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Unlocking inclusive education: A quality assessment of software design in applications for children with autism ☆

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ABSTRACT

Digital technologies are an essential resource for maximizing education opportunities, yet the COVID-19 pandemic has exposed learning inequities, particularly among underrepresented groups such as children with autism. In this study, we have evaluated the quality of a distinctive dataset of multiplatform software applications, encompassing both assistive and mainstream software, first-hand acquired from special education professionals and families of children with autism. Through a heuristic evaluation based on a system indicators, and an in-depth analysis, we aimed to (1) assess the quality and effectiveness of assistive technologies in supporting the education of children with autism; (2) determine the adaptability of mainstream applications to the unique educational needs of children with autism; and (3) explore the features and constraints of applications targeting children with ASD, categorized according to the needs they cover. The resulting quality ranking, organized by cognitive domains, provides insights into the engagement and effectiveness of applications supporting the learning of children with autism. Furthermore, the findings delineating the functionalities and limitations of these applications contribute to the identification of necessary software engineering best practices. These practices align with user-centered design principles and drive the development of accessible software, thereby fostering high-quality inclusive education for children with autism.

1. Introduction

The Salamanca Statement and Framework for Action on Special Needs Education (1994) (Mel Ainscow and Best, 2019) marked a significant global milestone by introducing the concept of inclusive education. This concept was further elevated to the status of a fundamental human right through the United Nations Convention on the Rights of Persons with Disabilities (2006) (United Nations (UN), 2006). Additionally, the United Nations 2030 Agenda for Sustainable Development (2015) reinforced this commitment to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (Assembly, 2015).

Despite these global endeavors, the realization of inclusive education remains a complex and persistent challenge. This issue is of paramount significance due to its potential to marginalize vulnerable groups, such as children with disabilities, within the educational system (Mel Ainscow and Best, 2019). Moreover, this marginalization extends beyond academics, affecting social inclusion by denying students with disabilities the full range of experiences to which they are entitled (Graham et al., 2023).

Among the groups that continue to face barriers to inclusive education are children with Autism Spectrum Disorders (ASD).[1] Autism is a neurodevelopmental condition characterized by communication difficulties, social challenges, and the presence of repetitive and restrictive behaviors (Wing and Gould, 1979). Children with ASD may also contend with attention deficits and hyperactivity disorders, among other variations in severity and onset (Flannery and Wisner-Carlson, 2020). Therefore, educational approaches must be tailored to accommodate the unique strengths and challenges presented by each learner with ASD, aiming to facilitate their academic success (Able et al., 2015).

Recognizing the natural affinity many children with ASD have for technology (Porayska-Pomsta et al., 2012), the synergy between software engineering and education holds promise for maximizing learning opportunities and enhancing equity and inclusion. Technology offers a systematic approach harmonized with the cognitive needs of children with ASD (Purnama et al., 2021), often allowing them to explore learning at their own pace and reducing social anxiety, which may accompany traditional learning environments.

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[1] This study uses person-first language ("people with autism") as it was the preferred option of the professionals and parents of children with ASD who participated in the study, aligning with our commitment to maximizing respect and inclusivity.

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This potential, combined with technology's ability to support the acquisition of a wide range of skills by children with ASD, has led to a surge in the development of technological solutions aimed at them, with a special focus on assistive technologies (AT) (Ghanouni et al., 2020). AT encompasses systems and devices, ranging from augmentative and alternative communication (AAC) technology (Gillespie-Smith and Fletcher-Watson, 2014) to social assistive robots (Scassellati et al., 2012), designed to empower individuals with special needs, enabling them to perform tasks they might otherwise find challenging or inefficient (Suhaila and Nordin, 2022).

Studies show that the use of AT for computer-assisted instruction (CAI) in comparison to teacher-implemented instruction (TII) for children with ASD provide an alternative to traditional one-on-one instruction in special education classrooms to enhance student independence in learning and to reduce teachers' workloads (Hu et al., 2020).

Nonetheless, despite the burgeoning support for inclusive education facilitated by software applications, the advent of the COVID-19 pandemic unveiled the true effectiveness and engagement of technology in facilitating education for children with ASD. It also brought to light an increase in disparities in learning opportunities among children (Chinchay et al., 2022). During this challenging period, teachers, therapists, and caregivers of children with ASD turned to a variety of multiplatform technologies, including both AT and non-assistive (mainstream) technologies, in an attempt to overcome the educational barriers presented by the pandemic. The choice of these software applications was often driven by individual judgments due to the absence of standardized criteria that could guide the selection of the most suitable technological resources to meet the educational needs of children with ASD (Chinchay et al., 2022; Larco et al., 2018a). The effectiveness of software solutions hinges significantly on their accurate identification and thorough evaluation for seamless integration into the learning process (Navarro et al., 2016), thus the use of a robust metric becomes imperative.

In this study, our primary aim is to assess the effectiveness of various multiplatform software applications employed in the educational context of children with ASD, focusing on how their designs adequately meet the educational requirements of these children. We also consider whether these applications were specifically developed for children with special education needs (AT) or if their use was adapted to address their needs in applications not originally designed for this purpose (mainstream). The research questions addressed were:

- RQ1. What is the quality and effectiveness of assistive technologies in supporting education for children with ASD?
- RQ2. How adaptable are mainstream software applications to the unique educational needs of children with ASD?
- RQ3. What are the areas of coverage and potential shortcomings of features within software applications targeting children with ASD, categorized according to the needs they cover?

To answer RQ1 and RQ2, we will employ a quality-based heuristic evaluation specifically designed to analyze applications that address the psycho-pedagogic needs of users with ASD. Through this evaluation process, we aim to establish a comprehensive technological ranking of the most effectiveness applications for meeting the educational requirements of children with ASD. For mainstream applications, higher quality will also indicate greater adaptability to accommodate to diverse learning styles and requirements. To address RQ3, we will conduct a feature analysis to identify the attributes of software that enhance inclusivity and highlight the challenges that remain to be addressed to improve the design and development of accessible software.

2. Background and related work

The integration of technology to enhance the education of students with ASD is not a recent phenomenon; it has a rich history spanning more than three decades (Knight et al., 2013). While numerous instances of technology aiding cognitive skills in children with ASD can be found in the literature (Wojciechowski and Al-Musawi, 2017; Esposito et al., 2017; Halabi et al., 2017; Garcia-Garcia et al., 2022), particularly in the domain of literacy skills, the quality of these studies often remains scant (Knight et al., 2013). There is a noticeable deficiency in literature that integrates research-based evidence with practical implementations in real-world settings, hindering the establishment of comprehensive and validated quality standards for software solutions that extend beyond individual or isolated experiences (Heng et al., 2021). Furthermore, it has been observed that some ASD researchers and experts occasionally determine the effectiveness of technological interventions without conducting in-depth practical assessments (Soares et al., 2021).

Educators, therapists, and caregivers responsible for children with ASD require not only awareness of available technological applications but also an understanding of the quality elements underpinning their effectiveness, particularly with respect to addressing the unique needs of this demographic. This knowledge is crucial for their successful integration into the educational process (Putnam et al., 2019). However, a significant challenge persists in locating this information supported by empirical research (Ghanouni et al., 2020; van der Meer et al., 2011). This limitation serves as a potential barrier to the adoption of technology within this context. It is plausible that this hindrance contributes to the incomplete integration of AT into the practices of teachers and therapists working with children with ASD (National Standards Report, 2009). Moreover, a lack of awareness about these technologies (Botelho, 2021), coupled with a dearth of guidelines for their methodological selection and evidence-based evaluation, compounds the challenge (Ghanouni et al., 2020).

While software engineering focuses on developing effective and efficient software, there are few cases where individuals with ASD have been considered (Márquez et al., 2024). However, we do have review studies about technologies for people with autism (Epifânio and Da Silva, 2020). These studies employ software engineering approaches to determine attributes such as application quality from the perspective of individuals with ASD. Additionally, the need for interdisciplinary collaboration between therapists and software engineers to produce superior results in accessible software design becomes evident (Constain Moreno et al., 2023).

In the absence of a standardized quality assessment framework for software designed for children with ASD, practitioners often depend on app store reviews and star ratings for their selection process (Ming et al., 2020). Nevertheless, these customer-generated ratings are inherently subjective and considered unreliable as quality indicators (Kuehnhausen and Frost, 2013).

Alternatively, professionals may consider international frameworks and established usability and accessibility references like the Universal Design for Learning (Rose, 2000) or the Web Content Accessibility Guidelines (WCAG) (Caldwell et al., 2008) to guide their evaluations. Nonetheless, while these guidelines offer valuable initial guidance, they tend to provide generic recommendations and do not sufficiently address the unique and diverse needs, requirements, preferences, and learning disparities exhibited by children with ASD (Dattolo and Luccio, 2017). In addition, many of the existing accessibility standards may not encompass the assessment of dynamic content generation or multimedia-intensive software, characteristics often found in modern educational platforms (Jeschke and Vieritz, 2007).

As a result, a limited number of studies have delved into the exploration of alternative quality indicators and devised their own metrics and evaluation tools. Stoyanov et al. introduced the Mobile Application Rating Scale (MARS) as a framework for assessing the quality of health and wellness applications. Grounded in a comprehensive literature review of mental health apps, the MARS scale evaluates aspects related to engagement, functionality, aesthetics, information quality, and subjective quality (Stoyanov et al., 2015). Larco et al. adapted the application of the MARS metric to evaluate free Android and iOS AT applications sourced from a systematic search aimed at supporting the learning of individuals with various disabilities, including autism, Down syndrome, and cerebral palsy. Their findings emphasized the ongoing need for customization and interaction improvements within these applications (Larco et al., 2018b,a).

In the domain of educational applications, Lee and Kim introduced an evaluation framework, encompassing key factors such as teaching and learning, screen design, technology, and economy and ethics. Nevertheless, this framework awaits empirical validation prior to its full adoption (Lee and Kim, 2015). Moving into the realm of education for individuals with special needs, Weng introduced a prototype of a rubric that provides an inclusive checklist along with a rating scale for the systematic evaluation of AT applications designed for iPad use (Weng, 2015). Within this same domain, Kraleva and Kralev conducted an assessment of the potential of mobile applications to serve as AT for children with special educational requirements, employing a utility metric as their assessment tool. Their results reveal that only a limited number of applications genuinely align with the distinctive needs of this specific user demographic (Kraleva and Kralev, 2018).

Gallardo-Montes et al. stand out in the limited body of research by introducing and successfully validating a heuristic exclusively tailored for assessing applications created for individuals with ASD. Their heuristic emphasizes the critical dimensions of design, content, and pedagogy (Gallardo-Montes et al., 2021). Furthermore, the quality indicators within this heuristic have undergone recent empirical testing using free Android applications, obtained through the Google Play Store search engine, specifically targeting this user group (Gallardo-Montes et al., 2022).

This overview of literature highlights the paucity of metrics that have been crafted and rigorously validated by experts for the assessment of the quality and effectiveness of technological applications tailored to the distinctive requirements of children with ASD. Moreover, there is a significant gap in the metrics empirically employed across a broad range of applications, including not only AT but also commercial and mainstream multiplatform solutions, covering both free and paid offerings.

In a novel and distinct approach, this study focuses on evaluating a unique dataset of applications acquired directly from special education professionals and families of children with ASD. This approach captures real-world utilization, contrasting with other studies that rely on systematic reviews or app store searches (Larco et al., 2018a,b; Gallardo-Montes et al., 2022). Additionally, our study is not limited to AT applications; it also encompasses mainstream applications, including both free and paid versions. This broader scope differentiates our work from previous studies that typically focus solely on AT applications (Stoyanov et al., 2015; Larco et al., 2018a,b; Weng, 2015), free applications (Larco et al., 2018a,b; Gallardo-Montes et al., 2022), or mobile applications on either iOS or Android (Weng, 2015; Gallardo-Montes et al., 2022).

3. Methodology

3.1. Data collection

In a previous study, an online survey was conducted with the objective of assessing the performance of technology in supporting the educational and daily living needs of children with ASD during the COVID-19 pandemic (Chinchay et al., 2023). This survey was disseminated to specialized educational institutions, families, and organizations actively involved in addressing ASD and intellectual disabilities, mostly in Spain. From this research endeavor, a dataset comprising 212 multiplatform software applications intended to provide educational assistance to children with ASD was gathered through primary data collection involving 295 participants. Among the participants, 75% were educators and therapists, while the remaining 25% were family members of children with ASD. Moreover, this prior investigation categorized the collected software applications into 12 distinct technological categories, encompassing attention, authoring tools, calculation, e-learning, emotions, entertainment, experience of self, language and communication, memory, planning and time management, social networking, and social skills. These categories were derived from a thematic analysis that initially utilized Gillespie's classification of assistive technology for cognition as a predefined codebook (Gillespie et al., 2012). Subsequently, new domains were introduced based on emergent codes from the data, emphasizing factors deemed critical for children with ASD (Chinchay et al., 2023).

The initial dataset of multiplatform applications also included participant-reported usage frequencies. To identify the most prominent applications utilized both before and during the pandemic within each technological category, we filtered them accordingly. Initially, we determined the median number of applications per category and retained all applications in categories with a count lower than this median. For categories with a higher number of applications, we only selected those with a usage frequency exceeding the median frequency for each respective category. Through this approach, 100 applications were identified for further analysis. Fig. 1 illustrates the exclusion criteria used for the final selection of software applications to evaluate their quality and effectiveness. These criteria encompass the following procedural steps:

1. Clean-up selection: This step involved the removal of duplicated applications and those that were nested within others (e.g., various Google products such as Google Drive, Meet, Hangouts, Slides, all integrated into Google Classroom, or applications bundled in Teacher's Pack). This process aimed to eliminate redundancy and ensure the availability of clear, non-duplicated data.
2. Identification: This phase entailed the identification and elimination of applications that lacked an educational focus or did not contribute to the learning process. Notably, applications categorized within the 'Social Networking' domain were excluded. Additionally, applications intended for users other than children with ASD, such as those targeting their relatives or teachers (e.g., Authoring tools), were also removed.
3. Eligibility: Applications that were no longer supported, discontinued, or subject to restrictive access imposed by regional administrative entities were eliminated from consideration.
4. Evaluation: Applications selected to support the learning of children with ASD were assessed using the Gallardo-Montes et al. heuristic (Gallardo-Montes et al., 2021).

The final selection comprised 54 multiplatform software applications, embracing both AT (26, with 15 free and 11 paid versions) and mainstream technologies (28, with 13 free and 15 paid versions). These applications were often accessible across various platforms, with 48 (89%) available as mobile applications, 17 (31%) as web-based platforms, and 7 (13%) as desktop applications.

Besides the assessment of quality and effectiveness, a comprehensive feature analysis will be conducted on the selected software applications. This analysis is aimed at uncovering the primary characteristics and identifying potential areas for improvement in applications designed to support the education of children with ASD.

3.2. Instruments

The assessment of software applications for quality and effectiveness relied on the indicator system established and validated by Gallardo-Montes et al. (2021). This metric was chosen due to its substantial

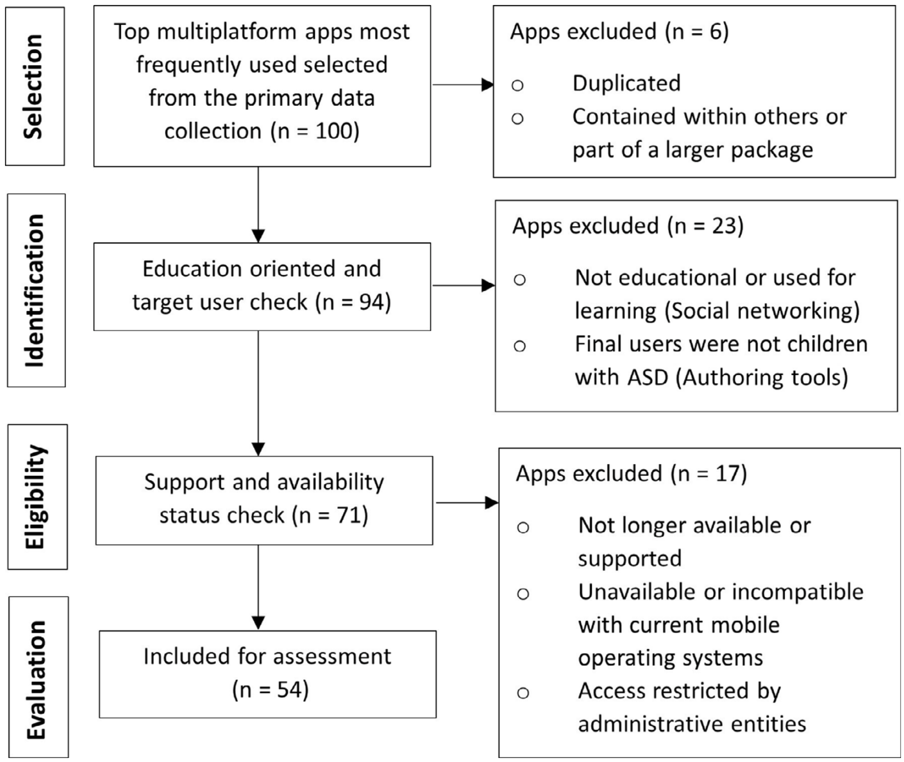

Fig. 1. Selection process for multiplatform software applications evaluation.

grounding in a comprehensive systematic literature review and its deliberate alignment with the psychopedagogical needs and attributes of individuals with ASD.

This heuristic framework, exclusively designed for assessing the quality of applications for people with ASD, is organized into three fundamental dimensions: Design/Form (D1), focusing on how the application was designed; Content (D2); and Pedagogy (D3), concerning the educational possibilities offered to individuals with ASD. As illustrated in Table 1, each dimension includes a series of indicators and subindicators to facilitate the heuristic's application. By assigning 1 point to each subindicator, D1 achieves a maximum score of 22 points (as personalization, velocity, and browsing contain an additional 11 sub-subindicators), D2 achieves 18 points (with content organization and parental control containing an additional 4 sub-subindicators), and D3 achieves 6 points. Therefore, the total score attainable through this evaluation system is a maximum of 46 points. This system of quality indicators also provides specific descriptions for each indicator. Its clarity, coherence, relevance, and objectivity have been evaluated by experts, resulting in excellent levels of internal consistency and inter-rater reliability.

3.3. Procedure

In a prior investigation, the final selected multiplatform software applications were classified into the technological categories of attention, calculation, e-learning, emotions, entertainment, experience of self, language and communication, memory, planning and time management, and social skills. This mapping process was guided by their intended functionalities and the reported usage patterns by survey respondents (Chinchay et al., 2023). Acknowledging that some applications could belong to multiple categories, each application was categorized according to its primary intended function before commencing the evaluation process. This classification was essential to mitigate redundancy across different categories. Additionally, applications were distinguished between AT and mainstream based on whether they were explicitly designed for users with special needs or targeted a broader audience. Subsequently, for paid applications lacking free trial options, their developers were contacted. Through their collaboration, temporary access to these applications was successfully obtained.

The 54 applications were evenly distributed among a panel of three experts specializing in software design for children with special needs. This team was responsible for conducting both the heuristic evaluation and feature analyses. The division of tasks involved one expert focusing on iPhone and iPad applications, while the remaining two experts concentrated their efforts on evaluating Android and desktop applications. The task distribution also considered the evaluation of applications within the same category by the same expert whenever feasible. The evaluation process for each application continued for days until all dimensions were thoroughly validated in accordance with the indicators system. The evaluation reliability was based on the internal consistency, coherence, relevance, and objectivity of the heuristic (Gallardo-Montes et al., 2021). Each expert was provided with the heuristic system template and a detailed description of each indicator. Regular meetings were conducted to discuss results among the experts.

The devices employed during this evaluation process encompassed smartphones, including the Samsung S22, Pixel 7 Pro, and Oneplus 8t, all running on the Android 13 operating system. Additionally, an iPad Pro, utilizing iPadOS 17, was included in the evaluation setup. Desktop applications were assessed on computers equipped with Windows 10 and Windows 11 operating systems. For web applications, the evaluation was conducted utilizing the Firefox and Chrome web browsers.

Regarding the feature analysis, the process initiated with the compilation of primary features outlined in the app stores or respective websites of each software application, grouping them per technological category. During the manual evaluation phase of each application, supplementary features were integrated into the collection as they were identified. Following the completion of this process, each expert conducted an individual qualitative analysis to identify recurring themes in the gathered data. These themes were subsequently deliberated among

Table 1
System of indicators based on dimensions and instrument for the assessment of applications for people with ASD.

Notation	Dimension	Indicators	Subindicators	Score
D1	Design/Form	Availability	Languages, updates, identifiable icon	22
		Ergonomics	Legibility, clarity, use of color, personalization	
		Usability	Velocity, browsing	
		Popularity	User rating, number of downloads, prizes	
		Accessibility	Access by users with ASD, use without internet	
D2	Content	Audio quality	Sounds, music, narration	18
		Narration	Voice modulation, clarity, neutral intonation	
		Content	Variety of topics, content organization, levels	
		Notifications		
		Help and tutorials	Written, audio format	
		Safety	Data protection, installation permissions, parental control, blocking of in-app purchases	
D3	Pedagogy	Interactivity	Use of own images or pictograms	6
		Adaptability to learning rhythms	Content suitable for ASD, sufficient time for activities, communication codes	
		Monitoring		
		Evaluation		

the three experts to ensure consistency and internal validity, culminating in a unified summary of main features per category. This analysis was aimed at uncovering the primary characteristics and identifying potential areas for improvement in applications designed to support the education of children with ASD.

3.4. Design and data analysis

Data analysis was conducted employing a cross-sectional non-experimental design methodology, which relies on the observation and measurement of variables without any intervening modifications. For this purpose, spreadsheets were crafted using Microsoft Office Excel to facilitate the evaluation process. These spreadsheets consisted of a master one containing an inventory of the software applications alongside their pertinent characteristics, such as their main technological category, type (assistive or mainstream), pricing, and platform. A secondary spreadsheet was dedicated to the template of the indicators system for each application, also featuring a section for conducting feature analyses.

The resulting quality ratings enabled the categorization of applications according to predefined score ranges (Gallardo-Montes et al., 2021). These ranges included 'not recommended' (scores of 22 or lower), 'recommended' (scores ranging from 23 to 36), and 'highly recommended' (scores equal to or greater than 37 points).

An statistical analysis was also conducted using IBM SPSS 28 software in order to explore in detail the data collected and to probe if any of the differences across the data was supported by statistics (e.g. if assistive applications got higher scores in any of the dimensions than the mainstream ones). This analysis involved loading each application's information on the system modeling the following variables:

1. Application Name: a string containing the name of the application.
2. Type: a numeric value indicating if the application was mainstream (0) or assistive (1).
3. Pricing: a numeric value indicating the type of monetization. This variable could be paid (0), freemium (1) or free (2).
4. Platform: a numeric value indicating the platform in which the application was tested. It could be Android (0), iOS or ipadOS (1), desktop (2) or web (3)
5. D1, D2 and D3: these numeric values corresponded with the score obtained on each dimension
6. Total: the sum of D1, D2 and D3

Once all the information was loaded, the following analysis were executed:

1. Descriptive analysis. This process provided us with an overview of the data and its descriptors
2. Distribution tests. In order to check the distribution of the data, we ran the one-sample Kolmogorov–Smirnov test before any other means comparison analysis. We checked the distribution of D1, D2, D3 and total.
3. Non-parametric tests. As the distribution of D1, D2, D3 and total did not follow a Normal distribution, Non-parametric tests were executed for each variable grouped by type, pricing and platform.
4. Finally, correlation tests were executed in order to evaluate the relation (if any) between type, pricing and platform.

4. Results

4.1. Quality assessment

The evaluation of the 54 multiplatform software applications yielded a quality ranking, classifying 5 (9%) as 'highly recommended', 40 (74%) as 'recommended', and 9 (17%) as 'not recommended'. In Table 2, we present the applications categorized as 'highly recommended' (scoring 37 points or higher). This table also includes details on the operating systems they were tested on, covering a selection of 3 AT and 2 mainstream applications. Among these, 3 are paid, 1 is freemium, and 1 is free. The applications within this group primarily fall into the technological categories of memory, calculation, entertainment, and language and communication. In contrast, the 'not recommended' group includes applications categorized under planning and time management, e-learning, entertainment, and language and communication.

The distribution of these applications in relation to the median total score (27.8) indicates that 14 AT applications and 13 mainstream applications scored above the median. This group comprises 9 paid, 7 freemium, and 11 free applications. Conversely, 12 AT and 15 mainstream applications, including 3 paid, 10 freemium, and 14 free applications, scored below the median.

Regarding the normality test of D1 — Design/Form, D2 — Content, D3 — Pedagogy and Total variables, the One-Sample Kolmogorov–Smirnov Test demonstrated that all variables did not follow a normal distribution. Consequently, we run non-parametric tests in order to evaluate the dependency of these values grouped by type, pricing and platform.

The type grouping analysis revealed a significant dependency of the D3 value on the application type, distinguishing between assistive and mainstream applications. This finding aligns with the inherent nature of the D3 dimension within the employed indicator system, which centers around the pedagogical aspects tailored to children with ASD.

Table 2
Ranking of highly recommended software applications. Note about type: AT: Assistive; M: Mainstream. Note about OS: : Android; : iOS or ipadOS; : Desktop (windows, mac, linux).

Application name	Type	OS	Pricing	D1	D2	D3	Total
NeuronUP	Assistive	Desktop	Paid	18	16	5	39
Smartick	Mainstream	Android	Paid	16	17	5	38
Smile and learn	Mainstream	Android	Paid	20	13	5	38
Language Therapy for Kids–MITA	Assistive	iOS	Freemium	19	14	5	38
Leo con Lula	Assistive	iOS	Free	18	13	6	37

As anticipated, the analysis confirmed that assistive applications tend to attain higher D3 values, a trend substantiated by statistical evidence.

When conducting a correlation test between type, platform, and price, we wanted to determine if there was any relationship between the type of application, the platform it was developed on, and its cost within that platform. Specifically, we aimed to understand whether assistive applications could focus their development efforts on a specific platform (for example iOS) and whether only paid applications could be considered more valuable within that platform. Alternatively, we wanted to explore whether they could be considered equivalent to, for instance, free applications on Android. Nevertheless the correlation test crossing each three grouping variables did not show any relevant result either so, can infer that there are no significant differences in this regard.

4.1.1. *Quality ranking by technological category*

Table 3 presents the quality ranking of software applications classified by technological category. Applications with a green background are categorized as “highly recommended”, those with yellow backgrounds are labeled as “recommended”, and those with red backgrounds belong to the “non-recommended” group. The operating system indicates the platform on which they were tested. Notably, there were 18 applications within the language and communication category, 7 in e-learning, 7 in planning and time management, 7 in entertainment (educational games), 6 in calculation, 4 in emotions, 3 in attention, 1 in memory, and 1 in self-experience. Unfortunately, no applications were available in the social skills category, as the lone application in this category, AutisMIND, was untestable due to its lack of compatibility with recent mobile operating systems.

Upon reviewing the results, it is evident that no application achieves the maximum score in D1 — Design/Form (22 points), with Smile and Learn coming closest. Similarly, none of the applications attains the highest score in D2 — Content (18 points); however, Smartick and NeuronUP come remarkably close. On the contrary, in D3 — Pedagogy (6 points), three applications, Sígueme, #SoyVisual, and Leo con Lula, achieve the highest attainable score.

Highlighting the top-scoring applications within each category, we find Sígueme (recommended) for Attention, a highly adaptable application for children with ASD. In Calculation, Smartick (highly recommended) stands out for its utilization of artificial intelligence (AI) to tailor the learning pace to the user. Matemáticas con Grin (recommended) also deserves mention for its interaction through an avatar. Within the E-learning category, predominantly composed of mainstream applications, ClassDojo (recommend with high score) emerges as an innovative educational platform that foster collaboration among teachers, families, and students. It also offers a rich assortment of tools for educators, interactive options for students, and even features such as a virtual playground. Focusing on Emotions, Breathe, Think, Do with Sesame (recommended) is notable for its work on emotional regulation. In the Entertainment category, while there are no AT, Smile and Learn (highly recommended) stands out with its activities tailored to special needs. For the Experience of Self category, there is only one application, iDo Hygiene, available only in English and that has not been updated for several years (recommended but with a lower score). In the Memory category, NeuronUP (highly recommended) is the sole representative, and it attains the highest score in the indicator system. This application, while requiring professional configuration for use, offers activities that can be used more independently by users with special needs. Within the Language and Communication category, despite the prevalence of applications, only two are rated as highly recommended: Language Therapy for Kids–MITA and Leo con Lula, both AT. Lastly, in Planning and Time Management, no application surpasses the median score. Time Timer, Día Día, and Mouse Timer are in the recommended group, while the rest remain categorized as ’not recommended’, with many of them being AT applications.

4.2. *Feature analysis*

The following subsections provide detailed descriptions of the features identified within each category, with a summarized overview presented in Table 4.

4.2.1. *Attention*

These applications offer a range of cognitive-visual and perceptual activities that encompass games and mini-activities, purposefully designed to enhance memory, speed, flexibility, and problem-solving. Additionally, most of these applications feature monitoring and evaluation system to track user progress. Users can usually also customize images, music, and videos to their preferences. The visual design and consistency within these applications are maintained using predictable visual interactions, repeated sequences that foster consistency and anticipation, and predictable environments based on real-life scenarios that recreate everyday experiences for users. Ultimately, many applications focus on enhancing image discrimination and fostering associations with real-world objects.

4.2.2. *Calculation*

Calculation applications frequently organize content by topics and age groups, allowing for a structured approach to learning. They could also provide options for user engagement, such as creating avatars or offering default characters to facilitate interactive experiences (e.g., Matemáticas con Grin). To ensure a safe and controlled environment, some of these applications restrict access to purchases and adjustments through pattern-based security measures. These applications offer progress tracking with detailed reports, motivational rewards, and customizable messages. Additionally, they incorporate user-guided interactive tutorials and adaptive learning using AI technology (e.g., Smartick), including diverse exercise types, such as writing, linking, selecting, and drag-and-drop activities, with visual and audio feedback provided at the conclusion of each task.

Table 3
Ranking of software applications classified by category. Note about type: AT: Assistive; M: Mainstream. Note about OS: : Android; : iOS or ipadOS; : Desktop (windows, mac, linux).

Category	Application name	Type	OS	D1	D2	D3	Total
Attention	Sígueme	AT	iOS	16	6	6	28
	Lumosity	AT	Android	16	7	4	27
	El Buho Boo	M	Android	15	7	2	24
Calculation	Smartick	M	Android	16	17	5	38
	Matemáticas con Grin	M	Android	14	15	4	33
	Flow Free	M	iOS	18	7	4	29
	Árbol ABC	M	Desktop	14	11	3	28
	Botones y Tijeras	M	Android	18	6	4	28
	Las Series Lógicas de Lucas	M	iOS	14	10	2	26
E-learning	ClassDojo	M	Desktop	19	8	5	32
	Microsoft Teams	M	Desktop	18	5	5	28
	Google Classroom	M	Desktop	16	5	5	26
	Aula virtual	M	Desktop	13	8	5	26
	Zoom	M	Desktop	16	3	2	21
	Espacio Onda	AT	Desktop	7	9	3	19
	Webex	M	Desktop	13	1	1	15
Emotions	Respira, piensa, actúa	M	Android	17	13	2	32
	Autismo - Descubra emociones (3d gratis)	AT	Android	14	10	4	28
	Breathe	M	Android	13	10	2	25
	EmoPLAY	AT	Android	12	8	4	24
Entertainment	Smile and learn	M	Android	20	13	5	38
	Masha y el oso - Juegos educativos	M	Android	18	7	4	29
	Piano Kids - Musica y Canciones	M	Android	19	7	3	29
	Teachers' Pack	M	iOS	16	7	5	28
	Minecraft	M	Android	14	9	2	25
	My PlayHome	M	Android	16	6	2	24
	Comida divertida	M	iOS	13	4	2	19
Experience of self	iDo Hygiene	M	iOS	13	8	3	24

(*continued on next page*)

4.2.3. *E-learning*

In this category, the applications exhibit a wide range of complexities and features. Many of these applications offer video conferencing capabilities, with options for live subtitles, call recording, and transcriptions. While some provide limited accessibility options, including prioritizing sign language users, persistent subtitle activation, and the ability to disable animations, customization primarily focuses on configuring participant views and saving chat messages after meetings. Additionally, advanced content settings are available for experts and teachers. Some applications with video capabilities enable the creation of unique virtual scenarios for participant placement, as exemplified by Microsoft Teams Together Mode and Zoom's Immersive View. Many e-learning platforms support integration and collaboration by enabling connections with other applications and providing tools for creating classes, subgroups, and calendars. Users benefit from access task and file repositories and have the flexibility to generate materials, notes, tasks, and grades. Furthermore, some applications incorporate additional tools, such as timers, a radio feature, and a noise meter. To enrich the learning experience, a rewarding system is typically integrated to motivate students, complemented by progress reports, class stories, and messaging capabilities. Moreover, students can create and customize avatars and explore innovative elements, such as virtual playgrounds (e.g., ClassDojo).

Table 3 (*continued*).

Language and communication	Language Therapy for Kids–MITA	AT	19	14	5	38
	Leo con Lula	AT	18	13	6	37
	#Soyvisual	AT	17	11	6	34
	Leo con Grin: aprender a leer	M	15	15	4	34
	José Aprende	AT	16	14	3	33
	Proloquo2Go	AT	19	10	3	32
	Grid 3	AT	16	10	4	30
	Niki Talk	AT	16	10	4	30
	LetME talk	AT	16	9	4	29
	Araword	AT	17	8	4	29
	Pictosonidos	AT	17	9	3	29
	Inference Pics	AT	16	7	5	28
	Dictapicto	AT	17	6	4	27
	Pictotraductor	AT	13	10	4	27
	Talking Pocoyó	M	16	8	2	26
	Logopedia	AT	14	7	4	25
	Conversation Therapy Lite	AT	11	8	5	24
	Conciencia Fonológica	AT	14	5	3	22
Memory	NeuronUP	AT	18	16	5	39
Planning and time management	Día a Día	AT	16	6	5	27
	Time timer	M	19	6	2	27
	Mouse Timer	M	18	5	2	25
	Fun Time Timer	AT	15	4	2	21
	Symbaloo	M	11	5	3	19
	Tempus Lite	AT	11	5	2	18
	Pictoagenda	AT	10	4	2	16

Table 4
Collection of main features provided by technological category.

Category	Summary of main features
Attention	Cognitive-visual and perceptual activities; Monitoring and evaluation; Personalization; Visual design and consistency
Calculation	Content organization and user interaction; Progress tracking and motivation; Learning features
E-learning	Video conferencing capabilities; Integration and collaboration; Customization and user control; Enhanced learning experience; Innovative features
Emotions	Emotional regulation; Emotion learning and recognition; Parental resources and personalization
Entertainment	Educational content and skills development; Multimedia enrichment; Activity reports and customization; Multiplayer collaboration and social skills
Experience of self	Self-care skills in multimedia instructions; Games for skill reinforcement
Language and communication	Augmentative and alternative communication; Communication enhancement; Customization and content view; Educational support; Progress monitoring
Memory	Cognitive Activities for rehabilitation and stimulation; Progress tracking and session planning; Customizable exercise settings
Planning and time management	Timer functionality; Routine and task management

4.2.4. Emotions

Emotions applications offer interactive activities dedicated to enhancing emotional well-being and problem-solving, while simultaneously aiding in the practice of techniques for fostering a sense of calm. Users can, for example, access customizable breathing patterns along with default exercises. Additionally, many of these applications serve for learning and recognizing emotions and facial expressions through engaging games, incorporating facial emotion recognition techniques (e.g., EmoPlay). Furthermore, some provide valuable resources for parents to navigate daily challenges with their children and empower personalization by allowing the crafting of personalized encouraging phrases.

4.2.5. Entertainment

These applications offer educational content and skills development through games that encompass various cognitive abilities, including comprehension, language, attention, memory, creativity, and multiple intelligences like linguistics, logical-mathematical, visual-spatial, and naturalistic. Additionally, some support the development of musical skills and provide activities for motor skills and sensory abilities. Moreover, these applications usually enrich the learning experience through multimedia elements such as illustrations, animations, stories, and sounds, including the integration of pictograms into stories (e.g. Smile and learn). Activity reports are offered, delivering detailed information on usage time and progress, while users have some options to configure features, including difficulty levels and a quiet mode without a chronometer for games. When multiplayer mode is provided it allows collaborative gameplay across various platforms, devices, and hybrid environments, promoting sociability and encouraging more effective interaction among peers.

4.2.6. Experience of self

Within the realm of Experience of self, applications offer features tailored to aiding users in acquiring self-care competencies. These applications deliver multimedia instructions replete with sequences for instructing users in an array of self-care tasks. These sequences can be presented in either video format or as a collection of images paired with text, complemented by audio narration harmonized with the on-screen textual content. Furthermore, it is a common practice for these applications to integrate mini-games that are directly aligned with the respective self-care activities.

4.2.7. Language and communication

In this category, augmentative and alternative communication systems with text-to-speech functionality are common. Few applications go a step further by providing users with tools for environmental control through a range of resources, including touch, switch, eye gaze, and pointing devices (e.g., Grid 3). Moreover, some applications cater to users with fine-motor challenges and vision impairments, offering options to adjust grid sizes, fonts (including size, case, and cursive handwriting), and image sizes, facilitating switch scanning and employing the VoiceOver screen reader. Additionally, some applications offer support for both symbol and text communication in multiple languages and provide features for transcribing audio to text and/or pictograms (integrated from ARASAAC (Anon, 2023)). Some other applications feature an extensive repository of visual materials and permit users to make custom additions. Educational support is paramount, offering games to enhance spoken language, improve articulation, attention, and memory, and facilitate learning of routines, emotions, and self-care. Furthermore, they usually provide text and video tutorials to guide users through the learning process, encourage high-level expressive, pragmatic, problem-solving language, and cognitive communication objectives, and incorporate a rewarding system to bolster user motivation. Some of these applications adapt the game difficulty based on the user's performance and stage. Finally, many of them include progress monitoring and result tracking features.

4.2.8. Memory

NeuronUP offers an extensive suite of cognitive activities tailored for rehabilitation and cognitive stimulation. These activities encompass both digital and paper-based exercises, thoughtfully categorized by cognitive processes, including orientation, attention, memory, language, executive functions, gnosias, praxias, visuospatial skills, and social cognition. Personalized monitoring to track results and progress is also available. Additionally, NeuronUP provides session planning resources suitable for both in-person and remote work scenarios. Users benefit from customization options that include adjusting instruction text, timers, total activity duration, interaction type (press or drag), downtime, and display settings, such as the number of items per row.

4.2.9. Planning and time management

These applications predominantly focus on timer-related features and the management of routines and tasks. Timer applications typically encompass functionalities allowing users to save and reuse timers, personalize attributes like colors, sounds, and display styles (e.g., wheel, bar, or graphical metaphors), select start and end sounds and animations, set repeat timers, and represent a wide spectrum of time durations. Users are provided with options for customizing timer settings or utilizing default configurations. Moreover, these applications offer the ability to associate timers with routines and waiting situations. Planning applications introduce visual agendas and calendars often integrated with pictograms and support data exchange through import and export features. Different agenda display options are sometimes provided allowing users to view tasks by year, month, week, day, and list views. Users are empowered to create personalized routines and events in the agenda, incorporating customizable details like activity names, time of day, multimedia attachments, and associated individuals and locations. Certain planning applications further optimize organization by providing features for managing website shortcuts through easily accessible buttons (e.g., Symbaloo).

5. Discussion

In the domain of educational support for children with ASD, the effectiveness of software solutions tailored to their needs relies heavily on their accurate identification and evaluation, facilitating their integration into the learning process (Navarro et al., 2016). Therefore, the resultant ranking of software applications offers valuable guidance to autism specialists and families, aiding them in making informed technological choices and thereby addressing a fundamental aspect of inclusion.

Although only 5 applications have achieved the status of "highly recommended", a potential limitation of Gallardo et al. heuristic could lie in its capacity to encompass a significant number of applications within the recommended group. This could be refined by modifying the group classification score value or introducing subindicators to evaluate elements such as the existence of advertising and its level of intrusiveness. We contend that applications like Leo con Grin: aprender a leer, #Soyvisual, Matemáticas con Grin, José Aprende, Breathe, Think, Do with Sesame, Proloquo2Go, and ClassDojo (all scoring above 32 points) might not currently belong to the highly recommended group, yet they are a few adjustments away from achieving that status and are equally commendable.

In the following subsections, we will conduct a detailed examination of the outcomes obtained in response to the research questions posited.

5.1. Quality and effectiveness of AT in supporting education for children with ASD (RQ1)

The rise of mobile technology, which holds the potential to enhance autonomy and improve the quality of life for individuals with disabilities (Doughty, 2011), has also led to an increased number of available applications, complicating the selection of effective options for autism interventions. This difficulty is compounded by the limited awareness of AT applications among educators and caregivers of children with ASD. Our findings show that the difference in the utilization of AT compared to mainstream applications to support education for children with ASD is not statistically significant, with only 26 out of the 54 software applications classified as AT. Furthermore, AT do not comprehensively address all cognitive domains, except for the domain of

Language and communication, which often constitutes a primary focus of learning interventions (Grynszpan et al., 2014).

The quality and effectiveness of AT in addressing the educational needs of children with ASD is evident in the ranking of applications that resulted from the evaluation process (Table 3). Contrary to potential expectations, highly recommended software applications are not all AT. In fact, AT achieves similar results to mainstream applications along the full ranking, standing out mainly in the area of Language and communication, as well as Memory. Furthermore, according to the statistical analysis, AT do not have a significant difference with mainstream applications in the evaluation of dimensions, with the exception of D3 — Pedagogy, where all applications achieving the maximum score are assistive. This indicates that although many AT focus their efforts on the pedagogical characteristics of children with autism, they exhibit limitations in areas related to software design, usability, adaptability, and maintenance (Ismaili and Ibrahimi, 2017).

During the heuristic evaluation of AT, several instances of non-compliance with the platform design guidelines were observed. Some of them even exhibited outdated user interfaces. Moreover, it was noticed that several AT solutions were not developed by commercial entities but rather by institutions specialized in assisting individuals with special needs or through temporary grants from such organizations. This particular characteristic might explain the lack of updates and maintenance for many of these applications. Consequently, even though these applications might have received initial recommendations and support from experts and families of children with ASD, they are frequently inaccessible for new users or on up-to-date devices. Notably, applications such as VirTEA, AutisMIND, Mefacilyta, and the mobile version of #SoyVisual were unavailable for testing due to the absence of current support. To address this issue, it would be advantageous for commercial companies to consider investing in these solutions, thereby contributing to their support and long-term sustainability. Such investment could also entail adapting mainstream applications to incorporate assistive features, ultimately extending their accessibility.

While the majority of AT applications are offered for free (15 out of 26), in contrast to the majority of mainstream applications that are paid (15 out of 28), our analysis did not establish a direct relationship between their quality and cost. For example, Espacio Onda is a paid application (19 €/year), but it faces challenges as its activities are not supported by modern web browsers and require users to employ their proprietary browser.

5.2. Adaptation of mainstream applications to the educational needs of children with ASD (RQ2)

Historically, the term "technology" within the sphere of disability predominantly referred to the domain of AT devices and services (Braddock et al., 2004). This had an impact in literature, where most studies assessing the quality of educational applications for children with ASD focus on the evaluation of AT (Larco et al., 2018b,a; Weng, 2015; Gallardo-Montes et al., 2022). The underlying assumption has been that AT is the sole or predominant means of support for this population. However, the empirical evidence reveals a different reality. Among the subset of 54 selected software applications used to support the education of children with ASD, it was observed that 28 were categorized as mainstream. Hence, it was imperative to assess the adaptability of these applications for children with ASD given that, despite the numerous commercially available educational applications, there is a lack of their evaluation in the literature (Weng, 2015).

While mainstream and AT applications are almost evenly distributed in the final ranking (Table 3), their alignment with the distinct educational requirements of children with ASD diverges in the dimension assessment. The dimension of pedagogy tailored to autism, D3, emerges as the domain requiring the most substantial enhancements. Particularly noteworthy is the limited utilization of diverse communication systems within these applications, where many predominantly rely on either text or audio formats, with minimal inclusion of alternative communication methods, such as pictograms. However, it is widely established that augmentative and alternative communication systems are a necessary communication medium for these applications (Abad et al., 2021). While the other dimensions yielded more favorable results, it becomes evident that a comprehensive revision of design guidelines, in collaboration with autism specialists, is necessary to facilitate a substantial leap in adaptation. This observation further reinforces the notion that many mainstream applications lack the capacity for independent utilization by children with ASD, necessitating external support. Consequently, although these applications can offer valuable assistance in addressing specific areas of interest for children with ASD, they simultaneously present challenges in terms of autonomy, accessibility, technical configurations, and the time required for fluent use.

In the ranking of highly recommended applications (Table 2), two standout mainstream applications, Smile and Learn, and Smartick, have demonstrated innovative learning methodologies designed for children, thoughtfully also considering those with special educational needs. Both applications are paid, aligning with the prevailing trend observed in the majority of mainstream applications included in our analysis (15 out of 28). Assessing the quality of these paid applications is deemed essential, particularly concerning their practical utility in the autism context. This distinction serves as a unique aspect of our study, as the existing body of literature often restricts its focus to the examination of free applications (Larco et al., 2018b,a; Gallardo-Montes et al., 2022).

The availability of various trading and payment models within mainstream applications can also impact their adaptability for children with ASD. Some payment-based applications may pose affordability challenges, making them accessible primarily to certain educational institutions while remaining financially out of reach for families with limited resources. Freemium options provide a valuable avenue for evaluating the effectiveness of application features. However, their functionality becomes restricted without the purchase of premium options. Furthermore, some free mainstream applications rely on advertising models that render them unsuitable for children with ASD. In some instances, these apps feature integrated purchases that are not adequately controlled or become excessively intrusive and distracting to users. These vulnerabilities necessitate consideration when tailoring applications for children with ASD.

5.3. Feature coverage and limitations of applications for children with ASD based on targeted needs (RQ3)

Table 4 encompasses the primary features derived from the examination of the software applications by technological category, elaborated upon extensively throughout the Results section. This analysis provides limited information in the areas of Emotions, Attention, Memory, Experience of Self, and Social Skills, primarily due to the smaller number of software applications available for these categories. Subsequent discussion per category follows.

5.3.1. Attention

All applications within the recommended group employ cognitive-visual and perceptual games and activities. The highest-scoring application, Sígueme, is an AT and has been meticulously designed to address the unique requirements of children with ASD, offering an extensive degree of content customization. Nonetheless, it faces the issue of lacking maintenance, with its most recent update dating back to 2016. This maintenance deficit has resulted in certain features not functioning correctly, thus diminishing its overall evaluation. The application with the lowest rating, Owlie Boo, is a mainstream one and receives a low score in the pedagogical dimension, primarily due to an abundance of advertisements. Collectively, applications within this category manifest the quality limitations previously expounded upon concerning both assistive and mainstream applications.

5.3.2. Calculation

The use of artificial intelligence, as exemplified by the highly recommended application Smartick, stands out for its ability to tailor the learning experience to each child's unique abilities and pace. This adaptability effectively caters to the needs of children with ASD, mitigating potential stress and loss of interest. Following closely in the ranking, Matemáticas con Grin, facilitates children's learning by introducing an avatar to accompany them during the educational journey. This interactive feature has the potential to enhance the attention and motivation of children with ASD while they engage in digital tasks independently. All the applications in this category are mainstream, which may be associated with this area offering the most diverse range of innovative features. Nearly all these applications are paid, freemium, or free with advertising, except for one that is entirely free (Flow Tree). In this context, the free with advertising applications attain the lowest scores, reinforcing the conclusion that this model may not be accessible for children with ASD. Additional design-related limitations found include the use of bright colors in certain applications and the inclusion of distracting elements, a practice discouraged for children with ASD (Pavlov, 2014). Limitations in the use of audio and narrations were also observed.

5.3.3. E-learning

The primary focus of these applications is on adult users. E-learning applications tend to feature complex user interfaces and, notably, none of them seem to provide a level of accessibility suitable for independent use by children with ASD. Additionally, most applications lack support for expanding communication methods, such as incorporating pictograms, alternative texts, or audio options associated with textual content. An additional accessibility concern arises in the context of video calling functionality present in certain E-learning applications. The limited support options available primarily address physical disabilities and do not adequately cater to cognitive impairments (Manco et al., 2023). Moreover, despite these applications offering an extensive range of features and content customization possibilities, they predominantly target educators. There is a clear need for more extensive options that facilitate the personalization of content tailored to children with autism, including the ability to modify tasks to suit each student's specific requirements. An additional observation is that only one application was AT (Espacio Onda). However, this application exhibits limitations in terms of usability, characterized by outdated, confusing designs and reliance on obsolete technology, along with concerns related to affordability, as it necessitates periodic payments. The most noteworthy application in this category, ClassDojo, introduces innovative features such as customizable avatars for students and access to a virtual playground. Despite these appealing features, ClassDojo has not emerged as the most widely adopted application, possibly due to strong competition from popular commercial alternatives, albeit with inferior outcomes.

5.3.4. Emotions

Emotions applications can be categorized into emotion learning applications and those designed for emotional regulation, aiding children with ASD in regaining calm during crisis situations. All the applications obtained fall within the recommended group, with Breathe, Think, Do with Sesame showing significant promise. This mainstream application stands out for its user-friendly operation and user interface simplicity. With a few refinements, it has the potential to attain a highly recommended status. These adjustments may encompass the expansion of communication codes by integrating text linked to audio and/or pictograms and introducing activity tracking features. It is worth noting that many commercial applications tend to be more accessible when they maintain simplicity, with accessibility diminishing as the complexity of use and content overload in the user interface increases. The application with the lowest rating, Emoplay, falls under the category of AT and encounters issues associated with maintenance (with its last update dating back to 2019). These maintenance challenges result in operational errors, particularly concerning its facial recognition of emotions. Additionally, the application could benefit from the incorporation of more user personalization options.

5.3.5. Entertainment

These applications play a pivotal role in enhancing skill development among children with ASD, particularly in areas like language and social skills, employing various games and educational activities. According to the results, none of the applications in this category are AT. Nevertheless, Smile and learn, which emerges as the highest-rated application in this domain and attains the highly recommended status, offers many functionalities tailored to the unique requirements of children with ASD. These include support for pictograms and the flexibility to customize the learning experience according to each child's pace. The remaining applications, despite their incorporation of various multimedia elements, achieve low scores in D2 — Content. The capacity for proper content adaptability and customization, coupled with the selection of suitable narratives, holds significant importance for children with ASD, given their susceptibility to emotional impacts (Hassan et al., 2021).

5.3.6. Experience of self

There is a scarcity of applications in this category, with only one application assigned to this domain. Regrettably, this singular app, iDo Hygiene, has not seen any updates since 2016. Consequently, there is a pressing need to develop software that can effectively support the development of identity awareness and body perception in children with ASD. These applications are vital for enhancing the overall quality of life for these children (Lucci, 2016).

5.3.7. Language and communication

In this category, we observed the highest level of application support for children with ASD, with nearly all applications (except for a couple) being AT. These applications adapt to the specific communication profiles of the children, offering a spectrum of options that encompasses alternative and augmentative communication tools for severe cases, as well as applications designed to enhance speech, reading, and writing abilities. Although these applications provide a diverse and well-developed set of features, only two of them achieve the highly recommended group (Language Therapy for Kids–MITA and Leo con Lula). The remaining applications attain high scores in the pedagogical dimension due to their strong educational components but receive lower ratings in content dimension. Notable limitations in quality content include usability issues in the user interface and outdated designs. Additionally, the configuration and customization of the application often depend on the complexity of the software and must be managed by a family member or educator. The most significant impact on this dimension was observed in the case of #SoyVisual, which is no longer classified as highly recommended as it once was (Gallardo-Montes et al., 2022) due to the absence of updates in its mobile version. Lastly, it is important to emphasize the affordability challenges associated with certain alternative and augmentative communication applications due to their high pricing.

5.3.8. Memory

A single application, NeuronUP, occupies this category, earning the distinction of being highly recommended and attaining the top score in the quality assessment. Noteworthy attributes of NeuronUP include extensive activities encompassing cognitive processes, offered in both digital and on paper formats. These activities are characterized by a high degree of content customization, enabling alignment with children's evolving needs and skill levels. One limitation of NeuronUP is its complexity, as it primarily targets professionals who must handle all the initial setup. There is a need for alternative applications that enable use by family members or facilitate independent usage by children with

ASD, featuring a more user-friendly design. Additionally, the cost factor presents a concern, with a subscription plan for use with children priced at approximately 50€/month. While this cost covers professionals and allows for an unlimited number of users, it could restrict accessibility to a wider audience.

5.3.9. Planning and time management

Applications within this category mainly encompass agendas and timers. Many of these tools require initial setup by educators or family members, which may not facilitate independent use by children with ASD. Additionally, this area has yielded the lowest scores, with none surpassing the median value. Several assistive applications have been rated as not recommended, with some facing issues related to maintenance or limitations in D2. Among the recommended applications, Día Día is a visual agenda specifically oriented to ASD users, featuring a simplified interface view, user-friendly guidance, and the inclusion of pictograms. However, it shares a common issue with several assistance applications, which is the lack of maintenance (last updated in 2019). The other two recommended applications are visual timers. Among them, Mouse Timer stands out for its user-friendly interface, providing various predetermined time options and representing the passage of time through a visual metaphor (a mouse eating apples). The results obtained in this category, coupled with the limited information on AT solutions supporting planning and time management skills (Desideri et al., 2020), underscore the necessity for the development of more comprehensive resources.

5.4. Recommendations and implications for software engineering

In general, we observed that the majority of software applications provide monitoring and evaluation systems for activities. However, these systems are typically designed for the use of parents and experts rather than being tailored to the understanding of children with ASD. Improved visualization methods that align with the cognitive needs of children with ASD could enhance their self-perception of learning.

Another significant constraint is that among all the applications analyzed, only a limited number are tailored for self-sufficient use by children with ASD, often necessitating external assistance from family members or educators. There is a clear need for a more user-centric approach, possibly involving participatory design methods, to enhance children's autonomy. Additionally, there remains an absence of activity customization, with limited options for incorporating adaptable elements or configuring information in diverse formats. The joint integration of various communication systems, such as audio, text, and pictograms, is also not a common feature.

Enhancing security measures based on patterns should also be a prudent step to inhibit unauthorized access to in-app purchases. Furthermore, it is recommended to minimize the use of applications featuring advertisements that could potentially disrupt the attention and overall experience of children with ASD.

Ultimately, based on our findings, the main recommendations for improving the quality of educational applications for children with ASD, along with their implications in the software development lifecycle, are as follows:

- **Allow content adaptation and personalization:** Engage in participatory design with educators and ASD experts to implement customizable settings. Ensure adaptability functions work correctly across different user profiles during the testing phase.
- **Use of diverse communication systems:** Develop suitable narratives, audio, text, and pictograms, which are significantly important for children with ASD. This should be integrated into the design and development phases.
- **Adapt visualization of activity results:** Understand the cognitive needs of children with ASD during the analysis phase to design and develop visual representations that promote self-perception of learning. These visualizations should be aligned with their cognitive needs and validated through user testing.
- **Simple design to foster greater autonomy:** Promote independent usage of applications by designing simple, intuitive interfaces that minimize content overload and provide user-friendly navigation. These designs should be tested with users with ASD to ensure accessibility and mitigate potential stress.
- **Enhance the User Experience:** While ensuring a simplified interface, avoid outdated designs. Develop engaging and motivating interfaces tailored to the learning experiences of children with ASD, such as incorporating avatars. These strategies should be validated through user testing with ASD users.
- **Review commercial support:** Inhibit unauthorized access to in-app purchases and consider alternative revenue models that do not rely on disruptive advertisements, which are not accessible for children with ASD.
- **Ensure Ongoing Maintenance:** High-quality applications can become obsolete or unavailable without proper maintenance, significantly impacting their users. This is particularly relevant for many AT applications, which need to include maintenance support and updates in their development lifecycle.

6. Limitations and future work

The quality ranking of software applications holds potential as a valuable resource for teachers, therapists, and families of children with ASD in identifying and selecting the most suitable educational resources. However, some limitations should be noted. The system indicator created by Gallardo et al. did not account indicators related to OS or price, as it assumes that special education centers primarily use free Android applications (Gallardo-Montes et al., 2021). Moreover, most indicators are specifically mobile-oriented, neglecting the broader range of applications utilized for children with ASD.

Given these considerations, it is essential to review and expand this heuristic to better reflect a more accurate sample of software applications. The 'recommended' group could also benefit from more precise definitions by modifying the group classification score value or introducing subindicators to evaluate factors such as the presence of advertising and its level of intrusiveness, considering the large number of applications classified within this group.

In future work, we aim to extend the study to an updated list of applications whose usage has persisted post-pandemic and to include more applications in the less represented categories. Additionally, we plan to involve teachers, families, and, whenever possible, the end-users with autism in the evaluation process to ensure a comprehensive and inclusive assessment.

7. Conclusions

Our study pioneers the comprehensive quality evaluation of multi-platform software applications, acquired directly from special education professionals and families of children with ASD, thus offering an authentic representation of applications that are genuinely ingrained in and utilized within the realm of educational support for children with ASD.

We identified 26 of these applications as assistive technology (AT), and 28 as mainstream, with a notable prevalence of mobile applications. The resulting quality ranking is poised to serve as a valuable resource for educators and families of children with ASD, aiding them in making informed decisions regarding the selection of highly effective software that cater to the diverse educational needs of these children, regardless of their assistive or mainstream nature. It also facilitates their seamless identification. In the highly recommended applications group, there were 3 AT applications (NeuronUP, Language Therapy for Kids–MITA, and Leo con Lula) and 2 mainstream ones (Smartick and Smile and learn).

In the evaluation of AT quality and the alignment of mainstream applications with the educational requirements of children with ASD, we found that AT applications commonly exhibit usability issues, while mainstream applications encounter challenges related to accessibility.

Despite their valuable role in supporting children with ASD, the engineering of AT applications necessitates dedicated attention to enhance their design, optimize user experience, and ensure ongoing maintenance, especially given their reliance on organizations affiliated with special needs support, often constrained by limited funding. Achieving a balance in support across cognitive domains is also essential to maximize the benefits of these applications, as well as bolstering user knowledge to facilitate their effective utilization.

Mainstream applications have also proven beneficial in aiding children with ASD, yet they often necessitate greater external assistance for configuration and use, primarily due to their relatively complex user interfaces. These accessibility limitations, impacting autonomous use by children, along with the required learning curve, constitute important challenges.

The analysis of application features across categories provides insights into technological functionalities and innovations, including the utilization of AI for personalized learning and the integration of personalized avatars. However, it also reveals existing limitations. Our findings, based on the dimension's evaluation, underline the importance of revisiting user-centered design principles in both AT and mainstream applications. Optimizing content adaptation and personalization, facilitating the use of diverse communication systems (audio, text, and pictograms), promoting the visualization of activity results to enhance self-perception of learning, prioritizing a simple design that fosters greater autonomy, enhancing the user experience, reviewing commercial support, and ensuring ongoing maintenance are essential imperatives.

These findings underscore the necessary improvements in the software design and development process required to attain high-quality and accessible applications tailored to the unique needs of children with ASD, and to enhance their opportunities for inclusive learning.

CRediT authorship contribution statement

Yussy Chinchay: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – original draft. **Javier Gomez:** Conceptualization, Investigation, Resources, Supervision, Writing – review & editing. **Germán Montoro:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors 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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