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Design of a mathematical problem-solving application for students with autism spectrum disorder

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ABSTRACT: This paper is devoted to the design, description and validation of the Android application TEAtreves, which focuses on structured arithmetic problem-solving for students with autism spectrum disorder (ASD). The application contains multiple adaptations to make it suitable for users with ASD. Validation was carried out with five students with ASD, obtaining positive results which confirm the strength of TEAtreves app for users with ASD. Results and future lines of work are discussed.

Keywords: Autism spectrum disorder, Mathematical problem-solving, Android application

1. Introduction

In the last decades, many researchers have been interested in the inclusion of technology into the teaching of students with autism spectrum disorder (ASD). For example, digital learning environments have been developed to help users with autism with the management of emotions and social relations (Fage et al., 2019; Grossard et al., 2017). Recent studies have shown the benefits of these resources for students with ASD, so that Technology-aided instruction and intervention (TAII) is considered an evidence-based practice (Wong et al., 2015). The range of technological means used is wide and goes from the computer to the use of robotics or virtual reality (Grynszpan et al., 2014; Odom et al., 2015), showing evidence of their effectiveness in diverse types of activities such as cognitive and social skills (Leung et al., 2021) or literacy skills (Pennington, 2010), among others.

Positive results are also obtained with students with ASD if we compare the use of technology with other teaching methods or resources. In Chen and Bernard-Opitz (1993), computer-assisted instruction was compared to personal instruction, finding no difference between participants' learning rate between both methods. However, for 3 of the 4 participants, computer-assisted instruction proved to be more motivating, and it generated fewer behavioral problems. Bouck et al. (2014) compared the use of base-ten concrete manipulatives to virtual manipulatives, finding both forms of manipulatives effective to teach participants to solve subtraction problems. In addition, during the intervention process, participants achieved slightly better results and faster independence by using the virtual manipulatives than by using the concrete material.

These findings may be due, in part, because some people with ASD may present difficulties in communication and social skills, restricted interests and activities (APA, 2013; Happé, 1993), alterations in theory of mind (Frith, 1989), deficits in executive functions (Ozonoff & Schetter, 2007) and can easily process visual information (Grandin, 1995). Therefore, the use of technology, such as a touch screen, can be effective for working on academic skills with students with ASD by providing them an active and participative learning that increases their motivation, and by improving their autonomy as they receive immediate feedback on their performance in the activity (Correia & Halabi, 2021; Ledbetter-Cho et al., 2018).

It should be pointed out that after comparing recent studies using desktop computers, hardware, mobile applications, virtual reality and web applications, the mobile application seems to be the most useful application software for students with ASD reaching a success rate of 83% in achieving their goals, because it allows them to focus and to maintain attention, as long as its design is clear and structured (Cabanillas-Tello & Cabanillas-Carbonell, 2020).

Devices as iPods, iPhones and iPads have also shown their effectiveness for users with developmental disabilities (Kagohara et al., 2013). Reviewing articles from 2002 on, Aspiranti et al. (2020) conclude that the use of iPad or tablet in the educational environment is an effective method to improve the academic performance in mathematics of students with ASD. These findings coincide with results obtained by other authors.

When comparing the performance and participation of four students with ASD or intellectual disabilities using iPad and computer, Arthanat et al. (2013) found that three of them significantly improved their academic skills, and one of the three preferred the iPad to the computer. Five of seven students with ASD maintained or improved their academic performance in developing basic mathematical skills by using iPad and increased autonomous task completion over traditional instruction (O'Malley et al., 2014).

Therefore, we focus on the use of specific applications -apps- to work on mathematical skills, which can be used on a touch device, that is, an iPad, tablet or mobile phone. Some studies show the effectiveness of these types of applications in improving the academic achievement of students with ASD, even though they are not specific to users with ASD or difficulties in mathematics. Zhang et al. (2015) selected 18 students from the same class, four of them with ASD, emotional disorder, dyslexia or learning difficulties, to compare their performance when using iPad for practice with three mathematical apps (Splash Math, Motion Math Zoom and Long Multiplication). The results reveal that participants improved their scores on all three assessments, narrowing the initial gap between participants with difficulties and their typically developing peers after using the apps (Zhang et al., 2015).

There exist many apps, both paid and freely available, so it is necessary to have guidelines that allow us to determine which are the most effective. For an application to be considered suitable for students with ASD, previous research has identified six frequently used recommended elements: "effectiveness, efficiency, satisfaction, ease of use, understandable and appearance" (Sofian et al., 2018, p. 4).

This coincides with the results obtained by other researchers. Britto and Pizzolato (2016) proposed a set of Guidelines for Accessible Interfaces for people with Autism (GAIA). GAIA is a set of recommendations on accessibility and web page design, which states that the interface should have a visual and textual vocabulary, be customizable, present a simple interface, use alternative representations (image, audio and/or video), contain information in an appropriate format to the user, provide feedback, contain instructions and elements of an appropriate size, the user should control the time to perform the task and there should be markers to move from one page to another, the system should present clear instructions and messages to facilitate interaction with its components, and the touch screen should have adequate sensitivity to prevent errors due to accidental touches (Britto & Pizzolato, 2016).

Dattolo and Luccio (2017) present similar guidelines to these authors, based on previous literature. They consider 4 categories: graphical layout, structure and navigation, user and language (Dattolo & Luccio, 2017). They compare some existing applications and evaluate them according to the proposed criteria, concluding that most of them have limitations in terms of graphical layout and navigation.

Gallardo Montes and collaborators have conducted several studies evaluating specific apps for students with ASD. They designed and validated the "System of Indicators and Instrument for the Assessment and Selection of Apps for People with ASD," focusing in three dimensions of the apps: design/form, content and pedagogic aspects (Gallardo-Montes et al., 2021b).

Using this instrument, Gallardo-Montes et al. (2021a) analyzed 88 apps, of which only 21 included mathematical content and, ordered from highest to lowest presence, the sub-areas of focus were: numbers, counting, addition and subtraction, place value of digits, problem-solving, multiplication and division. The authors conclude that only one of the apps, SmileLearn, contains these six sub-areas, so there is a lack of quality mathematical apps.

Using again this instrument, Gallardo-Montes et al. (2021c), assess 155 free apps on Google Play. Of these, only 14 apps reach the category of highly recommendable, and of these, only 3 present some content related to shapes and/or numbers (Otsimo, Autastico and Games for babies from 2 to 5). This reinforces the need to design quality mathematical apps for users with ASD.

Following the GAIA accessibility guidelines of Britto and Pizzolato (2016), Scotini et al. (2021) select and evaluate 18 specific apps for students with ASD in English or Portuguese, of which 7 are about numbers, quantification and logical sequences. In descending order of score within this category, the apps are: BitsBoard, Step by Step Pair by Numbers/ Step by Step Create a Series, Shop & Math, HearBuilder Sequencing, Camp Discovery, Montessori Preschool. The scores achieved by the apps vary depending on the categories evaluated and in general, the apps that obtain the best scores are those in the socio-functional skills category.

Regarding mathematics applications, non-specific for users with ASD, Cayton-Hodges et al. (2015) selected 16 mathematics applications on the Apple App Store and assessed them focusing on the quality of mathematical content, feedback and scaffolding, interactions and adaptability (Cayton-Hodges et al., 2015). They gave a list of recommendations for the design of tablet-based mathematics applications and pointed out that some available apps contain mathematical misunderstandings.

Due to these shortcomings, several researchers have designed their own digital environments adapted to people with ASD, for example:

- Learning Environment on Mathematics for Autistic Children (LEMA) for students aged between 6 and 12 years old, aimed to improve their geometrical reasoning (Santos et al., 2020).
- Web-based game application focused on helping high-functioning individuals with ASD to understand the concept of money and apply it in practical life situations (Caria et al., 2018).
- Multi-platform game application for teaching money and a product purchasing environment (Büyük et al., 2019).
- 123 Autismo aimed at teaching basic math skills such as "transposition skills, correspondence, pairing, identification of number and quantity, naming the number, number sequence and basic addition operations" (Teixeira & Cunha, 2019, p. 3).
- Proyecto@Matemáticas is an application that focuses on functional mathematics (use of money) and pre-calculus (correspondence, classification, numbers, quantification, addition and subtraction, among others), (Muñoz-Soto et al., 2016).
- Play and Learn Number (PLaN) is an application focused on teaching numeracy and calculation (Tashnim et al., 2017).
- Touchscreen-Assistive Learning Numeracy Apps (TaLNA) is an application focused on teaching basic numeracy and calculation (Kamaruzaman et al., 2016)

As we can see, none of these applications is focused on the process of teaching mathematical problem-solving, despite this is a core content of the educational curriculum (NCTM, 2000). Moreover, Chen et al. (2019) study the academic performance in mathematics and reading of children with ASD, finding a low-performing subgroup with poor mathematics skills compared with reading. These results align with findings by Bullen et al. (2020) who identify difficulties in problem-solving and numeracy skills in some students with ASD.

Several researchers have been interested in improving the problem-solving skills of students with ASD. The systematic review by Root et al. (2021) aims to provide an overview of which strategies work for which types of learners and under which conditions, for teaching word problem-solving to students with ASD. Authors identify 6 types of evidence-based practice: task analysis, system of least prompts, graphic organizers, explicit instruction, schema-based instruction, and technology assisted instruction.

Their results align with previous works (Barnett & Cleary, 2015; Gevarter et al., 2016) on mathematics interventions for students with ASD. In particular, these authors identify problem-solving cognitive strategies as an evidence-based practice for teaching mathematics skills to students with ASD. In this line, Whitby (2013) proved that the Solve it! Problem Solving Routine (Montague, 2003) consisting of seven cognitive strategies and three meta-cognitive strategies, was effective to improve the ability of 3 adolescents with ASD to solve word problems.

Given the notable lack of mathematical apps specific for students with ASD, the fact that some current apps need to be improved to adapt them to their needs (Gallardo-Montes et al., 2021a; Gallardo-Montes et al., 2021c; Scotini et al., 2021), and the difficulties of some students with ASD in problem-solving (Bullen et al., 2020), in this paper we detail the design, implementation and validation of a mathematical app for arithmetic problem-solving designed for students with ASD.

2. TEAtreves app design process

This application is part of a larger study developing techniques to improve the problem-solving skills of students with ASD. So, prior to the design and implementation of the TEAtreves app, an exploratory study was carried out with students with ASD who worked on arithmetic problem-solving with a physical worksheet. This worksheet was effective to improve the problem-solving skills of the participants (García-Moya & Blanco, 2023a). So, the main tasks that can be performed inside the app follow a modified digital version of this worksheet.

Afterwards, Google Play Store was used to perform a search of mathematical apps that work on number sense, vision and spatial perception, measurement of magnitudes, mathematical logical thinking or problem-solving. We scored the suitability of selected apps for users with ASD (García-Moya & Blanco, 2023b) according to the GAIA guidelines by Britto and Pizzolato (2016) and guidelines by Gallardo-Montes et al. (2021b).

Later on, and taking this into account, we implemented the TEAtreves app, designed with Java programming language on Android Studio environment installed on an MSI Z16 laptop.

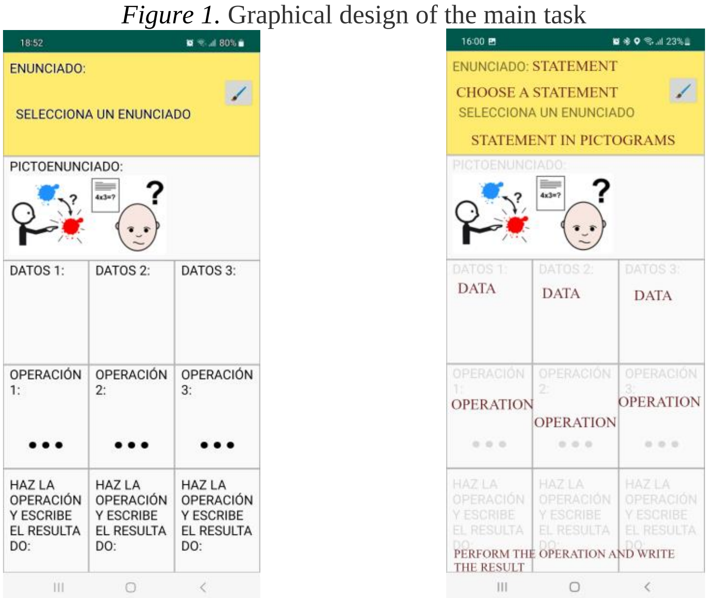
2.1. Design representative tasks

The main task performed within the application is to solve an arithmetic problem. This process is structured according to Pólya's (1957) problem-solving phases: understanding the problem, elaborating a plan, executing the plan, revising the solution. And includes several problem-solving cognitive strategies to guide the student along the process (Barnett & Cleary, 2015; Gevarter et al., 2016; Whitby, 2013).

During the exploratory study (García-Moya & Blanco, 2023a) we could check that many of the participants had serious troubles to understand the purpose of the last phase of Pólya's problem-solving routine (1957), so it has been eliminated in the application.

The general organization of the user interface while performing this task is based on the TEACCH methodology (Mesibov et al., 2005) that is widely used with students with ASD, bounding and structuring the workspace to promote autonomous student learning and self-regulation. The TEACCH methodology is based on the organization of physical environment; organizational strategies like the use of visual agendas to establish routines and encourage anticipation, so the student can know the sequence of tasks in advance; activities visually structured in steps to facilitate understanding; and the employment of sequences of activities that encourage student's autonomous work (Mesibov et al., 2005). The user interface looks like a worksheet -filled from left to wright and from top to bottom- with a separate square for each action/step to perform, so the user can see how many steps are done and how many are left to complete the task, which is presented visually in structured steps, always following the same problem-solving routine. This is reinforced by colors and multiple ways of presenting information (visual, audio and written). Figure 1 shows an example of the digital worksheet as displayed on a mobile phone. Figure 1(a) shows the original screen, and Figure 1(b) includes translation of Spanish text that appears in crimson. In what follows, translation of Spanish text in figures replaces the original text, preserving the appearance of the application.

Figure 1. Graphical design of the main task



(a) Original screen (b) Translation of Spanish text

In what follows, all pictographic symbols used inside the application have been adapted from Palao (n. d.).

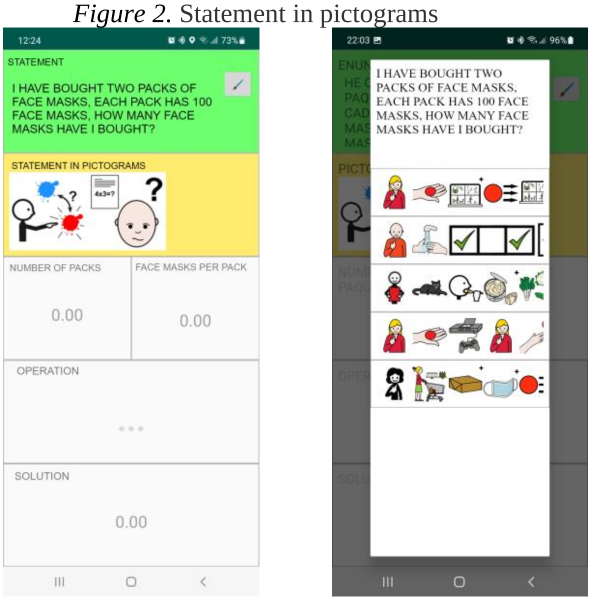
Figure 1 shows the initial stage of the process followed to solve an arithmetic problem, the space is structured such that the user progress from top to bottom and from left to right completing the data involved in the problem (understand the problem, rows 1 up to 3), choose the operations (elaborate a plan, row 4) until he or she performs the operations and writes the result (execute the plan, row 5).

Every square contains a written hint indicating what the user has to complete in that square. These hints are reminders of each one of the steps needed to solve the problem and their corresponding cognitive strategies:

Read the statement for understanding and choose the statement in pictograms (row 2); extract the data involved in the problem (row 3); hypothesize which operations are needed and write them (row 4); compute operations and write the results (row 5).

Long touches cause the application to read out any text to the user, either statements or hints. As the user makes progress in solving the problem and each square is unlocked (see Figure 2), the text included in that square is no longer shaded and can be read out by a long touch. Locked squares are shaded to avoid distractions, however, the contrast between text and background is customizable within Android operating system, so high-contrast fonts produce unshaded text. Notice this difference in Figure 2 and also between Figure 1(a) -high-contrast fonts- and Figure 1(b) -normal fonts-. In what follows, high-contrast fonts have been preferentially used to facilitate reading.

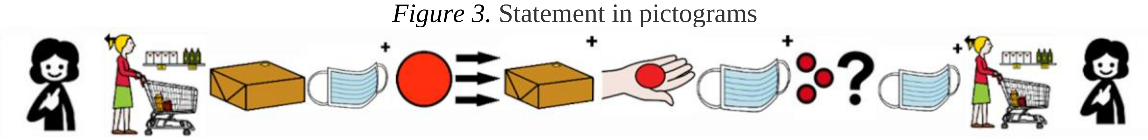
Figure 2. Statement in pictograms



(a) Statement (b) Statement in pictograms

Figure 2 shows the pop-up window in which the user chooses the pictogram statement for a better understanding of the meaning of the statement of the problem. This is one of the specific adaptations of the worksheet to users with ASD. In Figure 2(b) can be seen all the statements in pictograms corresponding to all the problems included in that category. In case of the statement in pictograms was longer that the width of the box, the user can swipe that pictogram sentence left and right to see it in full. Figure 3 shows the complete statement in pictograms corresponding to the problem displayed in Figure 2.

Figure 3. Statement in pictograms



Pictograms and other visual communication systems are widely used by educators working with students with ASD, who agree that aided Augmentative and Alternative Communication (AAC) systems are effective methods to promoting and improving functional communication for individuals with ASD (Alexander & Dille, 2018).

ACC systems are either unaided, such us manual signs, or aided, for example including graphic symbols displayed on communication boards, or devices relying on technology, such as speech generating devices (SGD), Ganz (2015). Several studies show the effectiveness of ACC systems for children with ASD, with strong evidence supporting the benefits of the Picture Exchange Communication System (PECS) (Bondy & Frost, 1994) and SGD, with weaker evidence for other image-based systems (Iacono et al., 2016). These findings suggest that additional research is needed in this line.

Previous results show that the use of pictogram sentences enhances the understanding of the problem statement and facilitates the achievement of a successful outcome (García-Moya, 2018; García-Moya, 2022).

2.2. Requirements and guidelines

The user interface design fulfills a list of requirements extracted from previous works (Britto & Pizzolato, 2016; Gallardo-Montes et al., 2021b) and based on previous research (García-Moya & Blanco, 2023b). In particular, the application meets the following characteristics (Britto & Pizzolato, 2016, p. 142), see Appendix A.

G1: Visual and textual vocabulary. Contents are delivered using colors and visual, textual and audible language. “The contrast between background and objects in foreground” let “to distinguish items and distinct content or relate similar information.” The language is simple and heading titles are employed to facilitate reading. Icons, images and pictograms are easily recognized.

G2: Customization. The application enables personalization of features such as vibration and sound and also to activate a reading mode for the sentences.

G3: Engagement. The interface is simple without distracting elements. Only the features “need for the current task to be performed by the user” are presented. Blank spaces between elements are used to separate them. Clear instructions about tasks are provided.

G4: Redundant Representation. The application provides alternative representations to text through image and audio. Pictograms present a visual equivalent for long sentences and audio instructions are also available.

G5: Multimedia. Information is provided in multiple representations. No disturbing sounds have been used.

G6: Feedback. Continuous feedback is provided that confirms correct actions or alerts to possible errors, using audio, text and images to represent the message.

G7: Affordance. Similar interactions produce similar and predictable results. Icons and buttons have an appropriate size and look clickable. The application always provides immediate “feedback over an interaction restriction with the system or a certain interface element.”

G8: Navigability. The navigation between pages is consistent and simple. The user controls “navigation and time to perform a task.”

G9: System status. The application presents adequate “instructions to interact with interface elements,” provides clear messages about errors and provides mechanisms to solve them. Number of incorrect attempts before showing the correct answer is not limited.

G10: Interaction with touch screen. “Touch screen interactions” “have the appropriate sensibility and prevent errors in selections and accidental touch in interface elements.”

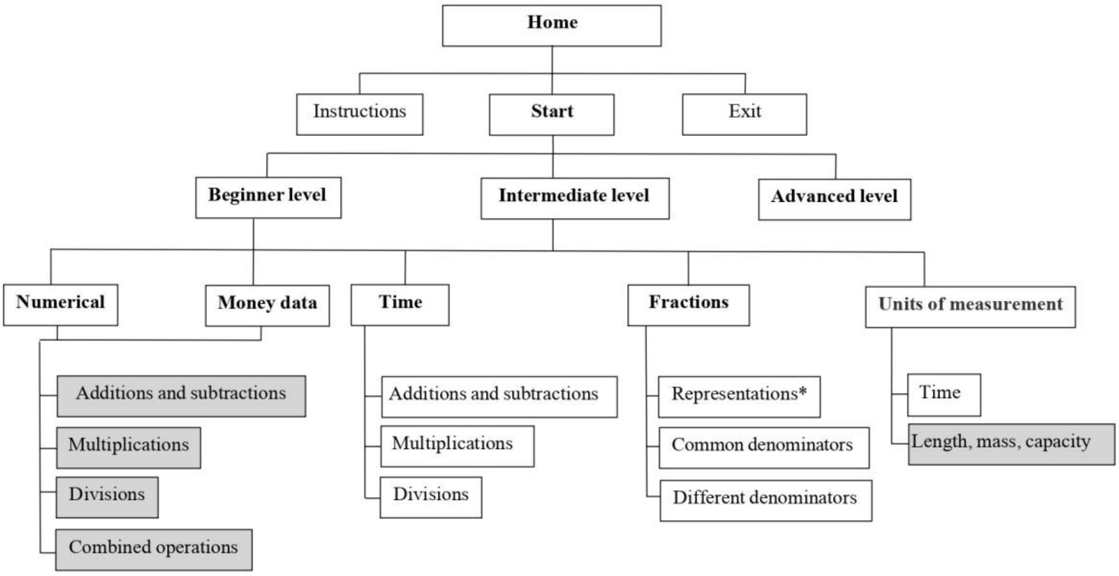
2.3. Flow diagram

Once the basic graphical design of the main task has been agreed, the next step is to develop the process flow. The flowchart provides the navigation map through the different levels and problem categories of the application, and it is shown in Figure 4.

As we can see in Figure 4, the application is structured into three levels of difficulty (beginner, intermediate and advanced). The beginner and intermediate levels are categorized into several types of problems: numerical, money, time, fractions and unit changes. Inside these categories, the user can practice several types of operations with whole numbers or decimal numbers. Whereas the advanced level problems, which cover all of the above types, appear randomly to prevent the user from knowing in advance what type of problem and operations to perform.

Selected types of problems are intended to cover the usual types of problems that are worked in primary education (NCTM, 2000). There are at least five problems in each category.

Figure 4. Design of flow diagram of TEAtreves application

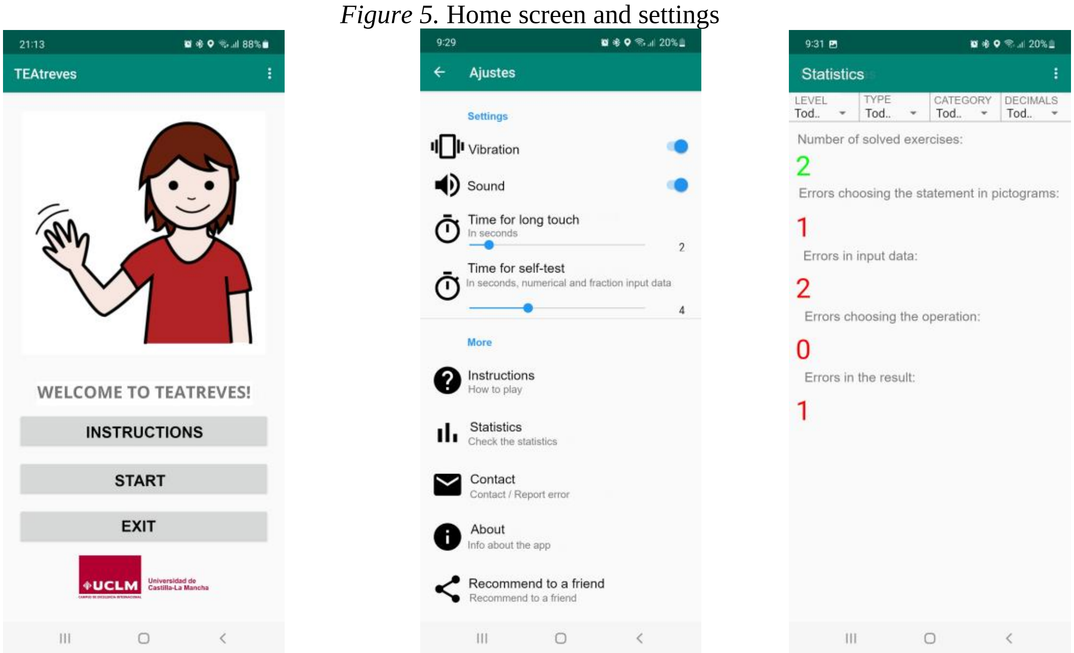


Note. Grey = this category is divided into problems with whole numbers and problems with decimal numbers; * = only in the beginner level.

2.4. Home screen and customizable settings

Figure 5(a) shows the home screen of the application. Clickable elements are clearly distinguishable from background. When the application opens an audible greeting welcomes the user, as well as in written and pictogram form. The three vertical dots on the upper right corner give access to statistics, settings and exit, which are clickable from every screen of the application.

Figure 5. Home screen and settings



(a) Home screen (b) Customizable settings (c) Statistics

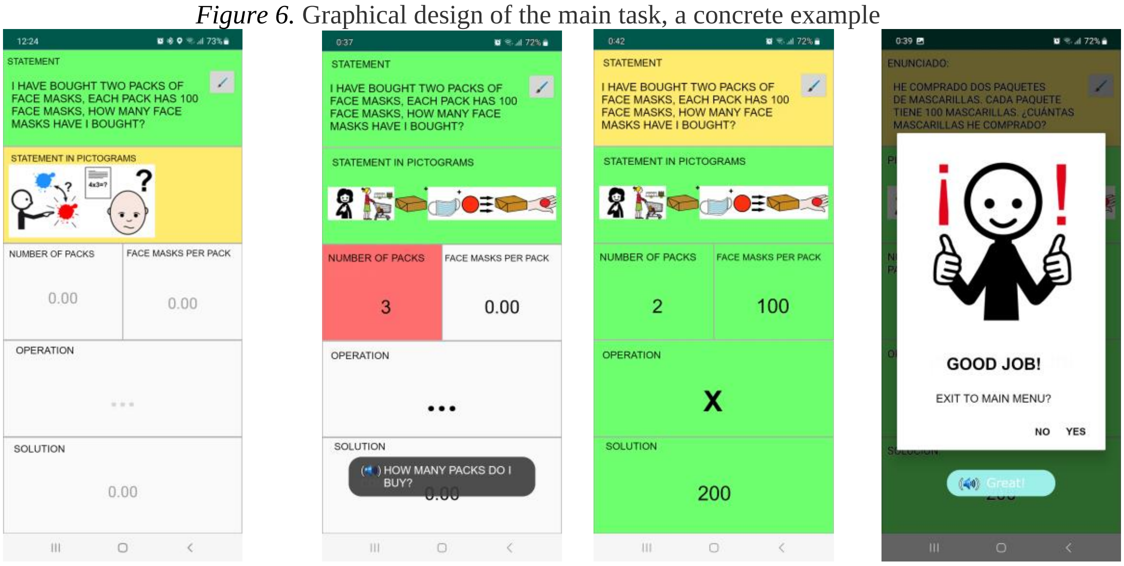
Customizable settings for the user include vibration (on/off), sound (on/off), time for long touch and time for self-test (Figure 5(b)) which lets the user control the time to perform the tasks. The color settings are directly customizable within Android operating system. The selection of colors has been made to be distinguishable on all electronic devices, as their final appearance may vary depending on the brightness, color or contrast device settings. Figures 10-13, showing the screen as displayed on a Tablet with alternative settings, illustrate a possible difference in color intensity.

Statistics section let the user, educator or facilitating person to check the progress of the user inside the application. Number of total exercises solved and total errors along the different rows of the main task are shown (Figure 5(c)). It is also possible to see the total number of errors by category of problems.

2.5. User interface design: Example of problem

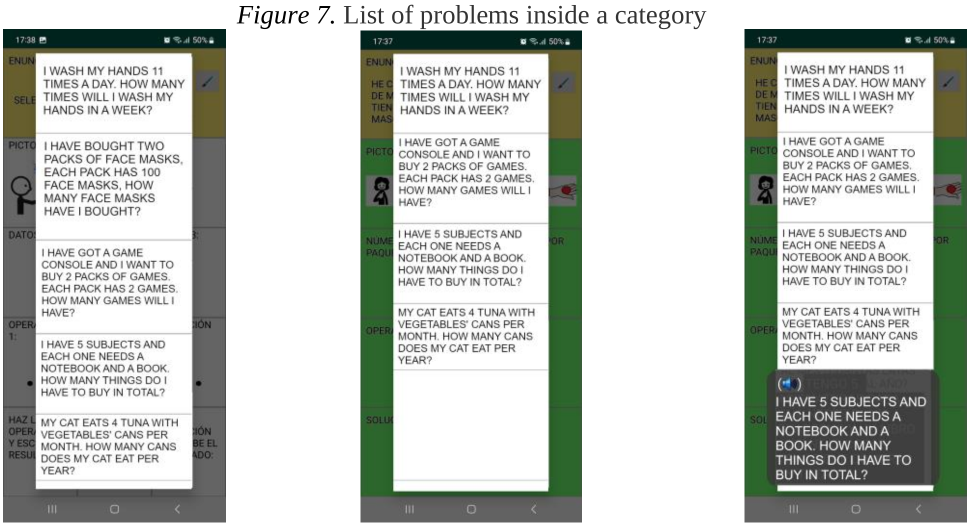
The general structure of the digital worksheet (Figure 1) is followed in all types of problems included in the application. Figure 6 shows the process followed to solve the following problem: I have bought two packages of masks. Each package has 100 masks. How many masks have I bought?

Figure 6. Graphical design of the main task, a concrete example



(a) Initial stage (b) Error in datum (c) Problem completed (d) Exit screen

Figure 7. List of problems inside a category



(a) Eligible problems (b) Problem removed (c) Audible/visual message

Figure 6(a) shows the initial stage of the process followed to solve the selected arithmetic problem. Completed squares are colored in green, current square is shown in yellow. If the user fails, both visual and audio support is given by asking a specific question to help the user continue -How many packages do I buy? -. In addition, the box is colored red (Figure 6(b)). If the user enters the correct answer, the box turns green and both visual and audible message is given as positive feedback. Figure 6(c) shows the final stage of the process.

When the user completes the problem, another visual and audible message is given as positive feedback - Excellent! Good job! -, which also gives the user the option to continue in this category or to go to the main menu (Figure 6(d)) – Exit to main menu? No/Yes -. If the user decides to continue, the application returns to the final stage (Figure 6(c)) where the square containing the statement has turned yellow to let the user to choose another problem within the same category (Figure 6(c)). All successfully completed problems are removed from the list of eligible problems to do (Figure 7), to prevent the user from doing the same problem several times.

The user also can make a long touch on any problem statement for the application to read it out and to see the same problem statement with a slightly bigger font (Figure 7(c)). The font size is customizable within the device's accessibility options, but not within the application.

2.6. Accessory modules design

2.6.1. Whiteboard

Throughout the process of solving a problem, the user may need to write by hand and perform some operations. This can be done within the application. Inside the square of the problem statement there is a pencil pictogram, which is clickable at any stage (see Figure 8). This element opens a pop-up window with the problem statement and a whiteboard which works like a writing paper for drawing, writing and performing the operations.

Figure 8. Whiteboard

(a) Pencil pictogram (b) Whiteboard

2.6.2. Input data types

Different types of problems involve several input data types. This can be number, money data, rational numbers, time and units of measurement. The simplest category of data types are numerical data (whole numbers or decimal numbers) that can be entered in fields as shown in Figure 6(b).

Money data and rational numbers are presented with graphical representations. Figure 9 shows the wallet where the user can touch the image of any coin or bill to select it and put it inside the wallet or eliminate it from the wallet. Money images from Banco de España (2023).

Figure 10 shows the rectangle where the user can touch the suitable number of cells to give a graphical representation of the required rational number. In these representations, the denominator is already fixed, so the user has to show understanding of the meaning of the rational number in order to select the correct number of cells.

Time data are presented in several forms, depending on the needs of the problem statement. When it is necessary to express the time in a clock, the default android clock is used (see Figure 11(b) and Figure 11(c)). When a quantity of time is expressed in a single unit, a numeric field is used as in Figure 11(d).

When the amount of time is expressed in several units, a time selector as in Figure 12 is used. The user can select hours, minutes and second by dragging on each selector.

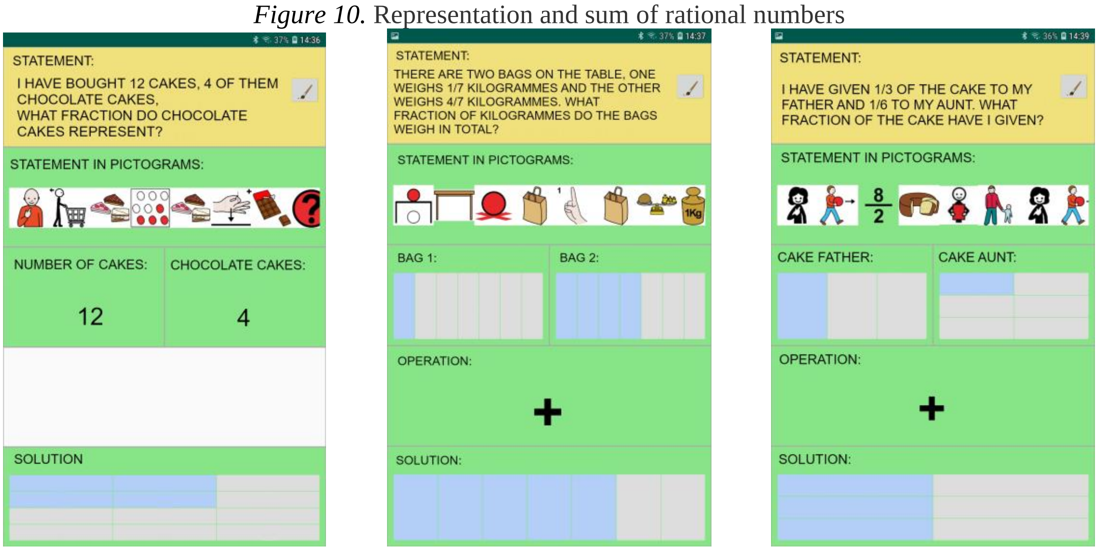
To express units of measurement, the pop-up window includes a numerical field and a unit selector as shown in Figure 13.

Figure 9. Wallet and money input data

(a) Statement (b) Empty wallet (c) 5 euro bill

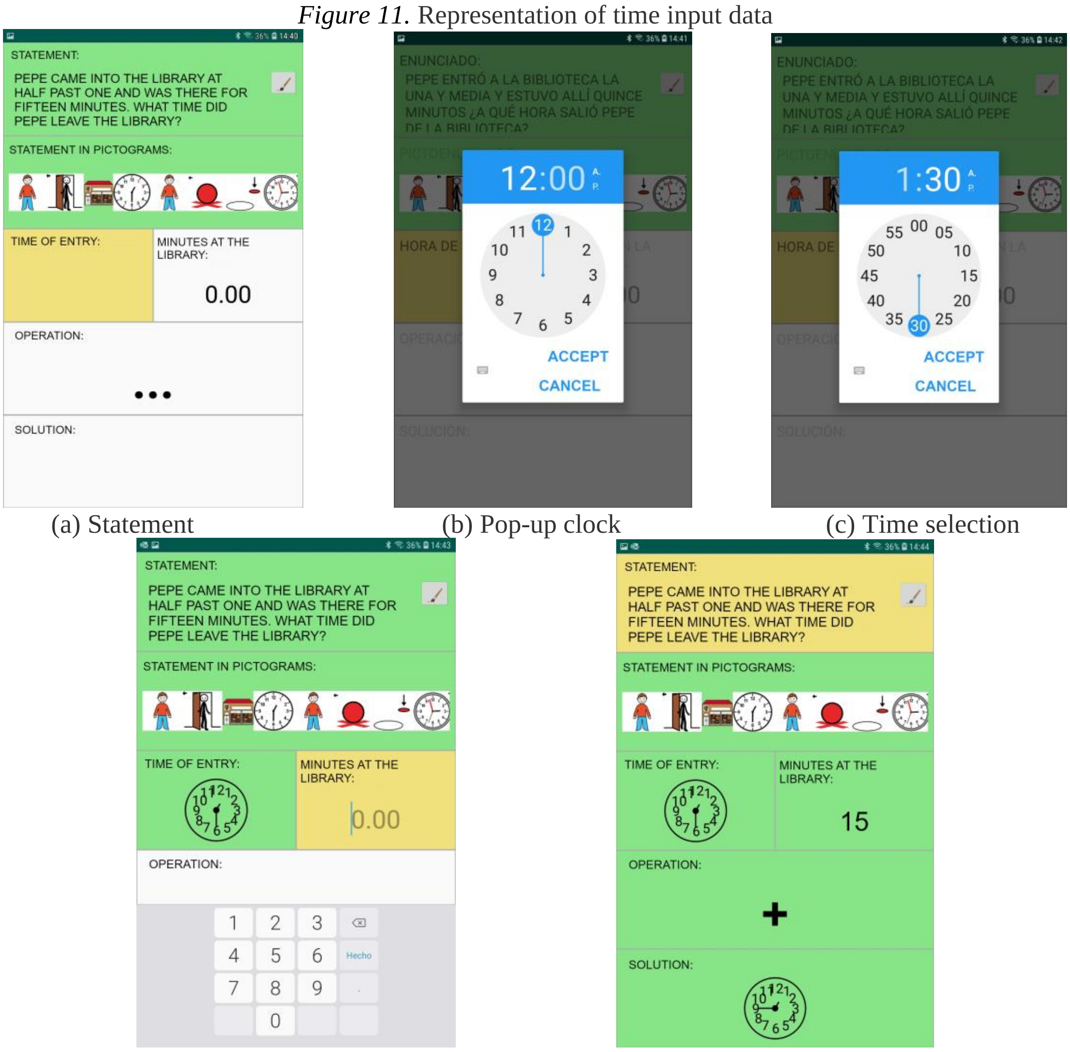
(d) 2 euro coin (e) Money data completed

Figure 10. Representation and sum of rational numbers



(a) Representation (b) Common denominator (c) Different denominator

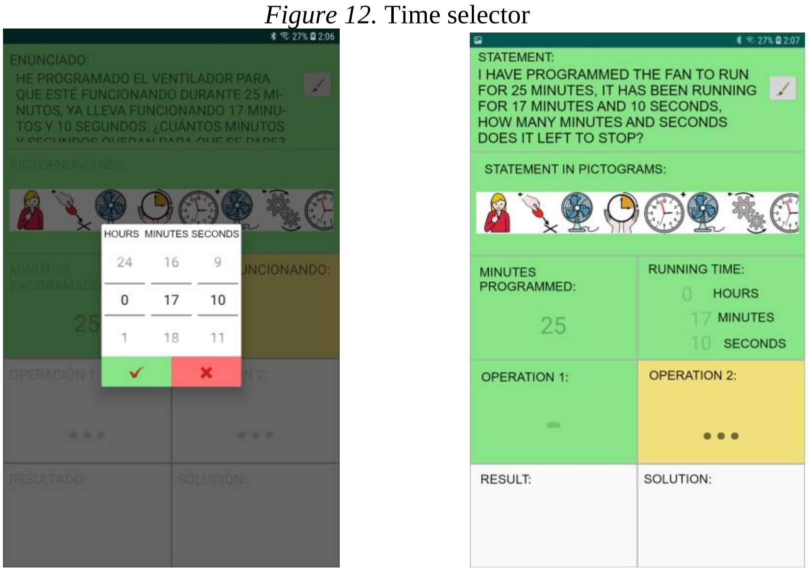
Figure 11. Representation of time input data



(a) Statement (b) Pop-up clock (c) Time selection

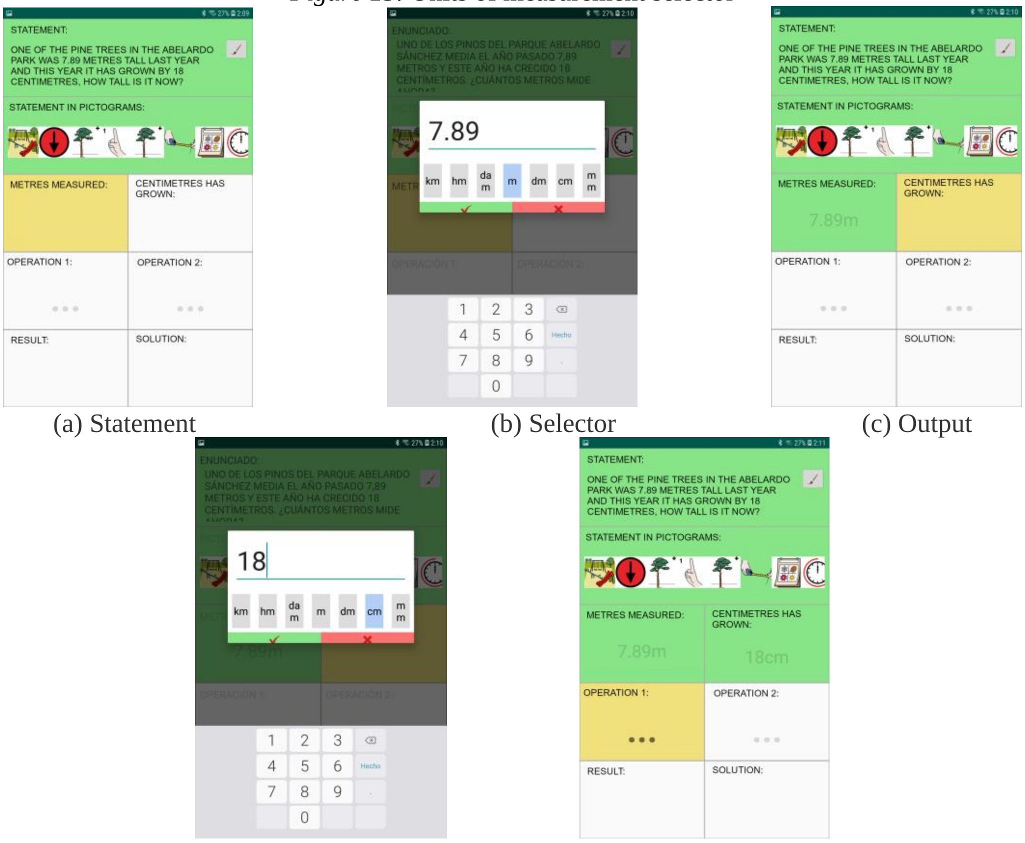
(d) Input in minutes (e) Final stage

Figure 12. Time selector



(a) Time selector (b) Visual aspect of the output

Figure 13. Units of measurement selector



(a) Statement (b) Selector (c) Output

(d) Selector (e) Output

3. TEAtreves application validation

The evaluation of the suitability of the application for users with ASD was divided into three steps. First, we tested if the application fulfilled the list of requirements stated in previous works (Britto & Pizzolato, 2016; Gallardo-Montes et al., 2021b). Afterwards, a pilot study was conducted with some users with ASD. Finally, two external expert evaluators assessed the application.

3.1. Evaluation by researchers

Both researchers rated the application according to GAIA guidelines by Britto and Pizzolato (2016) and the following codes: A if the application satisfy the criterion; B if the application partially fulfills the criterion; C if the application does not satisfy the criterion; N/A if this criterion is not applicable to TEAtreves. Afterwards, within each accessibility criterion, the average percentage scores achieved by the application were calculated as shown in Table 1.

Table 1. Average percentage and percentage of agreement by category

Criterion	% Average A	% Average B	% Average C	% Average N/A	% agreement
G3: Engagement	100	0	0	0	100
G6: Feedback	100	0	0	0	100
G10: Interaction with touch screen	100	0	0	0	100
G1: Visual and textual vocabulary	75	25	0	0	100
G5: Multimedia	66.6	16.6	16.6	0	66.6
G7: Affordance	66.6	16.6	16.6	0	33.3
G4: Redundant Representation	50	50	0	0	66.6
G9: System status	33.3	33.3	16.6	16.6	0
G8: Navigability	25	50	25	0	0
G2: Customization	12.5	25	50	12.5	25

Categories obtaining the highest average percentages of A are engagement, feedback, interaction with touch screen and visual and textual vocabulary (100% of agreement between the scores of the two evaluators), followed by multimedia, affordance and redundant representation. All these categories reach low percentages of C as can be seen in Table 1.

To guarantee compliance with these criteria we adopted these design decisions: (G3) simple interface where distracting elements are avoided; only active square is unshaded to focus attention; all elements appear separated; step-by-step guided problem-solving process; (G6) continuous feedback is provided through audio, text and images; (G10) times for long touch and self-test are customizable to prevent errors; (G1) the selection of colors let to distinguish items between background and foreground; upper case letters and a simple visual, textual and audible language are used; every square has a heading title (textual and audible); pictographic symbols have been adapted from ARASAAC (see Footnotes section) to make them easily recognizable; some statements and pop-up windows contain long paragraphs so criterion 1.3 is assessed with a B; (G5) multiple ways of provide information; no disturbing sounds; (G7) similar elements produce predictable results; (G4) alternative representations to text through image and audio are provided.

Customization is the category where both researchers assign the highest number of C scores (50% of the items) because the type of features that are customizable inside the application differs from the ones listed in this criterion. As discussed above, the application enables personalization of vibration and sound, time for long touch and time for self-test (see Figure 5), and additionally, lets to activate a reading mode for the sentences (see Figure 7). However, other interface elements, such as color, text size or font are not customizable within the application. GAIA guidelines by Britto and Pizzolato (2016) are initially intended for Web interfaces, so they do not include features typical of mobile devices, such us vibration and types of touches.

As can be seen in Table 1, customization, navigability and system status are the categories in which the evaluators' scores differ the most. This may be due to different interpretations of the criteria when they are applied to mobile applications instead of web applications. Navigation and system status are mainly determined by Android operating system. Regarding criterion 9.3, there is no limit to the number of attempts, the correct answer is not shown, so the user can try the problem at another time.

Table 2 shows the average percentage of A, B, C and N/A scores obtained by the application and the percentage of agreement rates which were calculated between the scores of the two evaluators.

Table 2. Average percentage of A, B, C and N/A scores and percentage of agreement

% Average A	% Average B	% Average C	% Average N/A	% Agreement rate
58.9	23.2	14.2	3.5	57.14

The results achieved by TEAtreves, with a high percentage of A scores together with a low percentage of C scores in seven of the ten categories, and an overall average percentage of A scores around 60%, make it suitable for users with ASD.

Moreover, the System of Indicators and Instrument for the Assessment and Selection of Apps for People with ASD by Gallardo-Montes et al. (2021b)-see Appendix B-, was also considered to evaluate the application. Both researchers independently evaluated the design, content and pedagogic aspects of the application. First author obtained a total score of 34 points and the second author a total score of 33 points out of 46 possible points, therefore, TEAtreves reached with this instrument the category of recommendable application for users with ASD.

The rate of agreement was 86.4% for design, 77.7% for content and 100% for pedagogical aspects. The average of the scores assigned by researchers for every dimension measured with this instrument was 15.5 (out of 22) for design, 13 (out of 18) for content and 5 (out of 6) for pedagogical aspects.

Regarding the design (dimension 1), the application was not available in several languages, only in Spanish; did not allow to modify the size, color or type of the font; and was not yet available in Google Play Store, so there was no data about its popularity (in terms of number of downloads, user ratings and awards). Therefore, the score of TEAtreves in this category was 15 - 16 points respectively for each evaluator, who agreed on the above indicators.

With respect to the content (dimension 2), the application achieved 14 – 12 points respectively for each evaluator, who agreed that it did not have music, did not send notifications and did not have parental control for internet access.

Some of these items do not apply to TEAtreves in its current version, for example, the application does not have internet access or integrated purchases. So, there was no need to include parental control for internet access or settings, or purchase blocking.

In the dimension of pedagogical aspects, the application scored 5 points from both researchers. The only item that it did not satisfy was not allowing the user to add personalized images and/or pictograms.

3.2. Pilot study

A pilot test was carried out with students with ASD, in order to verify the suitability of the application for this type of users.

3.2.1. Participants

The participants were selected from a larger study developing techniques to improve the problem-solving skills of students with ASD. In this study, participants were enrolled by researchers through associations of people with autism and school guidance teams. For the present study, five participants that met the following inclusion criteria were selected: (1) being diagnosed with ASD according to the Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-V, APA, 2013), (2) being between 6 and 14 years old, (3) having prior knowledge of numerical addition and subtraction facts, verified with an initial test.

All participants were enrolled in different mainstreams public schools in the southeast of Spain and were diagnosed with ASD by a child psychiatrist from Social Security. All five were in the moderate autism range, according to their scores on the Childhood Autism Rating Scale (Schopler et al., 1988).

Student A was 9 years and 7 months old. He had a comorbid diagnosis of ADHD and ASD. His IQ was 62 (WISC-V, Wechsler, 2015). He was a 4th grade elementary school student, and according to his teachers, his mathematics skills were equivalent to a 2nd grade of elementary education. He received six hours a week of special education services in the subjects of mathematics and language.

Student B was 8 years and 3 months old. His IQ was 92 (WISC-V, Wechsler, 2015). He was a 3rd grade elementary school student. He received two hours a week of special education services, aimed at working on language and mathematics skills.

Student C was 8 years and 11 months old. She had a comorbid diagnosis of Dyslexia and ASD. Her IQ was 87 (WISC-V, Wechsler, 2015). She was a 4th grade elementary school student. She received four hours a week of special education services, aimed at working on language and mathematics skills.

Student D was 9 years and 2 months old. He had a comorbid diagnosis of ADHD and ASD. His IQ was 68 (WISC-V, Wechsler, 2015). He was a 4th grade elementary school student. He received six hours a week of special education services, aimed at working on language and mathematics skills.

Student E was 10 years and 5 months old. He had a comorbid diagnosis of ADHD and ASD. His IQ was 45 (WISC-V, Wechsler, 2015). He was a 5th grade elementary school student, and according to his teachers, his mathematics skills were equivalent to a 1st grade of elementary education. He received ten hours a week of special education services, aimed at working on language and mathematics skills.

3.2.2. Procedure

The second author met the families of the participants, holding an individual interview with every family to be concern about the characteristics of the students and their diagnoses. These interviews were held at the building of the association of people with autism to which the participants regularly attended. After explaining the student what the study consisted of and to check that he/she wanted to participate voluntarily, all families signed the informed consent form.

Each participant used TEAtreves application installed on a Samsung Galaxy Tab A10.1 during a unique session of 45 minutes, the tablet was equipped with a protective case for children to prevent breakage and to ensure the safety of the participant. The session also took place in a classroom of the association's building, which was free of distractions. This classroom consisted of a large rectangular table, two chairs and a window through which natural light came in. In addition, during the session, a family member of the student was present, without taking part in the student's work.

The participants used the application freely choosing arithmetic problems from several of the categories available at the application.

3.2.3. Social validity

Social validity is a useful tool to measure the social relevance of the effects of interventions programs (Gresham, 1983). Each student, together with the family member who had been present during the session, answered a semi-structured satisfaction questionnaire. Questions regarded usability of the application and its features, to verify the appropriateness of TEAtreves for users with ASD.

Moreover, they could suggest improvements and could give their opinion on several aspects, such that, if they considered the application useful to learning solving-problems skills, or if they have enjoyed testing the application.

3.2.4. Result of social validity

Participants attempted between 9 and 13 problems, were able to complete between 90% and 100% due to application errors (except participant E who completed 4 problems out of 7). The time spent on each problem ranged from 1.3 to 6.58 minutes and the average was 3.13 minutes per problem. The mean time in seconds at each stage (row of the worksheet) was as follows (1) 66.94; (2) 14.85; (3) 61.37; (4) 14.08; (5) 37.98. Participants needed more time to read (and listen to) the problem statement several times, and to complete the problem data. The success rate (steps completed on the first attempt) was 59.1%, and they made between 0 and 8 errors per problem, with an average of 2.6 errors per problem. The type of problems they had most difficulty with were money, time and changing units of measurement.

After the testing session with TEAtreves, participants fulfilled an opinion questionnaire, answering yes or no to some questions regarding understanding of the elements of the user interface and the problems selected, easy to use, and the usefulness of pictograms and audible/visual messages, among others.

All participants affirmed they had understood the statements of the problems they selected to solve, and that the pictogram statements helped them to understand the problem. They also stated that they believed the application was useful for learning to solve arithmetic problems and that they had enjoyed the training with the app, founding it attractive and motivating. All participants also agreed on the usefulness of the colors to know what they had to do, the steps they had already taken and the steps that still needed to be taken during the process.

Regarding to the audible messages, listening to the problem statement and the auditory support and prompts were helpful for all participants - except participant A- to understand and solve the problem successfully. Participant A was unable to use this option due to a technical failure in the device.

All participants were able to use TEAtreves app autonomously, except participants A and D because they had poor solving-problem skills and exhibited a lack of concentration during the session.

Participants and families could also make suggestions to improve the adaptation of the application to their needs. Some of these suggestions were to fully color the active box in which the student is located, and that the positive visual reinforcement should also be accompanied by an audible message. Both suggestions are already included in the current version of the application, as seen before.

They also mention that they would use the app because they think it was motivating for users with ASD to learn, as it contained all texts in capital letters, which makes them easier to read, and also because the application guided the users through learning in a visual and structured way.

3.3. Evaluation by external experts

Two external evaluators unaware to the study hypothesis, full-time professors with 9 and 31 years of experience in the field respectively, assessed the application following the same instruments as the researchers. The results obtained from Britto and Pizzolato (2016) guidelines are shown in Table 3.

Table 3. Average percentage and percentage of agreement by category

Criterion	% Average A	% Average B	% Average C	% Average N/A	% agreement
G3: Engagement	100	0	0	0	100
G6: Feedback	100	0	0	0	100
G10: Interaction with touch screen	100	0	0	0	100
G1: Visual and textual vocabulary	100	0	0	0	100
G8: Navigability	75	0	25	0	50
G7: Affordance	66.6	33.3	0	0	33.3
G5: Multimedia	66.6	0	33.3	0	100
G4: Redundant Representation	66.6	0	33.3	0	33.3
G9: System status	50	33.3	0	16.6	33.3
G2: Customization	12.5	25	50	12.5	25

Categories obtaining the highest/lowest average A percentages are the same as in the previous evaluation, except for G8. Navigability gets better score because both evaluators consider the user controls navigating and time to complete tasks. In the rest of the categories, there are small differences with respect to the evaluation performed by researchers. Some differences are due to the fact that: G4 (33% of C) one of the external evaluators considers that audio instructions as such are not provided, and the textual equivalent of symbols/pictograms/icons does not apply to an app; G5 (33% of C) both external evaluators pointed out the impossibility of directly enlarge images. TEAtreves achieves a slightly higher average percentage of A (69.6%), and average percentages of B (10.7%), C (16.0%) and N/A (3.5%) similar to those of the researchers' evaluation. The overall percentage of agreement is 64.28%.

Results obtained from Gallardo-Montes et al. (2021b) instrument are also similar to those obtained by researchers. The mean scores were 16 (17 – 15, out of 22) for design, 11.5 (13 – 10, out of 18) for content and 5 (5 – 5, out of 6) for pedagogical aspects. The total score was 35 – 30 points. Content is the dimension obtaining slightly lower scores, compared to researchers' evaluation, because some items do not apply to TEAtreves, as mentioned above. The rate of agreement between evaluators was 81.8% for design, 83.3% for content and 100% for pedagogical aspects.

4. Discussion

Some students with ASD present difficulties in the acquisition of mathematical content, such us problem-solving or numeracy skills (Bullen et al., 2020; Chen et al., 2019). However, they understand more easily content presented in a visual form (Grandin, 1995) which leads them to be motivated to work with computer applications, mobile devices or tablets and touchscreens (Cabanillas-Tello & Cabanillas-Carbonell, 2020; Correia & Halabi, 2021; Ledbetter-Cho et al., 2018).

In order to contribute to the improvement of the problem-solving skills of students with ASD, the TEAtreves application was designed, implemented and validated.

The evaluation of the application following GAIA guidelines (Britto & Pizzolato, 2016) was performed by both researchers and two external evaluators independently. The application reached very good ratings in four out of ten categories (75%-100% of A, and 0% of C), showing a good level of accessibility in terms of G3-engagement, G6-feedback, G10-interaction with touch screen and G1-visual and textual vocabulary. Navigability also gets a good A percentage according to external evaluators, as well as G7-affordance, G5-multimedia and G4-redundant representation. The general score achieved was around 60%-70% of A scores and around 14%-16% of C scores. These results improve those reached in previous works (Scotini et al., 2021) where categories that achieved the best scores were G10, G1 and G7 for the applications evaluated. Only 7 of the 18 applications evaluated contained mathematical skills, and within those applications, only two - *BitsBoard* and *Step by Step* – obtained better A scores than TEAtreves, with a 68% and 61% respectively, with C scores being slightly higher than those reached by TEAtreves (18% and 25% respectively), considering both evaluations.

G2-Customization is the category that achieved the highest number of C scores (50% of the items), even so, this percentage is much lower than the 79% obtained by Scotini et al., (2021) within the applications evaluated. They also achieved higher C scores than TEAtreves in the categories G9-system status (60%) and G8-navigability (43%), compared to 0%-16% and 25% respectively achieved by TEAtreves.

TEAtreves fully satisfies criteria G3 – engagement and G6 – feedback, providing continuous feedback to the user to guide him or her through the problem-solving process and to keep the user motivated. This fact, together with the findings discussed above, make TEatreves a suitable application for users with ASD, according to accessibility guidelines by Britto and Pizzolato (2016).

With respect to the evaluation following the instrument by Gallardo-Montes et al. (2021b), TEAtreves reached the category of recommendable, with a mean of 33.5 – 32.5 points respectively.

The analysis performed by these authors showed that recommendable applications were below the mean in dimensions 2 (mean 11.27) and 3 (mean 3.78) but above in dimension 1 (mean 16.99). Whereas highly recommendable applications attained scores above the mean in all dimensions (Gallardo-Montes et al., 2021a). However, TEAtreves was above the mean in dimensions 2 and 3, and below the mean in dimension 1. This suggests that TEAtreves would achieve the status of highly recommended application with minor changes, such as being available in Google Play Store, and the corresponding criteria could be applied.

5. Conclusions

TEAtreves is a mathematical arithmetic problem-solving app designed for students with ASD, intended to teach the user a problem-solving routine. Results of evaluations have shown TEAtreves is a recommendable application for users with ASD (Britto & Pizzolato, 2016; Gallardo-Montes et al., 2021b), achieving similar or better results than other applications with mathematical content, being furthermore satisfactory, easy to use, understandable and with a clear appearance (Sofian et al., 2018).

Participants in the pilot test were able to use the app independently, complete the selected tasks and found TEAtreves motivating and suitable for users with ASD. Future versions of the app will include color and text/image size personalization to improve customization options.

It is expected that the TEAtreves application was used in educational settings to promote the inclusion of students with ASD and facilitate their learning of arithmetic problem-solving skills.

Future lines of work include the development of interventions testing the application with students with ASD and their typically developing peers in inclusive contexts.

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Appendix A. Set of guidelines

(Britto & Pizzolato, 2016, p. 142)

G1 – Visual and Textual Vocabulary

1.1 Colors shouldn't be the only way to deliver content and the contrast between background and objects in foreground must be appropriate to distinguish items and distinct content or relate similar information.

1.2 Use a simple visual and textual language, avoid jargons, spelling errors, metaphors, abbreviations and acronyms, using terms, expressions, names and symbols familiar to users' context.

1.3 Be succinct, avoid writing long paragraphs and use markups that facilitate the reading flow such as lists and heading titles.

1.4 Icons, images and label of menus and actions should be compatible to real world, representing concrete actions and everyday life activities in order to be easily recognized.

G2 – Customization

2.1 Allow color, text size and font customization for interface elements.

2.2 Provide options to customize information visualization with images, sound and text according to individual user's preferences.

2.3 Provide options to customize the amount of element in the interface, their arrangement and enable features personalization.

2.4 Enable a reading or printing mode for activities involving reading and concentration.

G3 – Engagement

3.1 Avoid using elements that distract or interfere in focus and attention. In case you use it, provide options to suppress those elements on screen.

3.2 Design simple interfaces, with few elements and which present only the features and content need for the current task to be performed by the user.

3.3 Use blank spaces between Web page elements to separate different contents or focus the user attention on a specific content.

3.4 Provide clear instructions and orientation about tasks to ease the user understanding of the content and the content language, in order to stimulate, motivate and engage the user.

G4 – Redundant Representation

4.1 The Website or Web application must not rely only in text to present content. Provide alternative representations through image, audio or video and ensure that they will be close to the corresponding text.

4.2 Symbols, pictograms and icons should present a textual equivalent near to facilitate symbol understanding and contribute to enrich user's vocabulary.

4.3 Provide audio instructions and subtitles for texts, but ensure that this is not the only alternate content representation.

G5 – Multimedia

5.1 Provide information in multiple representation, such as text, video, audio and image for better content and vocabulary understand, also helping users focus on content.

5.2 Allow images magnification for better visualization and ensure they continue to be understandable when enlarged.

5.3 Avoid the use of disturbing and explosive sounds, like sirens or fireworks.

G6 – Feedback

6.1 Provide feedback confirm correct actions or alerting about potential mistakes and use audio, text and images to represent the message, avoiding icons with emotions or facial expressions.

G7 – Affordance

7.1 Similar elements and interaction must produce similar, consistent and predictable results.

7.2 Use bigger icons, buttons and form controls that provide appropriate click/tap area and ensure that the elements look clickable.

7.3 Provide immediate instructions and feedback over a interaction restriction with the system or a certain interface element.

G8 – Navigability

8.1 Provide a simplified and consistent navigation between pages, use location and progress indicators and present global navigation buttons (Exit, Back to home page, help) on every page.

8.2 Avoid automatic page redirects or expiration time for tasks. The user is who should control navigation and time to perform a task.

G9 – System status

9.1 Present appropriate instructions to interact with interface elements, provide clear messages about errors and provide mechanisms to solve the errors.

9.2 Allow critical actions to be reverted, cancelled, undone or confirmed.

9.3 In interactive lessons and educational activities, it is recommended allow up to five attempts before showing the correct answer.

G10 – Interaction with touch screen

10.1 Touch screen interactions should have the appropriate sensibility and prevent errors in selections and accidental touch in interface elements.

Appendix B. Instrument for the Assessment and Selection of Apps for People with ASD

(Gallardo-Montes et al., 2021b, pp. 10-11), English translation extracted from (Gallardo-Montes et al., 2021d, pp. 8-9)

Indicator Sub-indicator No (0) Yes (1) Observations

Design/Form Dimension

1.1 Availability
1.1.1 Languages
1.1.2 Updates
1.1.3 Identifiable icon

1.2 Ergonomics
1.2.1 Legibility
1.2.2 Clarity
1.2.3 Use of color
1.2.4 Personalization. Changes in the text
1.2.5 Personalization. Changes in the audio

1.3 Usability
1.3.1 Speed. Quick opening
1.3.2 Speed. Absence of dead time
1.3.3 Browsing. Simple and intuitive
1.3.4 Browsing. Quick
1.3.5 Browsing. Correct functioning
1.3.6 Browsing. Buttons identifiable
1.3.7 Browsing. Buttons the correct size
1.3.8 Browsing. Buttons well placed
1.3.9 Browsing. Access to the menu from all screens

1.4 Popularity
1.4.1 User rating
1.4.2 Number of downloads
1.4.3 Prizes/Acknowledgements

1.5 Accessibility
1.5.1 Access to the app by users with ASD
1.5.2 Use without internet connection

Content Dimension

2.1 Quality of audio
2.1.1 Sounds
2.1.2 Music
2.1.3 Narrations

2.2 Quality of the narration
2.2.1 Voice modulation
2.2.2 Clarity
2.2.3 Neutral intonation

2.3 Contents
2.3.1 Variety of topics
2.3.2 Content organization. Distribution
2.3.3 Content organization. Visualization
2.3.4 Different levels

2.4 Notifications
2.4.1 Sending of notifications

2.5 Help and Tutorials
2.5.1 Written format
2.5.2 Audio

2.6 Safety
2.6.1 Data protection
2.6.2 Necessary installation permissions
2.6.3 Parental control in the app itself. Access to internet
2.6.4 Parental control in the app itself. Content settings
2.6.5 Blocking of in-app purchases

Pedagogic Dimension

3.1 Interactivity
3.1.1 It allows the user to add images or personalized pictographs

3.2 Adaptation to pace and learning
3.2.1 Content suitable for the users
3.2.2 Sufficient time to complete tasks
3.2.3 Different codes of communication

3.3 Monitoring/Assessment
3.3.1 Progress is monitored
3.3.2 The activities done are assessed

TOTAL SCORE: