between children with ASD and their neurotypical peers. Silva et al. (2019) promote collaborative task performance in the classroom using the *CoASD* environment. Mora et al. (2017) and Mairena et al. (2019) encourage social initiation and collaborative behaviours with the multi-user experience game, *Lands of Fog*. Additionally, studies exclusively focused on integrating game mechanics and dynamics to *enhance autonomy*, such as Hernández et al. (2022), who use the *PlanTEA* software for planning medical appointments and communicating with specialists through gamified activities. Adjorlu and Serafin (2019) stimulate their abilities to navigate the city. Elshahawy, Bakhaty, and Sharaf (2020) establish personal care behaviour guidelines during the pandemic with gamified activities. Vallefuoco, Bravaccio, Gison, and Pepino (2021) use virtual simulation games that recreate situations like the shopping process, promoting their autonomy.

More recently, Wang et al. (2022) observe that digital gamified environments are gaining relevance in interventions with this student group, integrating play and prioritising the visual channel, ensuring the meaningfulness of the experience. On the other hand, Dantas and Nascimento (2022) incorporate interactive playful missions with AR resources, achieving an increase in information assimilation. While there are studies that implement gamification and incorporate AR to stimulate linguistic skills (Lee, Chen, et al., 2018; Mota et al., 2020; Najeeb et al., 2020; Wendt et al., 2020, etc.), they do not specifically address socio-emotional skills. Therefore, the novelty of this study lies in analysing the impact of an intervention supported by an Augmented Gamified Environment (AGE) to develop these skills.

3. Augmented gamified environment "From Cabin Boy to captain: In Search of the Lost Treasure": a scenario for intervention

To enhance the socio-emotional skills of students with ASD, an Augmented Gamified Environment (AGE) was developed. This immersive digital space merges playful learning with activities supported by Augmented Reality (AR), fostering students' immersion in their learning process through interaction with digital devices (López-Bouzas y Del Moral, 2022). The AGE created, "From Cabin Boy to Captain: In Search of the Lost Treasure" (https://bit.ly/3VGKxWR), incorporates activities that stimulate socio-emotional skills through challenges or missions combining digital resources and AR applications (iOS and Android versions) integrated into a pirate narrative.

The environment's design followed the guidelines of Arzone et al. (2020) and Derks et al. (2022) to promote self-awareness, self--regulation, motivation, empathy, and social skills in digital gamified settings, alongside those mentioned by Nabie and Gharebaghlou (2022) to increase interpersonal relationships and play skills, or to facilitate emotional recognition (Pires et al., 2022). It aligns with the Universal Design for Learning framework criteria (Carrington et al., 2020), incorporating various codes (text, voice-overs, information windows, images, videos, etc.), diverse information (physical, virtual, visual, auditory, and audio-visual), and different resources (sheets, markers, cards, books, etc.). Subsequently, it was validated by experts according to the guidelines stated by Madariaga et al. (2016) regarding adaptability, functionality, reliability, and usability required in the design of educational software, especially aimed at students with ASD. The experts assessed its suitability (López-Bouzas et al., 2022) and made timely suggestions that were incorporated into the final prototype used in the intervention.

The AGE integrates various missions structured into three levels of gameplay suited to different learning paces (Fig. 1). Upon completing them, the student receives gold doubloons as a reward to progress in the story and earn more prizes: spyglasses, hooks, or pirate hats. The game journey includes feedback elements -as recommended by Carrington et al. (2020)-: descriptive, using some characters to give directions; evaluative, informing the player about the adequacy of the tasks; explanatory, integrating guidelines to correctly perform each task; and interrogative, incorporating questions that invite students to reflect on

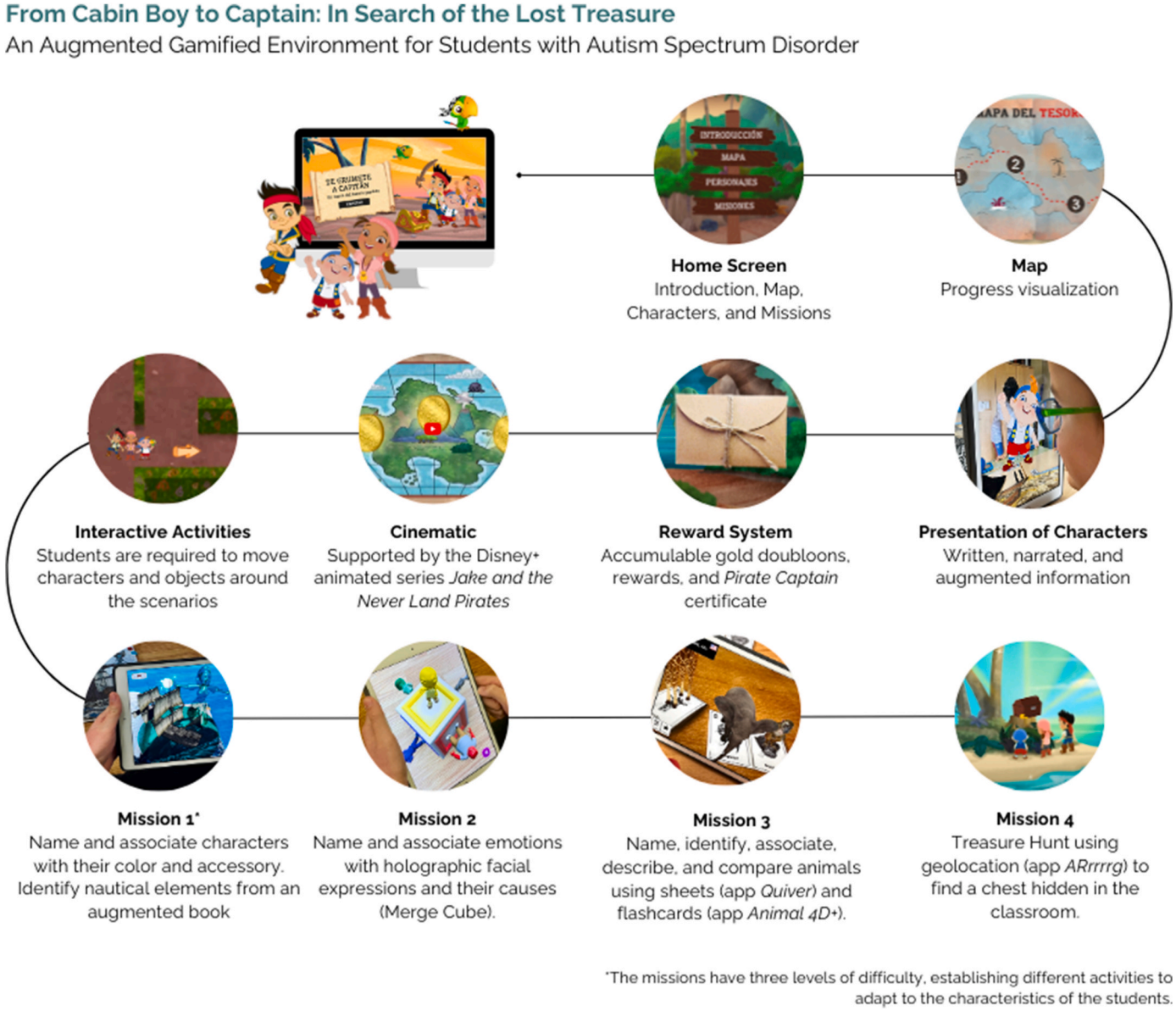

Fig. 1. Description of the age.

their performances.

Specifically, one of the missions involves matching emotion emojis with facial expressions using the *AffdexMe* app, which allows analysing and responding to facial expressions using AR. Another requires identifying each character from the movie *Inside Out* with the emotions reflected in certain sequences. Challenges are also presented to associate emotions with their causes by interacting with the *MomentAR* app and using the *Merge Cube* support (Fig. 2). The website for the designed game (https://de-grumete-a-capitan.webnode.pt) provides access to the apps used.

The AGE was implemented in an intervention with students with ASD. Initially, their socio-emotional skills were recorded after performing various interactive tasks presented in a playful app, obtaining a score that allows understanding their baseline situation (pre-test), and analysing their evolution after the intervention (post-test), as well as evaluating the environment's impact on their socio-emotional skills.

Therefore, the objectives of this research are: 1) to determine the impact of the intervention supported by the Augmented Gamified Environment (AGE) on the possible increase of socio-emotional skills of students with ASD; and 2) to analyse the extent to which this possible increase is related to the individual variables of the students: gender, age, degree of ASD, comorbidity, and type of language.

4. Methodology

This research is empirical, non-experimental, descriptive, and correlational in nature, adopting an exploratory and analytical character as typified by Cohen et al. (2011). Specifically, as noted by Bisquerra (2005) and McMillan and Schumacher (2005), this is justified by the following criteria: it is an *empirical* study, as the research relies on the objective collection of evidence using valid and reliable instruments; it is *non-experimental*, given that there is no manipulation of variables nor is it possible to compare an experimental group with a control group, since the socio-emotional skills of a single specific group of students with ASD who have used the designed serious game have been analyzed; it is a *descriptive* study as the primary aim is to present results related to a specific intervention, without intending to generalise these results to the entire population of individuals with ASD; furthermore, it is a *correlational* study, as, although there is no prior manipulation of variables, attempts are made to find explanations based on their interrelationships. In this case, correlations between socio-emotional skills and classification variables have been established to determine whether the latter could influence and condition the former.

It employs a design supported by a pre-test/post-test, as suggested by Kung et al. (2019), to investigate with this student population. Specifically, the study measures the impact of an intervention with an Augmented Gamified Environment (AGE) on the development of socio-emotional skills. The sample selection was intentional and non-probabilistic, incorporating participants who exhibited characteristics of interest for the study, as indicated by Hernández and Carpio (2019). That is, students previously diagnosed with Autism Spectrum Disorder (ASD) from Public Special Education Centres were included. The initial hypothesis is that an educational intervention supported by an AGE improves the socio-communicative skills of students with ASD.

4.1. Sample description

There are varied opinions on the appropriateness of the sample size for researching with these individuals. Derks et al. (2022) and Kim et al. (2020) suggest a large sample size. However, given the heterogeneity of this student population, Mercado et al. (2019) and Papoutsi et al. (2022) acknowledge that large samples are not always necessary. On the other hand, Griffin et al. (2021) and Lee et al. (2022) establish a range between 20 and 40 subjects. Therefore, in this study, intentional sampling was employed. The sample consists of students from three out of the five Public Special Education Centres in the region who volunteered to participate in the intervention.

Specifically, there are 54 male and female students, whose families provided consent. The recommendations for researching with minors (Shaw et al., 2011), the standards of the Declaration of Helsinki (World Medical Association, 2008), and the ethical regulations of the University of Oviedo (BOPA 141/23/VII/2019) were followed. The students had been previously diagnosed with ASD by specialists from the competent authority, i.e., the Department of Education of the University of Oviedo. The subjects belong to the following centres: C.P.E.E Castiello de Bernueces (N = 26), C.P.E.E Latores (N = 18) y C.P.E.E Juan Luis Prada (N = 10), achieving a participation rate of 91.5% regarding students with these characteristics from these centres. The distribution of the sample is depicted in Fig. 3.

4.2. Instrument

The *DiagnosticApp* instrument was designed ad hoc to measure the socio-emotional skills of the subjects before and after the intervention with the AGE (pre-test/post-test) . It consists of five variables, inferred from the DSM-5™ with four categories each, measured with a Likert scale (0 = very low, 1 = low, 2 = medium, 3 = high) (Table 1).

The instrument was validated through exploratory factor analysis, given the sample size, yielding significant results in Bartlett's test of sphericity (p = 0.000) and a high value in the Kaiser-Meyer Olkin adequacy test (KMO = 0.872). The maximum likelihood method was chosen – following the approach of Lloret-Segura et al. (2014) – with an

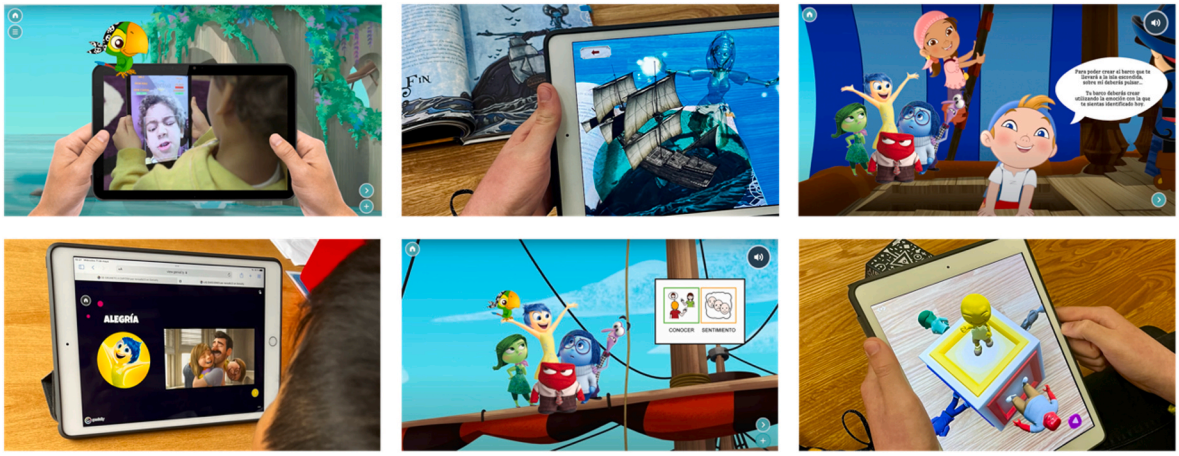

Fig. 2. Examples of AR activities that stimulate socio-emotional skills.

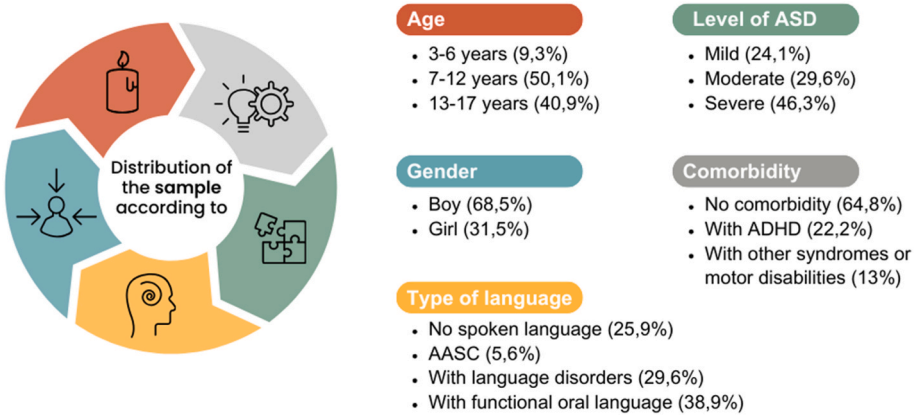

Fig. 3. Percentage distribution of the sample according to classification variables.

Table 1
DiagnosticApp.

Variables	Categories (1 = very low, 2 = low, 3 = moderate, 4 = high)
(V1) Identification of primary emotions from facial expressions	1. Does not identify primary emotions 2. Only identifies joy and sadness 3. Identifies joy, sadness, and anger 4. Identifies all of the primary emotions: joy, sadness, anger, fear, and surprise
(V2) Identification of secondary emotions from facial expressions	1. Does not identify the secondary emotions 2. Only identifies disgust and shame 3. Identifies disgust, shame, and boredom 4. Identifies all of the secondary emotions: disgust, shame, boredom, and nervousness
(V3) Identification of primary emotional states from facial and bodily expressions	1. Does not identify primary emotions 2. Only identifies joy and sadness 3. Identifies joy, sadness, and anger 4. Identifies all of the primary emotions: joy, sadness, anger, fear, and surprise
(V4) Identification of secondary emotional states from facial and bodily expressions	1. Does not identify the secondary emotions 2. Only identifies disgust and shame 3. Identifies disgust, shame, and boredom 4. Identifies all of the secondary emotions: disgust, shame, boredom, and nervousness
(V5) Identification of the cause-effect relationship of emotions linked to a context	1. Does not identify the cause-effect relationship of emotions 2. Identifies between 1 and 10 cause-effect relationships of emotions 3. Identifies between 11 and 20 cause-effect relationships of emotions 4. Identifies between 21 and 30 cause-effect relationships of emotions

eigenvalue criterion >1, resulting in the values for each variable explaining the total variance (Table 2) .

Table 3 shows that a single variable could explain more than 80% of the results. All variables exhibit a high proportion of explained

Table 2
Total variance explained by each factor.

Factor	Initial eigenvalues		
	Total	% de variance	% accumulated
1	4.116	82.323	82.323
2	0.357	7.139	89.463
3	0.265	5.299	94.761
4	0.161	3.221	97.982
5	0.101	2.018	100.000

Table 3
Communalities and factorial matrix.

Variable	Comunalities		Factor 1
	Initial	Extraction	
V1	0.719	0.686	0.828
V2	0.847	0.898	0.947
V3	0.790	0.779	0.883
V4	0.806	0.836	0.914
V5	0.658	0.691	0.831

variability in the factor and a substantial presence in that factor (in all cases, exceeding 0.800).

This interpretation is reflected in the sedimentation graph (Fig. 4) and the high degree of goodness of fit of the data to the model (χ^2 = 13.00 and sig. = 0.000).

The confirmatory factor analysis validated the unidimensional *DiagnosticApp* instrument for measuring socio-emotional skills. Therefore, it was used to compare the subjects' levels before and after the intervention with the Augmented Gamified Environment, attempting to confirm any potential improvement.

4.3. Procedure

The instrument served to measure the socio-emotional skills of the students through the execution of various activities integrated into the *AutisMind* app (https://autismind.com/), specifically designed for students with ASD. The activities feature 6 levels of difficulty and include examples of emotional recognition or fun social situations, along with motivational phrases and music to capture attention. Its use is simple and intuitive, avoiding information overload and unnecessary details, and it presents progressive difficulty with visual supports to facilitate understanding, thus avoiding frustration. It provides immediate feedback, allowing instant verification of the correctness of responses. It incorporates a gamification system with reinforcements and rewards that increase as levels are completed. It adapts functions to each user and informs them of their progress (Fig. 5).

Upon completing the tasks, individual scores of the students were recorded using the *DiagnosticApp* instrument, hosted on *Google Forms*, following a similar procedure implemented in other research studies with individuals with ASD (Bahrawi, 2023; Goswami et al., 2021). The recorded scores related to their socio-emotional skills were used to identify the initial level of each subject, as a pre-test, before the intervention with the Augmented Gamified Environment.

Subsequently, they played with the "From Cabin Boy to Captain: In Search of the Lost Treasure" Augmented Gamified Environment. After the intervention, the students performed the activities with the *AutisMind* app again, and their scores were once again recorded using the

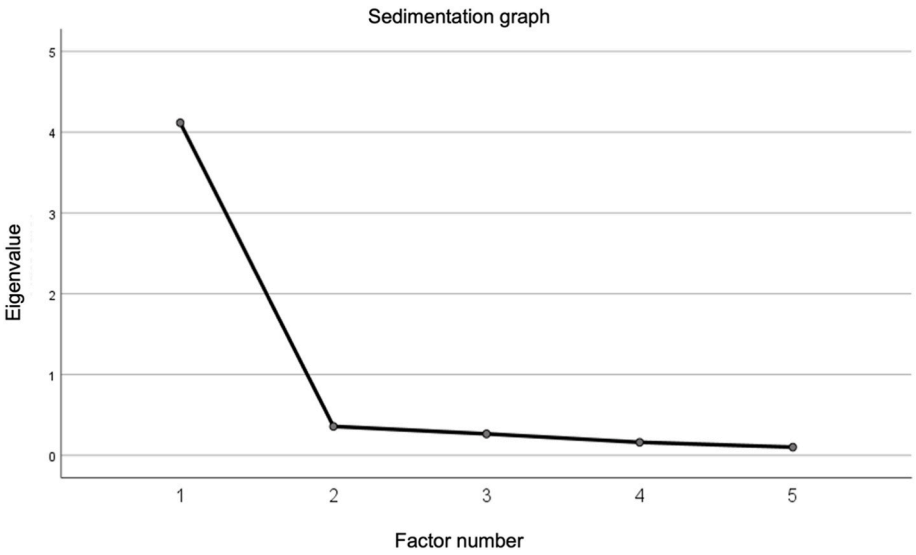

Fig. 4. Scree plot.

Fig. 5. AutisMind screen and images of task execution.

DiagnosticApp instrument, as a post-test. Finally, the data were analyzed, and pre-test/post-test scores were compared to verify the existence of statistically significant differences after the use of the Augmented Gamified Environment. Additionally, the influence of the classification variables of the students was analyzed.

The phases of the research process are summarized in Fig. 6.

Measures of central tendency, such as the mean, and measures of dispersion, such as the standard deviation, were used to represent in a straightforward manner the socio-emotional level achieved by the sample. Since the sample does not meet normality criteria, non-parametric tests were used in subsequent analyses. Specifically, the Wilcoxon Rank Sum Test was used to contrast the mean rank of pre-test and post-test variables, the Mann Whitney *U* Test to compare results between two groups, and the Kruskal Wallis Test to contrast between three or more groups. Additionally, Pearson's correlation was applied to confirm the interrelation between subject identification variables and

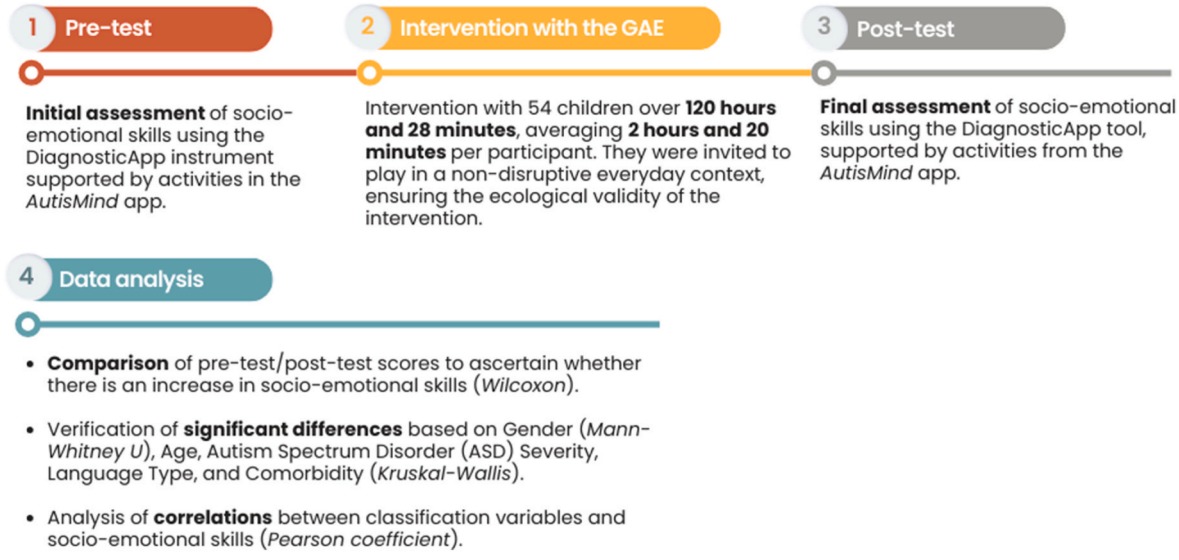

Fig. 6. Phases of the study process.

their socio-emotional skill level.

5. Results

The impact of the AGE is evident through the increase in scores across the five variables defining socio-emotional skills, comparing pre-test and post-test values. In particular, it was observed that several missions integrated into the AGE contributed to stimulating the minors' ability to identify primary emotions (V1) and secondary emotions (V2) based on facial expressions of augmented reality characters integrated into the AGE with the *MomentAR* app. An increase is also noted in the ability to associate primary (V3) and secondary (V4) emotional states with facial and bodily expressions. This relates to the type of AGE activities aimed at identifying emotional states with the corresponding emojis using the *AffdexMe* app. Furthermore, an increase is confirmed in the ability to establish cause-and-effect relationships of emotions (V5), which is associated with missions requiring the *Merge Cube* support and the appeal of augmented reality images to link an emotional state with its cause in each context (Fig. 7).

Overall, there is an increase in scores achieved in the post-test (Table 4). However, the subsequent contrast of means only reveals statistically significant differences regarding the ability to identify primary emotions based on facial expressions (V1), secondary emotional states based on facial and bodily expressions (V4), and to establish the cause-and-effect relationship of emotions (V5). Logically, this student body presents limitations associated with socio-emotional skills, leading to a greater increase in those skills that only require identification, as they entail a lower cognitive load.

In considering the classification variables, it is observed that the scores of the subjects do not vary significantly after the intervention concerning *gender*. However, variations are evident in relation to the *type of language* and the *degree of ASD* among students (Table 5). In all cases, the scores show an increase in the post-test.

Concerning *age* and *comorbidity* variables, an increase in scores is observed following the intervention (Table 6). Consequently, students with comorbidities exhibit a significant improvement in all skills in the post-test, except for the ability to identify primary emotions (V1). Conversely, age shows significant differences in the post-test ($p = 0.004$). A notable increase is also observed in the ability to identify secondary emotional states (V4) (pre-test: $p = 0.045$; post-test: $p = 0.036$) and to establish cause-and-effect relationships of emotions (V5) in the pre-test ($p = 0.017$).

Table 7 compiles the means recorded in socio-emotional skills according to classification variables, both before and after the intervention with the AGE (see Table 8).

Irrespective of *gender*, there is improvement in the identification of primary emotions (V1. Boy: $p = 0.000$; Girl: $p = 0.000$) and secondary emotional states based on facial and bodily expressions (V4. Boy: $p = 0.023$; Girl: $p = 0.024$). Boys significantly enhance their ability to identify secondary emotions (V2. $p = 0.006$). In contrast, girls increase their capacity to establish the cause-and-effect relationship of emotions linked to a specific context (V5. $p = 0.033$). Regarding the *severity of ASD*, a widespread increase is observed, albeit significant only in the ability to identify primary emotions in those with severe ASD (V1. $p = 0.000$) and in their ability to establish the cause-and-effect relationship of emotions in those with moderate ASD (V5. $p = 0.040$).

Table 4
Test of means for pre-test and post-test values.

	$\bar{x}$ Pretest	$\bar{x}$ Postest	DM	p
(V1) Identification of primary emotions from facial expressions	2.0	2.5	0.5	**0.000**
(V2) Identification of secondary emotions from facial expressions	1.3	1.4	0.1	0.133
(V3) Identification of primary emotional states from facial and bodily expressions	1.8	1.9	0.1	0.083
(V4) Identification of secondary emotional states from facial and bodily expressions	1.2	1.3	0.1	**0.024**
(V5) Identification of the cause-effect relationship of emotions linked to a context	1.1	1.2	0.1	**0.033**

Furthermore, concerning *type of language*, there is significant improvement in the ability to identify primary emotions based on facial expressions (V1) for subjects who: have no oral language ($p = 0.012$), have associated language disorders ($p = 0.006$), and have functional oral language ($p = 0.010$). Significant improvements are also observed in their ability to identify secondary emotions based on facial expressions in those with associated language disorders (V2. $p = 0.020$). Regarding associated *comorbidity*, it is noted that students without comorbidity ($p = 0.000$) and those with Attention Deficit Hyperactivity Disorder (ADHD) ($p = 0.012$) significantly improve their ability to identify primary emotions based on facial expressions (V1).

The overall score for students in *socio-emotional skills* is derived from the sum of scores in the mentioned five variables. This value is categorized into four levels using a Likert-type scale calculated based on the proportion over the total basis: very low (cases between 0.00 and 0.25), low (cases between 0.26 and 0.50), medium (cases between 0.51 and 0.75), and high (cases between 0.76 and 1.00). The results are depicted in Fig. 8.

The mean score in the *socio-emotional skill* variable for the subjects has significantly increased both before and after the intervention with the AGE (pre-test: $\bar{x} = 1.46$ vs. post-test: $\bar{x} = 1.59$; $p = 0.007$). On an individual level, it is noted that in 13 cases, this increase is statistically significant. Overall, the profile of this group of subjects is characterized by being children, over 7 years old, having a mild or moderate degree of ASD associated language disorders, and no comorbidity. Fig. 9 illustrates the increase in means concerning the socio-emotional skills of students based on the severity of ASD and type of language.

Correlations between the classification variables and socio-emotional skill are presented in Table 5.

As expected, it is observed that older students, with higher functionality in language type, and lower degree of ASD exhibit a higher level of socio-emotional skill both before and after the intervention with the AGE. It is also noted that subjects with a higher severity of ASD

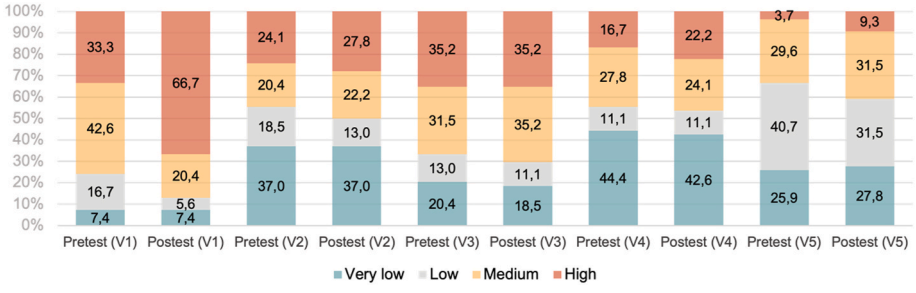

Fig. 7. Percentage distribution of students according to the level achieved in each variable before and after the intervention.

Table 5
Means for each variable (pre-test/post-test) by type of language and ASD severity.

V	Pre-test/post/test	Classification variables								
		Type of language					Severity of ASD			
		Lacked oral language	AACS	Language Disorders	Functional oral language	p	Mild	Moderate	Severe	p
1	Pre-test	1.00	3.00	2.00	2.57	**0.000**	2.69	2.38	1.44	**0.000**
	Post-test	1.71	3.00	2.50	2.86	**0.010**	2.69	2.69	2.20	0.374
	Evolution	0.71	0.00	0.50	0.29	–	0.00	0.31	0.76	–
2	Pre-test	0.14	3.00	1.06	2.05	**0.000**	2.31	1.88	0.44	**0.000**
	Post-test	0.21	3.00	1.38	2.00	**0.000**	2.38	1.94	0.56	**0.000**
	Evolution	0.07	0.00	0.31	−0.05	–	0.08	0.06	0.12	–
3	Pre-test	0.57	3.00	1.75	2.52	**0.000**	2.69	2.38	1.00	**0.000**
	Post-test	0.64	3.00	1.88	2.52	**0.000**	2.69	2.38	1.12	**0.000**
	Evolution	0.07	0.00	0.13	0.00	–	0.00	0.00	0.12	–
4	Pre-test	0.07	3.00	1.19	1.62	**0.000**	1.92	1.63	0.48	**0.000**
	Post-test	0.14	3.00	1.31	1.71	**0.000**	2.08	1.75	0.52	**0.000**
	Evolution	0.07	0.00	0.13	0.10	–	0.15	0.13	0.04	–
5	Pre-test	0.43	1.67	1.06	1.52	**0.001**	1.62	1.44	0.64	**0.001**
	Post-test	0.36	2.33	1.19	1.67	**0.000**	1.92	1.56	0.64	**0.000**
	Evolution	−0.07	0.67	0.13	0.14	–	0.31	0.13	0.00	–

Table 6
Means for each variable (pre-test/post-test) by age and comorbidity.

V	Pre-test/post/test	Classification variables							
		Age				Comorbidity			
		3–6	7–12	13–17	p	Without comorbidity	ADHD	Multi-disability	p
1	Pre-test	1.40	2.00	2.18	0.210	2.11	1.33	2.71	**0.007**
	Post-test	1.40	2.63	2.50	**0.004**	2.57	1.92	2.86	0.272
	Evolution	0.00	0.63	0.32	–	0.46	0.58	0.14	–
2	Pre-test	0.60	1.11	1.73	0.071	1.46	0.42	2.14	**0.006**
	Post-test	0.60	1.26	1.77	0.115	1.54	0.42	2.43	**0.002**
	Evolution	0.00	0.15	0.05	–	0.09	0.00	0.29	–
3	Pre-test	1.00	1.78	2.05	0.161	1.91	1.00	2.71	**0.005**
	Post-test	1.00	1.85	2.09	0.125	2.00	1.00	2.71	**0.003**
	Evolution	0.00	0.07	0.05	–	0.09	0.00	0.00	–
4	Pre-test	0.20	1.04	1.55	**0.045**	1.26	0.33	2.14	**0.004**
	Post-test	0.20	1.11	1.68	**0.036**	1.34	0.33	2.43	**0.002**
	Evolution	0.00	0.07	0.14	–	0.09	0.00	0.29	–
5	Pre-test	0.60	0.89	1.50	**0.017**	1.20	0.50	1.71	**0.004**
	Post-test	0.60	1.11	1.50	0.098	1.31	0.50	2.00	**0.003**
	Evolution	0.00	0.22	0.00	–	0.11	0.00	0.29	–

Table 7
Test of means in each variable (pre-test/post-test) by sample traits.

Variable		1		2		3		4		5	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Gender	Boys	2.24	2.53	1.65	1.53	2.18	2.24	1.35	1.35	1.12	1.29
	Girls	1.92	2.43	1.16	1.35	1.65	1.70	1.08	1.22	1.11	1.19
Severity of ASD	Mild	2.69	2.69	2.31	2.38	2.69	2.69	1.92	2.08	1.62	1.92
	Moderate	2.38	2.69	1.88	1.94	2.38	2.38	1.63	1.75	1.44	1.56
	Severe	1.44	2.20	0.44	0.56	1.00	1.12	0.48	0.52	0.64	0.64
Type of language	Lacked oral language	1.00	1.71	0.14	0.21	0.57	0.64	0.07	0.14	0.43	0.36
	AACS	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.67	2.33
	Language Disorders	2.00	2.50	1.06	1.38	1.75	1.88	1.19	1.31	1.06	1.19
	Functional oral language	2.57	2.86	2.05	2.00	2.52	2.52	1.62	1.71	1.52	1.67
Comorbidity	Without comorbidity	2.11	2.57	1.46	1.54	1.91	2.00	1.26	1.34	1.20	1.31
	ADHD	1.33	1.92	0.42	0.42	1.00	1.00	0.33	0.33	0.50	0.50
	Multi-disability	2.71	2.86	2.14	2.43	2.71	2.71	2.14	2.43	1.71	2.00

demonstrate lower functionality in type of language.

6. Discussion and conclusions

The intervention supported by the designed Augmented Gamified Environment (AGE) has contributed to the enhancement of socio-emotional skills in students with ASD, irrespective of individual variations. The missions within the environment facilitate the identification and verbalisation of various emotions. Additionally, the inclusion of characters from the film *Inside Out*, combined with the motivation provided by augmented reality, helps students associate each emotion with its corresponding context, thereby stimulating their socio-emotional skills. The motivation linked to the integration of missions and rewards in this pirate adventure encourages students to engage with the characters, which in turn promotes the development of emotional skills, similar to the findings of Dantas and Nascimento (2022). Specifically,

Table 8
Correlations between socio-emotional ability and classification variables.

	Gender	Age	Severity of ASD	Type of language	Comorbidity	LSES (Pre-test)	LSES (Post-test)
Gender	1						
Age	0.029	1					
Severity of ASD	−0.033	0.024	1				
Type of language	−0.204	0.239	−0.572[a]	1			
Comorbidity	−0.046	0.026	0.098	0.198	1		
LSES (Pre-test)	−0.158	0.379[a]	−0.692[a]	0.592[a]	0.054	1	
LSES (Post-test)	−0.104	0.372[a]	−0.668[a]	0.563[a]	0.057	0.978[a]	1

LSES: Level of socio-emotional skills.
* The correlation is significant at 0.05 (bilateral).
[a] The correlation is significant at 0.01 (bilateral).

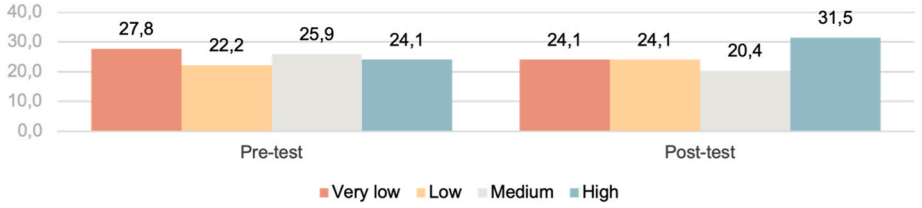

Fig. 8. Percentage distribution of subjects according to the level of socio-emotional skills before and after the intervention.

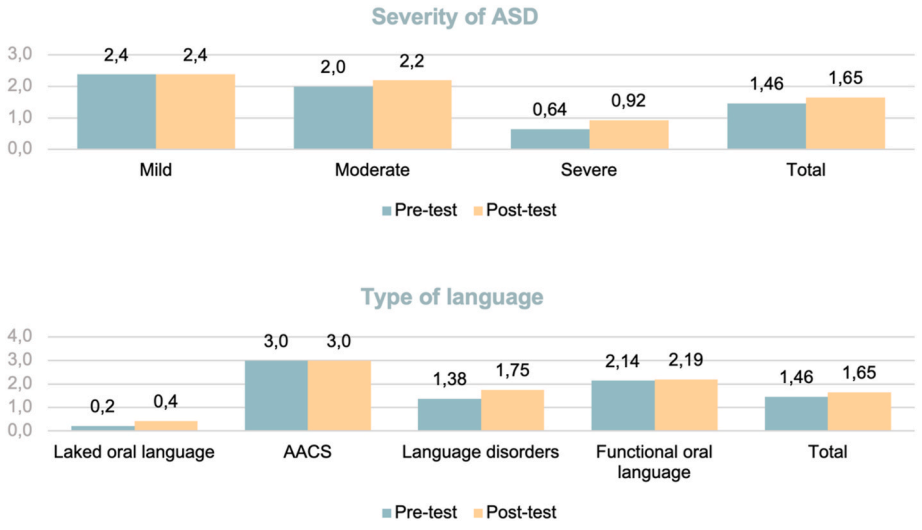

Fig. 9. Means achieved in socio-emotional skill before and after the intervention based on the severity of ASD and language type.

the most significant improvement is observed in the ability to identify primary emotions through facial expression recognition. Moreover, the activities incorporating augmented reality facilitate image association, resulting in meaningful learning, as concluded by Mota et al. (2020).

Socio-emotional skills are enhanced following the intervention with the AGE, regardless of individual characteristics. Notably, the greatest increase is observed in the identification of both primary and secondary emotions based on facial expression recognition. Andrés-Roqueta et al. (2017) highlight that gamified narratives are crucial as a motivational component for acquiring emotional competence. Furthermore, post-intervention data confirm that all students activate their socio-emotional skills, although Camargo et al. (2019) emphasize that using digital gamified environments presents challenges due to the complex clinical conditions and broad symptomatology within this spectrum. Specifically, as concluded by Wang et al. (2022), such structured digital environments that visually organise the game enhance the assimilation and significance of the experience, resulting in greater learning. Fridenson-Hayo et al. (2016) also underscore that an attractive aesthetic in these scenarios contributes to better emotional recognition.

In particular, the AGE *From Deckhand to Captain: In Search of the Lost Treasure* is an ideal resource for stimulating the socio-emotional skills of this student group, as its immersive narrative promotes engagement in tasks involving emotional recognition, identification, and association. The playful activities are motivating and encourage participation to achieve the game's objective. Additionally, the activities and resources are versatile and can be applied in other contexts. Undoubtedly, gamified environments are suitable resources for enhancing the socio-emotional skills of these students, as Tang, Falkmer, Chen, B?lte, and Girdler (2019) note, they are safe environments that promote autonomy and reduce feelings of frustration and anxiety, leading to better information assimilation and meaningful learning.

However, the data indicate that, despite the immersive nature of the AGE, some children required additional assistance to interact with various resources to complete the tasks. Specifically, the degree of autonomy among students varied considerably; some engaged with the game independently, while others needed constant support to navigate the missions and understand the activities. This highlights the need to develop support resources to assist children in the independent use of

the AGE, ensuring that the game is accessible and effective for all users.

It is observed that differences in the effectiveness of the game do not align strictly with the user's age or type of language, but rather with the degree of ASD presented. This implies that a 5-year-old child with a mild degree of ASD may face similar challenges to a 17-year-old adolescent with severe ASD. Therefore, it is crucial to adapt the AGE not only based on age but also considering the severity of ASD to provide effective support that allows users, regardless of their age, to achieve the same level of competence in recognizing and using emotions.

As study limitations, it should be noted that interventions with students who have comorbid ADHD and/or severe ASD were more complex due to their reduced attention capacity, necessitating the spacing of activities. The results pertain to a relatively small sample, and it would be necessary to expand this and analyse the implications of associated comorbidities in greater depth.

Future research should explore the personalisation of the AGE according to each user's specific needs, including the possibility of modifying colour schemes, visual contrast, or icons and avatars to simpler or more detailed versions depending on the user's needs. Different game modes could also be integrated, adjusted to the difficulty, pace of missions, and type of challenges based on the user's abilities. This might include adjustable difficulty levels, more detailed instructions, or contextual aids during the game. Additionally, designing resources and scenarios that recreate real-life situations within a motivating narrative is recommended. Comparative studies between experimental and control groups could also be conducted. Translating the AGE into other languages to examine differences across cultural contexts would also be beneficial.

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Selection and participation of children

For the ethical considerations regarding our study involving human subjects, we confirm that all procedures were conducted in accordance with the principles outlined in The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Additionally, our manuscript adheres to the Recommendations for the Conduct, Reporting, Editing and Publication of Scholarly Work in Medical Journals, ensuring the inclusion of representative human populations in terms of sex, age, and ethnicity, as per those recommendations. The terms "sex" and "gender" have been used accurately throughout the manuscript.

Furthermore, we obtained approval from the appropriate institutional committee(s) to conduct our study in compliance with relevant laws and institutional guidelines. The ethical approval(s) obtained were dated [insert date(s)] and referenced as [insert reference number(s)]. It is important to note that all procedures were performed with the informed consent of the participants. Prior to the intervention, families of the minors involved in the study provided consent for their participation after being fully informed about the nature and purpose of the research.

We affirm that the privacy rights of all human subjects were strictly observed throughout the study. Our manuscript contains a statement confirming that informed consent was obtained from all human subjects involved in the experimentation.

Moreover, we want to emphasize that the data derived from our study did not involve unethically sourced organs or tissue. We declare that all organs or tissues used in our study were procured in accordance with the WHO Guiding Principles on Human Cell, Tissue and Organ Transplantation. It is crucial to highlight that the organs or tissues used were obtained with autonomous consent free from coercion, and they were not sourced from executed prisoners or prisoners of conscience.

Regarding animal experiments, we confirm that all experiments complied with the ARRIVE guidelines and were conducted in accordance with the appropriate regulatory frameworks, including the U.K. Animals (Scientific Procedures) Act, 1986, EU Directive 2010/63/EU, or the National Research Council's Guide for the Care and Use of Laboratory Animals. The sex of animals was indicated where applicable, and the influence of sex on the results of the study, if relevant, was duly addressed in the manuscript.

We appreciate your attention to these ethical considerations and assure you that our study was conducted with the highest regard for ethical standards and integrity.

CRediT authorship contribution statement

Nerea López-Bouzas: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **M. Esther del Moral-Pérez:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jonathan Castañeda-Fernández:** Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Nerea reports financial support was provided by University of Oviedo. Nerea reports a relationship with Ministry of Universities and Innovation that includes: funding grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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