# Specialized Intervention Using Tablet Devices for Communication Deficits in Children with Autism Spectrum Disorders

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**Abstract** — New possibilities offered by mobile devices for special education students have led to the design of skill acquisition software applications. Advances in mobile technologies development have made progress possible in helping teachers with autistic students modelling and evaluation. “Chain of Words” theoretical basis is the autism inventory known as IDEA (Inventory of Autism Spectrum Disorders). Our application is based on the functional area of communication. Tests carried out in educational institutions using “Chain of Words” have shown that it is an adequate intervention supporting tool for such deficits. In addition, teacher can customize task contents according to each child’s characteristics; thus allowing a more personal intervention within the communication field.

**Index Terms**— Mobile and Personal Devices, users with special needs, autism

## 1 Introduction

In recent years, mobile devices have undergone a great development both regarding hardware and software. As for hardware, they now have bigger touchscreens with higher resolution and more multimedia features to play audio and video. As for software, they offer new user interface controls which enable a more precise adaptation to the new ways of interaction and integrated APIs for text to speech and automatic speech recognition. Thus, it is possible to better explore such devices in order to develop innovative applications. Besides, interest has been greater due to a reduction of costs as well as to the support offered to users in different fields such as education [1], [2], [3]. Within the educational field, applications for Android and iOS mobile devices have given rise to groundbreaking educational scenarios from pre-school to high school education, based on access from everywhere and at any time. With mobile devices, students are able to get involved in learning activities without considering their physical limitations [4]. In addition, mobile devices are playing a key role as a very useful tool inside and outside the classroom [5]. Nevertheless, teaching special education students with the support of mobile devices is still a poorly researched field, as suggested by [6].

Special and Inclusive Education is a process by means of which ordinary schools are looking for and producing the supports required by students with learning difficulties, special educational needs or with any type of disability. The expression “special educational needs” was first used in the 70s, but it was widely spread in the 80s by the Warnock Report, prepared by the Secretary of Education of the United Kingdom in 1978. In the specific case of Spain, the law on Education which is now in force, the LOE 2/2006 passed on the 3rd. of May, in its Title II, mentions the term ACNEAE (students with specific needs of educational support), as it refers to “any student who requires, during his or her complete schooling, or any part thereof, certain specific educational support and care as a consequence of disability or severe behaviour disorders” (section 73).

Regarding students with special educational needs we may mention, among others, those belonging to the autism spectrum [7]. For autism diagnosis, teachers rely on specialists’ report and among other questionnaires, on the IDEA inventory (Inventory of the Autism Spectrum) [8], the main purpose of which is to assess the severity of autistic features and how deep they are in a person who is older than 5-6 years old. IDEA has been chosen – out of other similar tests such as CARS (Childhood Autism Rating Scale) or ADOS (Autism Diagnostic Observation Schedule – because the other tests involve rating scales with a few items giving marks which are not highly relevant for the teacher. Besides, IDEA is a test with a wide theoretical and technical basis; it is more qualitative than others and, therefore, the teacher may analyse, in detail, the person’s potential and evaluate twelve characteristic dimensions of students with autism spectrum and/or serious development disorders. At the same time, dimensions are divided into four characteristic levels. The main aims of the IDEA inventory are to establish, during the diagnosis procedure, the severeness of the user’s autistic features, to help the teacher prepare learning strategies and evaluate medium and long-term changes taking place in the student’s behaviour.

It is within this educational context that we developed the dmTEA [9] technology. It allows to carry out, in the classroom, some evaluation of users on autism spectrum, and it may be adapted to specific needs by means of different activities. In this respect, dmTEA offers the teacher a detailed report with marks for each dimension. With the information obtained, families and experts have the possibility to plan an intervention together, focusing on the dimensions that exhibit a greater affectation status and improving them gradually with the most appropriate activities for each case based on the report data. Apart from the above target for dmTEA, we want to work on each of the four disorder blocks included in IDEA (socialization, language and communication, anticipation and flexibility, and symbolization) individually, in such a way that teachers perform specific tasks in order to be able to solve those deficits, on top of the “treatment” carried out by experts through behavior modelling.

Based on the results gathered from the dmTEA app study and with students from an autism specialized educational


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institution, we have observed that there are some fields on which technology exerts greater influence, such as in the case of communication and language skills. This is why we have specifically focused on this field to support the interventions based on the functional area of communication. This block may profit by the use of specific applications on mobile devices, since the latter are portable, mobile and affordable, offer touchscreens interaction and simple pictographic material managing [10]. At present, there are many project applications with fixed and closed contents which do not offer the possibility to personalize said contents to adapt them to the user. This feature has changed over the last few years with new applications such as e-mintza or Piktoplus [11]. Even though, such projects help users suffering from autism with their communication tasks, most of them are, basically, communicators which only reproduce sentences made up with pictograms [12], [13]. Observing this lack of applications focused on the functional area of communication, we propose to help children with autism to communicate by learning how to gradually build different sentences, pronounce them and reinforce their grammar, syntax and phonetics, working on the shortcomings presented by applications previously named.

With that in mind, we have developed the mobile application “Chain of Words”, a tool where sentences designed by specialists can be built, and which is based on the “Word Train” [14]. There are two main purposes. The first one is to determine the gradual progress regarding the child’s communicative deficits during sessions, thanks to the acquisition and learning of new vocabulary and building sentences. We shall not forget that children with problems focused on oral language are not able to properly pronounce words and even if they manage, they are usually misunderstood and words are not accurately pronounced from a phonetical point of view [13]. The second one is to make a comparison between the use of Chain of Words and the most traditional ways of intervention based on tools such as PECS (Picture Exchange Communication System) [15] or PowerPoint, highlighting the best customization of the content offered by "Chain Words" against these systems.

We have used “Chain of Words” with children in educational institutions in northern Spain through the support of regional education authorities (Research & Innovation Project Principado de Asturias). And we have realized that for communication-focused interventions, this is an educational tool which may be used for learning and expanding vocabulary and for building sentences in Spanish. The portable, mobile and affordable nature of such devices is a clear advantage to these children if compared to more traditional tools. We have also noticed that teachers from these educational centres have considered “Chain of Words” an adequate tool, specifically due to the child’s interest and its flexibility to create contents adapted to autistic children’s specific characteristics and needs.

## 2 Background

The principles of “The Universal Design for Learning” (UDL) [16] encourage the offer of universal access to educational curricula for all students, thus ensuring equal opportunities. Moreover, in the particular case of education, The Universal Declaration of Human Rights (1948) (www.un.org/en/documents/udhr/) states the right to education and equal access to education for all on the basis of merit (Art 26). The scientific community has been conscious of this need. Within this context, Wu et al. [6] point out the lack of applications for learning with mobile devices for users with special educational needs, as they are limited to only 0.56%. Within this group of users with special needs, students with autism spectrum have been the focus of part of the development of educational systems using the benefits offered by mobile devices. The reason is that they offer several possibilities both in the expressive as well as in the receptive language, thanks to the reduction of linguistic contents in favour of multimedia content such as graphism, iconicism and touch interaction [17].

Within the field of the psycho-educational therapies for the treatment of users with ASD (Autism Spectrum Disorders), there are two functional areas regarding interventions, those focused on social interactions and those focused on communication [18] which have been our basis for this research. There is a wide range of applications which vary from more communicative aspects to others which are merely educational. Within the applications facilitating communication, we may mention some examples such as the pictogram-based sentence-builders -designed at the beginning of the year 2000 for PDAs [13]- to the most recent ones developed in mobile systems (DiegoSays; play.google.com/store/apps/details?id=com.benitez.DiegoDice). There are some other applications such as iCAN [10], a system which aims to alleviate the problems encountered by caregivers of children with autism using traditional PECS (Picture Exchange Communication System) without compromising its advantages. Specifically, iCAN addresses the issues in educational content creation by streamlining the entire process digitally, educational materials portability by placing the materials entirely on a tablet device, and educational interface management by providing intuitive interactions for managing and retrieving the appropriate content. It is also possible to acquire vocabulary based on the use of images and sounds by means of an application called BIUTIS [19], which stores the results in a server to be able to analyse them later; or to work on different language aspects both at the reception level as well as at the expressive one to improve the communication with PlayPad [20]. Another type of most recent applications addressed to users who are experts working with people suffering from autism is, for example, VocSyl, a computerized tool to provide real-time visual feedback on key elements of speech prosody: syllable breaks, pitch, rate, and volume [21].

There are also, some other applications that foster users’ social skills. One of them is MOSOCO [22], which capitalizes on augmented reality to practice social aspects in real-life situations. Another application is ECHOES [23], a game built to help young children with autism spectrum conditions practice and acquire social communication skills interacting with an intelligent virtual character in the context of social situations. Furthermore, we also have HANDS [24], which offers the possibility to work with social situations and daily situations by means of customizable sequences of text, image, video and sound.

TABLE 1
PC APPLICATIONS FOR AUTISM SPECTRUM DISORDERS

| Application | Aim | Author/Publisher/Web |
|---|---|---|
| Socrates 102 activities | It allows the design of tasks aimed at distinguishing figures, colours and geometrical shapes which allow the evaluation of mental flexibility and receptive language features. | EMME Interactive |
| Adibú | It has exercises which guide the tasks towards receptive language disorders, anticipation and suspension, by means of exercises focused on solving problems and eye-hand coordination. | COKTEL EDUCATIVE |
| Responsive Face | It allows the creation of stories and to watch animated films, fostering the recognition of face expression and feelings. | www.mrl.nyu.edu/~perlin/facedemo/ |
| Clic | It allows to match up images and to orally interact by means of questions and replies or by learning new nouns and adjectives. | Francesc Busquets www.xtec.es/recursos/clic |

From a pedagogical point of view, there are different personal computer applications which partially cover the dimensions offered by IDEA. For our work, we have made a selection of them (Table 1), choosing those which give the possibility to cover the greatest part of said dimensions, focusing on the activities specifically related to autism patterns [25].

In general, most of the applications have the following characteristics [26]:

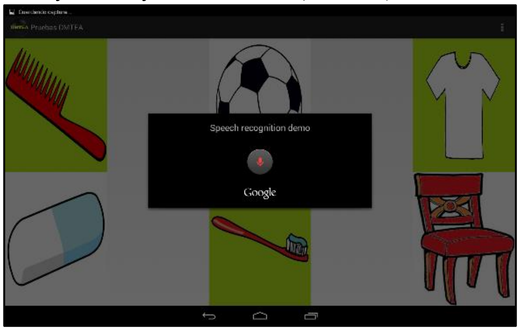
1. They offer a controllable situation and environment; they are a highly-predictable partner which offers perfect and understandable contingencies: by pressing the same key, the same results are always obtained.
2. They present a multisensorial –mainly visual-stimulation, offering benefits to people with ASD (Autism Spectrum Disorder).
3. Their effort and motivation capacity is really high, fostering attention and reducing frustration as a consequence of mistakes.
4. They foster to carry out autonomous work and to develop self-control skills. The ICTs are adapted to personal characteristics, thus allowing different learning rates and a greater level of customization.
5. They are an active learning element with versatility, flexibility and adaptation as main features.

TABLE 2
IDEA DIMENSIONS REGARDING THE MAIN DISORDERS

| Disorders | Dimensions | | |
|---|---|---|---|
| Socialization | 1. Social relationship | 2. Joint reference | 3. Inter-subjective and mentalist |
| Communication and language | 4. Communicative functions | 5. Expressive language | 6. Receptive language |
| Anticipation and flexibility | 7. Anticipation | 8. Flexibility | 9. Meaning of the activity |
| Symbolization | 10. Fiction | 11. Imitation | 12. Suspension |

## 2.1 dmTEA: Application for the Diagnosis of ASD

Based on the previously-mentioned characteristics and applications, we have focused on developing the dmTEA application [9], [27], which builds on the activities specifically related to autism patterns [25]. dmTEA is an evaluation and diagnosis tool for autism which includes a set of learning activities based on the IDEA [8] inventory using, for this purpose, mobile technology. Specifically, IDEA estimates autism by means of twelve dimensions which are the main disorders that define it. These dimensions are gathered, creating four blocks which correspond to the four sections mentioned by Lorna Wing [7]: socialization, language and communication, anticipation and flexibility, and symbolization (Table 2).




The final aim of the tasks designed is to work on deficits in order to achieve, by behaviour modelling, gradual solutions at the same time that students acquire the necessary knowledge and competences. From the 26 tasks initially suggested, experts –in this case, the teacher who works with the children daily and two professional experts on autistic disorders from our University– have chosen twelve. The most suitable tasks for interacting with the mobile device for the specific context were selected. Based on the supporting technology used, we may consider different groups of activities within this same tool:

1. Touch activities: Activities which use the mobile device touchscreen to press different elements such as a requested picture, any mood or a specific object out of several options and even to paint a tree (see Fig. 1).

2. Drag & Drop activities: Activities where elements can be dragged with the finger when pressing on them. Some examples of these activities are: creating diaries with pictograms or moving elements towards their outlines (see Fig. 2).
3. Activities with voice recognition: The child's voice can be recognized so that the teacher can determine if the child pronounces the names of some objects properly (see Fig. 3).
4. Multimedia supported activities: Videos or gifs are played and the child must imitate the actions shown on the screen, i. e. greeting or clapping (see Fig. 4).

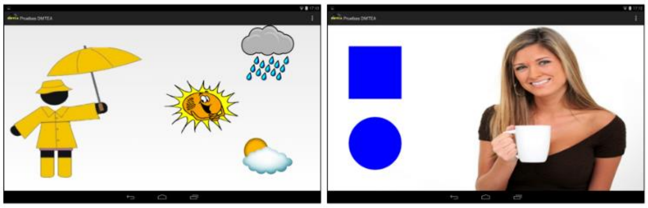


Figure 1. Touch Group. Screenshots of activities: "Press on a figure" and "Guess the weather"

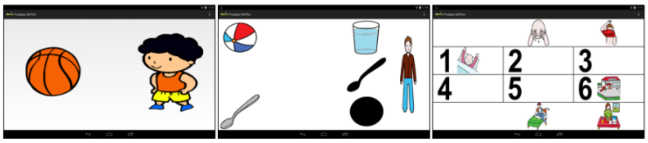


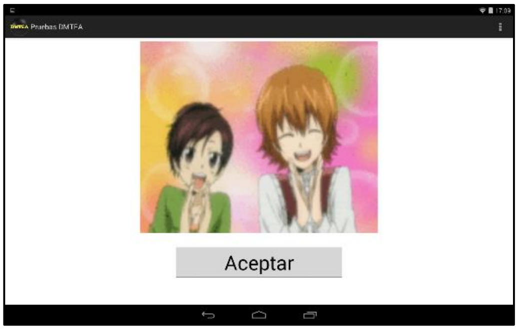
Figure 2 Drag & Drop Group. Screenshots of activities: "Drag the ball towards a child", "Drag objects towards their outlines" and "Steps to go to school"

Besides, all the activities use voice synthesis to instruct the child what he or she has to do in each exercise, or to guide him or her during the exercise with new instructions or to give feedback such as congratulations for each action.

With the tasks designed, experts decided which IDEA elements were the most suitable to be evaluated with a tablet device. Then, we designed an assay for user testing. This assay is a simplified version of the Delphi Method [28], in which other experts, by means of observation, grade tasks and dimensions, filling in a matrix form in which rows are dimensions while columns represent tasks [29], [30]. Specialists grade the relationship between the tasks and the dimension from 0 to 10, 0 being an invalid relation and 10, an excellent result in the task.

Figure 3. Voice recognition Group. Screenshot of activity "Repeat the name of the objects"

Figure 4. Multimedia Group. Screenshot of activity "Clap as in the video"




The tasks are completed with two users, one suffering from severe autism (Kanner type) and the other one with moderate autism (High-Functioning type) in an autism specialized educational centre located in northern Spain. The assay is based on two case studies, which are given several and different activities over a period of time for data collection. The teacher will give the main instructions on each activity, since they are the closest to the children. In this way, we avoid expert confusion in grading, which is, wrong test assessments that could have been deemed unsuitable, when the real problem is the lack of trust in other people. All activities may be repeated to model the student's behaviour, thus allowing a better understanding of what it is requested in the task and proper completion by following their teacher's instructions.

These tests are carried out over two weeks, and two tasks are performed daily so that the student does not feel tired. The first week is focused on sessions during which the students are in contact with the tasks; while the second week is focused on consolidation, making sure the tasks are understood better and performed efficiently.

Once all tests have been carried out, the data collected are analysed to determine the suitability and compliance of the tasks with IDEA's pattern and to check the agreement between two observers. The value of the Berk index (agreement between observers) has shown that in both cases there has been an excellent level of agreement between experts for all the tasks ($\sigma_o^2$>= 0.83). This rate was chosen because it analyses observers' variance avoiding, for example, Kappa's randomization error. In this way, only the observation effect remains, i.e., the concordance of subjects, by removing the intra-subject error.

In the case of moderate autism, the highly saturated dimensions are 5 (expressive language), 6 (receptive language) and 8 (mental and behavioural flexibility). "Highly-saturated" means all those dimensions with a higher mark than the expert-specified threshold. This information allows to make initial assessments of functional diagnosis with reference to the dimensions mentioned. In this case, the most consistent relations have taken place in task "press on a specific figure" with dimension 8 (flexibility), in task "to put objects to their outline shapes" with dimension 6 (receptive language) and in task "weather forecast" with dimension 5 (expressive language).

In the case of severe autism, the most saturated dimensions due to the tasks carried out are 1 (social relationship), 2 (joint reference), 5 (expressive language), 6 (receptive language) and 11 (imitation). Thus, it can be said that the set of tasks gives us the possibility to establish initial estimations of the functional diagnosis about such dimensions. It may also be observed that relationships are not bi-univocal, i.e., tasks are not related to all the dimensions in the same way. The most consistent relations may be observed in the task "to establish the steps to go to school" with dimensions 1 (social relationship) and 2 (capacities of joint reference), "to put objects to their outline shapes" with dimension 6 (receptive language) and "to move a ball towards a child" with dimension 11 (imitation).

Observing the diagnosis results with dmTEA, we could establish that the block of dimensions with the highest marks was regarding communication and language (dimensions 5 and 6). Therefore, we have created "Chains of Words", a supporting app for intervention and focused on the functional area of communication for children suffering from ASD. The study of the two systems used by the experts in the educational institutions chosen, such as PECS and PowerPoint, gives us the possibility to obtain their most efficient features and to apply them to mobile devices. The first one is PECS system [15], based on the exchange of cards which represent different words (names, nouns, verbs, adjectives) to learn how to build sentences and to communicate. The second one utilizes a system which allows to learn how to create and pronounce sentences and which is based on the above procedure with cards but, in this case, using PowerPoint, placing a photo with the sentence to be created in the middle of the slide. The child must recognize all the words in the sentence, one by one, and the pictograms representing it will appear by means of a teacher-guided animation.

## 3 Our Proposal: Chain of Words

Having analysed the validity of diagnosis with dmTEA "Chain of Words" is designed with the purpose of intervening gradually in language and communication disorders (Communicative functions, Expressive language and Receptive language). Each element of IDEA is subdivided into 4 levels which determine the degree of involvement for each dimension. At the same time, each level has different items [24] which define the characteristics that represent it so that, according to them, educators may establish at which level the child suffering from autism (and who has said characteristics) is. Taking into account the items of the language and communication block, we have tried to find out a relation to the application designed in order to deal with the different related problems in each dimension.

Considering the features mentioned by Nicolás [26] in communication and language deficits, we have designed "Chain of Words" to be used on tablet devices. Their touchscreen and portable nature add an advantage if compared to traditional systems such as the use of pictographic cards both when materials are managed by teachers [10] or children who are going to use the application [31]. In addition, "Chains of Words" is an application designed for tablet devices which takes advantage of the affordability, mobility and portability features of mobile devices. Thanks to its multimodal interface, children may interact by touching the screen and, at the same time, listening and pronouncing the words and sentences aloud. Though in "Chain of Words" tests are carried out in an educational institution, the ordinary practice is that children, due to their special features, work individually with a teacher and, outside the classroom with other children.

In order to be able to explore all the possibilities regarding communication with autistic users, the joint work of autism experts and technicians allows the implementation of two activities which are part of "Chain of Words" (Fig 5, Screen b). In the navigability diagram, an interaction diagram is shown both for teachers as well as for children. In the first activity, the child repeats the names of different objects shown on the screen. In this case, a system of customized contents has been created so the teacher may decide which objects are to be shown on screen, grouping them into different categories with common features (Fig 5, Screen d). The aim is that the child presses on each object, listens to his or her name and repeats it properly and, then, the teacher must assess if the task has been completed properly (Fig 5, Screen e). Based on such assessment, the app sends a positive or negative feedback, either as a sound or visual cue, by covering the object pressed with another one which represents if it has been done in the right or wrong way (Fig 5, Screen f). In addition, when the whole object panel is completed, a video will be played to encourage the kid to continue working with the application (Fig 5, Screen j). In the same way, pictures may also be replaced by the word they represent.

The second activity allows teachers to create sentences with the pictograms from ARASAAC (www.arasaac.org). Those pictograms were chosen because they are useful and they are highly used at the national level, and based on the SPC (Pictographic System of Communication) for children with autism [32] and have colour frames according to different word types (verb: green; name of a person: yellow; object: orange; etc.). Colors may be turned off if the teacher decides so. Apart from the ARASAAC pictograms, other types of images may be used, such as photos of the class to adjust sentences to the most suitable context. Besides, the teacher may choose among the options if each photograph of the list will have its related word or will be included only as a text with no picture, based on the child's reading and writing skills. This second activity is made up of two

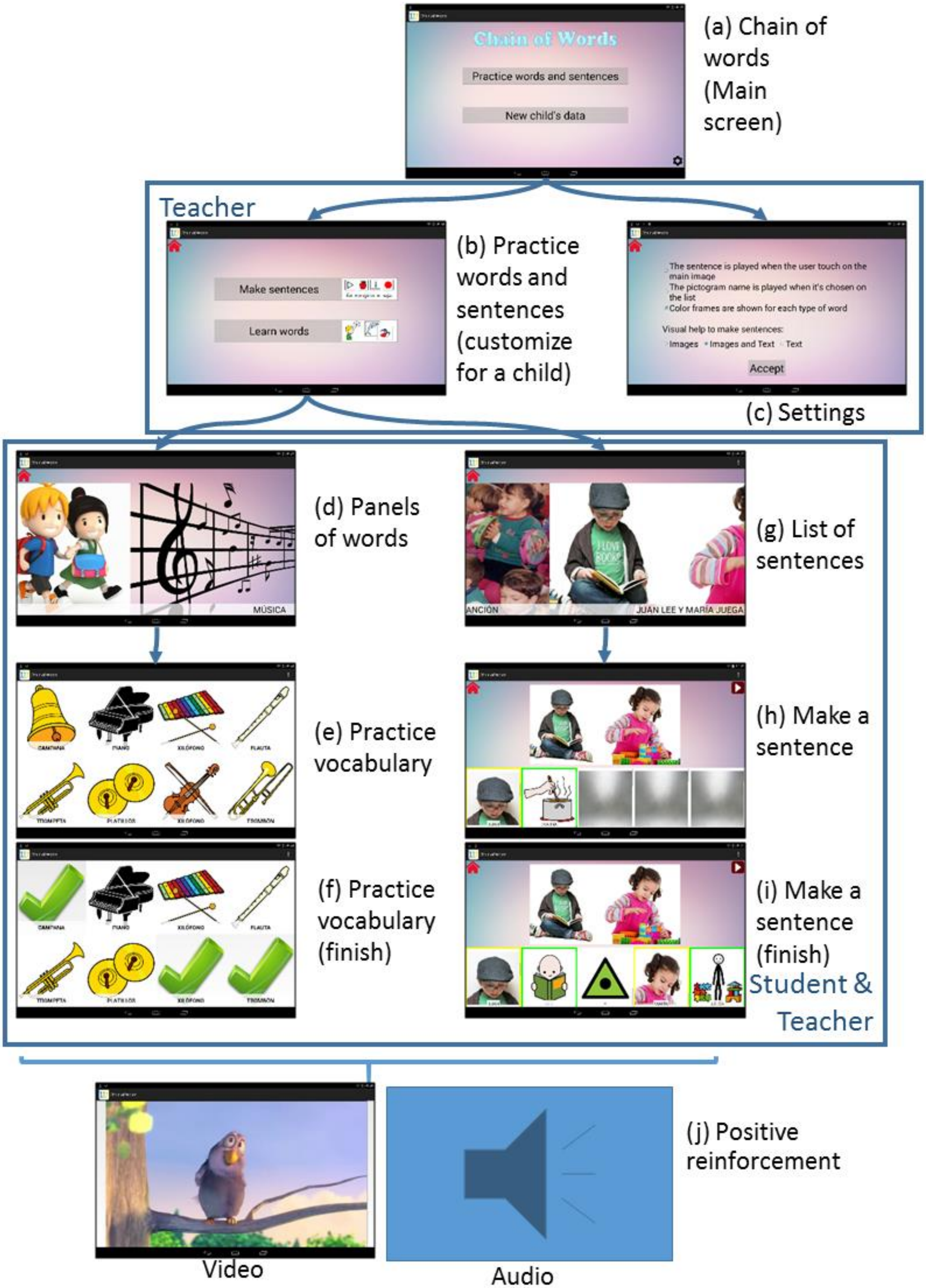



Figure 5. Diagram of navigability of Chain of Words. It shows the different screens of the application with the players who should interact in each part of the application.

different sections. The first one shows a screen with a list of sentences, and each of them has a picture which represents it (Fig 5, Screen g).

It is organized according to the level of difficulty of the sentences chosen by the teacher. Each sentence appears individually when the kid drags his or her finger horizontally to show them. To choose the sentence the child must build, the teacher presses on the respective picture. In this section, the teacher decides if the child is able to pronounce the sentence only with the image attached to it, without any visual support representing each of the words of said sentence. In the second section, a sentence shall be built, which will be defined based on an image located in the middle of the screen -which is the one shown in the previous list (Fig 5, Screen h). For this purpose, the child has a set of pictogram lists located at the bottom and which the kid will drag vertically to choose the suitable pictogram. Sentences have around 2 to 5 words and the number of words may vary based on the child's skills as assessed by the teacher. An example for the child (Fig. 6) will be the sentence: "David come helado" (David eats an ice-cream). For this sentence, the child must choose the pictograms "David", "Eats" and "An ice-cream" from the lists offered. In this section, the teacher also determines if the child is able to pronounce the sentence but, in this case, the child will have the visual support of each of the words chosen when building the sentence. Both the teacher and the child may also check if the sentence is properly designed by pressing a key which compares the source one to the one built by the child (Fig 5, Screen i). Based on the result of this comparison, the child receives a sound feedback, either if the sentence has been right or wrong. Said sound is chosen by the teacher, who picks the most suitable tones for each child (Fig 5, Screen j).

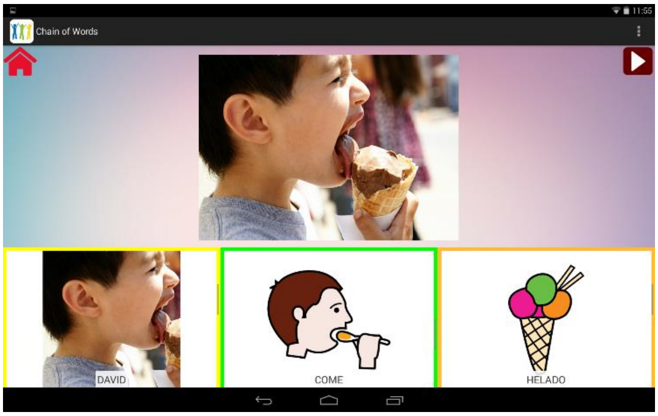


Figure 6. Screenshot for the sentence building activity.

"Chain of Words" gives teachers the possibility to create materials which are adapted and customized for each child because special autism characteristics may vary from child to child [33]. In the same way, the feedback displayed to children when completing tasks is tailored to each specific case and both the vocabulary and the sentences may include real photographs of the children and their schoolmates. All contents may be customized, from the selection of sentences to the selection of each of their words. Finally, the tool stores, by means of a log system, all the actions carried out by the child, such as the pictograms chosen from each list, the vocabulary learnt, the sentences built or if the sentence is matched up to the picture. The final target is to conclude if the kid is making any progress in sentence building.

The application uses different mobile technology supports. The first and most important one is the touchscreen which is used in two different ways: pressing different elements to choose a word or to check if a sentence is properly organized or dragging the list of sentences or pictograms as in a "drag & drop" activity. The second one is the possibility to synthesis the text to be orally reproduced. The child must listen to the words to be repeated or the sentence to be created. The third one is the reproduction of multimedia elements to offer both sound and visual feedback in a clip when an activity is finished.

The tool also includes an internal database to store children's data which will later be used to complement the information on the log files. These data are also used by the application to create an internal folder system where each child can have his or her own adapted contents (sentences, vocabulary and feedback) and so there is no need to set the structure anew each time another child uses the application.

## 4 Methodology

To evaluate the research hypothesis previously raised, we have designed a mixed methodology. From the first part, which is quantitative, a progress analysis is obtained using logs with the child-application interactions. In the second part, which is qualitative, specialists' experience expressed by collecting opinions is confronted with different interviews.

Both parts are implemented in two public schools where teachers are used to this type of technology. Both, educational objectives and skills to be acquired by children with autism are specified by the Regional Education Department. Autism specialist teachers cover several schools and so every autism expert has children from different schools.

Both schools have children with special educational needs among their students and, for the purpose of our study, those with the communicative problems mentioned in the IDEA were considered. In Spain, autism is usually diagnosed at age 5. Nevertheless, symptoms may appear during the maternal period and thus, professionals working with autistic children are the most suitable to determine when such tools shall be used. In our case, sample selection is carried out by teachers from both schools.

The sample is made up of eleven children (Table 3). Children know their teachers and have a very close relation with them, therefore making it easier to conduct the "Chain of Words" tests for determining progress in the communicative deficits, as well as a comparison of the system with other more traditional ones, such as PECS or PowerPoint. Over the study duration, all parents of the children taking part in the sample were informed about the study and their kids' progress.

TABLE 3
INFORMATION ABOUT THE CHILDREN CHOSEN TO TAKE THE "CHAIN OF WORDS" TESTS

| ID | Sex | Age | Communication difficulty |
|---|---|---|---|
| C1 | M | 3 | High |
| C2 | F | 4 | Low |
| C3 | F | 5 | Medium |
| C4 | M | 8 | Low |
| C5 | M | 7 | Medium |
| C6 | M | 4 | High |
| C7 | M | 4 | High |
| C8 | F | 5 | Medium |
| C9 | M | 6 | Low |
| C10 | M | 5 | Medium |
| C11 | F | 5 | Low |

The second stage was session design. Teachers designed sessions, individually adapting them to each child's specific needs. A certain number of tasks and sessions had to be specified (during an average of about 15 minutes, so that the child did not feel tired), as well as the frequency. The result was 10 sessions for vocabulary and 7 sessions for sentences. These sessions took place over three months in the second term of the academic course 2014-2015. During each session, teacher and child worked individually in one of the school classrooms. Each child was instructed what he or she had to do and his or her behaviour was modelled, if necessary. All children had used mobile devices at school before so there was no need to teach them how to use the application.

### 4.1 Procedure and Data Collection

In order to make the quantitative measure, the application analyses 6 variables which allow us to, in turn, measure the children's progress. Automatic speech recognition for children is a challenging topic in computer-based speech recognition systems [34], [35]. This challenge requires us to provide educators with success and failure markers for words and sentences in "Chain of words". In the case of the word learning activity, the teacher checks on the app whether the child is successful with a given word. So, "Chain of Words" has collected right and wrong cases in logs files for each session and child. On the other hand, in the sentence building activity, right and wrong answers are also considered. In this case, we have also reflected different levels of difficulty. These levels of difficulty are related to the progression sequence of the morphological and syntactical development children experience while learning Spanish [36]. And it is adapted by teachers to the specific educational environment of this study (Table 4).

TABLE 4
LEVELS OF DIFFICULTY

| Difficult degree | Type |
|---|---|
| 1 | He/She uses the word "phrase" |
| 2 | He/She overlaps two words |
| 3 | He/She builds Subject-Verb sentences |
| 4 | He/She builds Subject-Verb-Object sentences (3 words) |
| 5 | He/She builds Subject-Verb-Object sentences (4 words) |
| 6 | He/She uses the article "the"(masculine in Spanish) |
| 7 | He/She uses the article "the"(feminine in Spanish) |
| 8 | He/She uses the indefinite article "a/an" (masculine in Spanish) |
| 9 | He/She uses the indefinite article "a/an" (feminine in Spanish) |
| 10 | He/She uses the personal pronoun "I" |
| 11 | He/She uses the possessive determiner "my" |
| 12 | He/She builds Subject-Verb-Object sentences (5 words) |

Both word and sentence marks for each session are determined by the following formulas:

$$Mark\ Vocabulary = \alpha - \beta$$

$$Mark\ Phrases = \frac{\alpha - \beta}{2} + \frac{(\delta * 0{,}75) + (\mu * 1{,}5) - (\varepsilon * 0{,}75) - (\gamma * 0{,}5)}{2}$$

Percentage of success (α), percentage of failure (β).
Maximum level of difficulty successfully achieved (μ), number of sentences built with a different level of difficulty (γ), maximum (δ) and minimum (ε) levels of difficulty.

Constants in the formulas are expert-suggested weights which allow the calculation of sentence marks taking both correct and wrong answers into account, as well as the levels of difficulty. Thus, the maximum and minimum levels of difficulty reached by the child are given a weight of 0.75 by the experts. Nevertheless, teachers consider that the maximum level of difficulty of a sentence properly built weighs double and, therefore, their mark is 1.5. Besides, the parameter of total number of levels performed is given a weight of 0.5, as experts value more the maximum level of difficulty successfully achieved than the amount of levels carried out.

Reports of class attendance show a 33% absenteeism rate. Missed school data are retrieves following the procedure specified by Fernández-Alonso, Suárez-Alvarez and Muñiz [37], which combines replacement-based recovery methods according to the subject's average for incomplete data and the Hope-Maximization algorithm, in this case with no auxiliary variables. In Spain, teachers grade assessments based on a 0 to 10 mark rank, and this is the reason why the numerical values obtained in the formulas are standardized within this range, from which final marks are calculated. Considering these final marks, a statistical analysis is implemented for which the independent variable is the child and the dependent variables are the word and sentence marks. Finally, to identify the advantages of "Chain of Words" against traditional systems, individual-student surveys were conducted with the teacher four weeks after the last time the app was used. In this survey, which is included in Fig. 9, teachers have compared "Chain of Words" to other tools used in more traditional communication-focused interventions. They are using interventions such as PECS and PowerPoint. In the survey, teachers have to answer 7 questions with the Likert scale, from 1 to 5, checking features such as efficiency or preference of the interventions mentioned above. In each of the questions, the "X" represents the method assessed from 1 to 5. Apart from the survey, we have asked teachers to share their feedback.

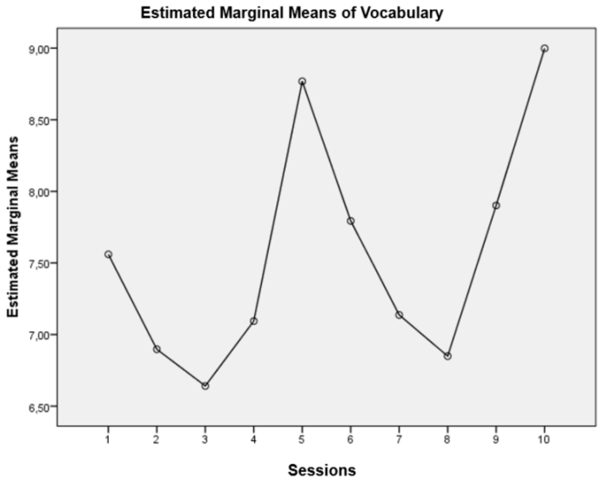



Figure 7. Chart with mark average regarding vocabulary per session

## 5 Results

After having processed the logs regarding children's interaction and the surveys, we have obtained some results with which we have tried to determine the validity of our study hypothesis.

### 5.1 Progression of Communication Deficits

Descriptive statistics of sentence- and vocabulary-related variable marks can be checked in Table 5.

TABLE 5
STATISTICAL DESCRIPTORS

| | N | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **Vocabulary** | 11 | 7.5639 | 2.3759 | 3.7250 | 9.6990 |
| **Sentences** | 11 | 6.2063 | 2.1729 | 2.8085 | 9.5000 |

For the dependent variable "Vocabulary", Friedman's test shows that some distributions of marks are significant (p=.03). The chart corresponding to the sessions (Fig. 7) shows a linear trend (p=.01), which indicates global progress in vocabulary work, appreciating sessions with high and low performance, as is normal in autistic children.

Assessments indicate that all children showed improvements in their ability to articulate words and phrases and these results are in line with those found by other studies about speech output in non-verbal children with autism [38]. In the case of sentences, Friedman's test shows significant differences (p =.03) between the first and last session with a trend that is shown in the chart (see Fig. 8).

### 5.2 Comparison of Chain of Words and Traditional Methods

The results obtained from the survey shown in Fig. 9 give an idea of the difference between "Chain of Words" and a traditional method. We consider it is necessary to complement said results with the opinions given by teachers which are focused on two main aspects: use and flexibility, and communication support offered by "Chain of Words". We have herein included three opinions collected by experts regarding the above-mentioned aspects:

"Chain of Words is better than the PECS card system", and the following is added: "The PECS card system is more difficult to use because the cards get dirty when they are continuously used and they look bad after some time".

"I used to work with PowerPoint to introduce texts and pictures adapted to each child. Nevertheless, "Chain of Words" structure for building sentences and vocabulary makes it easy to add photos, videos, texts and sounds customized to each case, and the most important feature is that children can interact with these elements."

"The interactions offered by the tablet allow me, in some cases, to customize the child's behaviour for the tasks offered by "Chain of Words", giving us the opportunity to have a communication feedback among ourselves which is difficult to be achieved with PECS cards or PowerPoint".

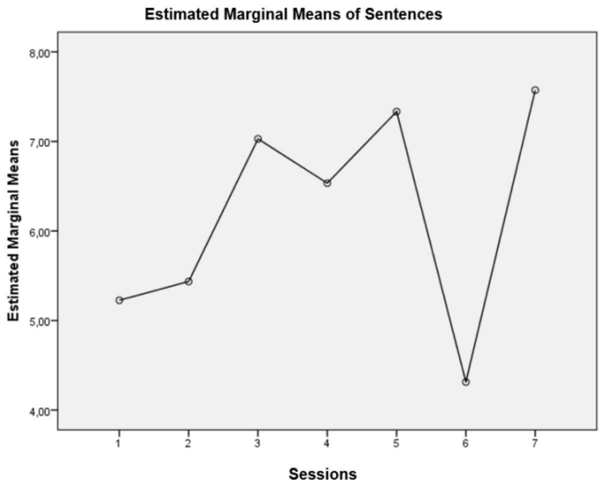



Figure 8. Chart with mark average regarding sentences per session

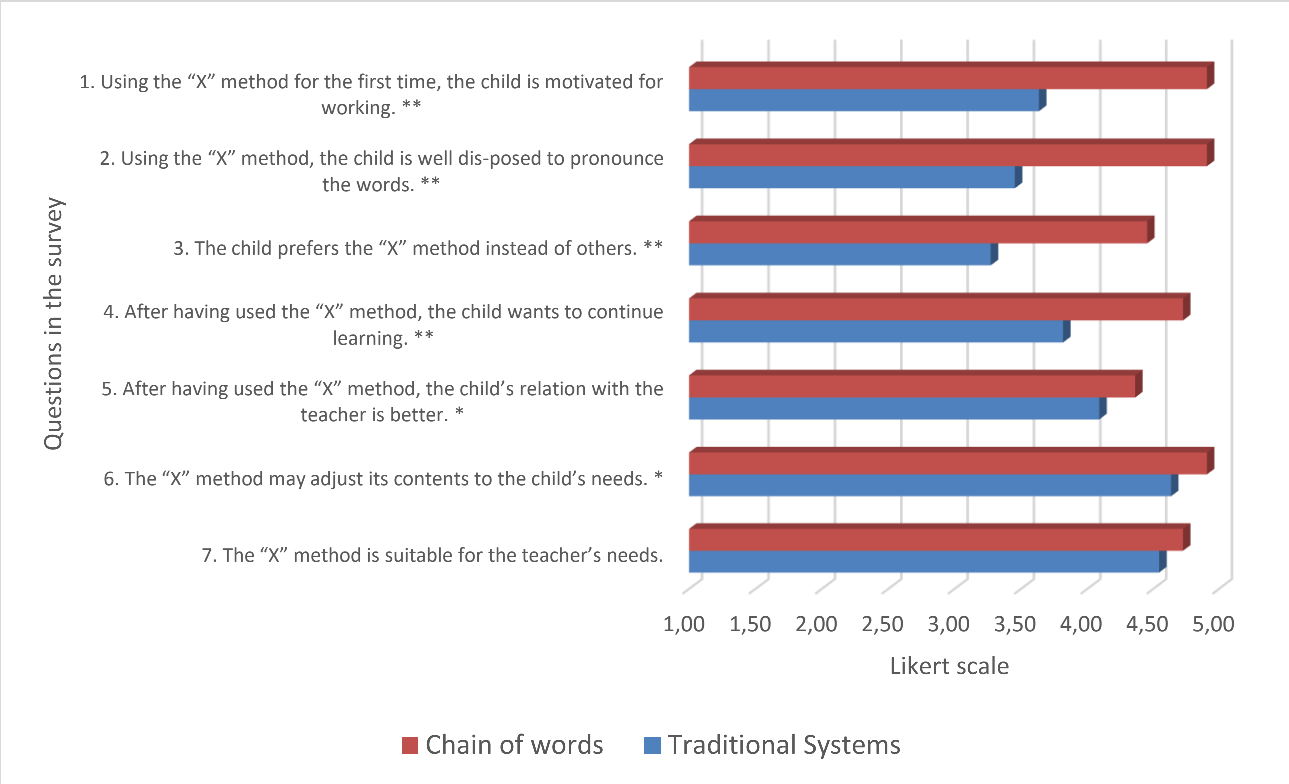



Figure 9. Statistical result obtained based on the interviews carried out by the teachers (t-test, * is p<.05 and * is p < 0.001, where N=11). Marks are measured according to the Likert scale, where 1 means that the teacher is considerably in disagreement and 5 means that the teacher agrees completely. The orange colour refers to "Chain of Words" and the blue colour is for traditional systems.

## 6 Discussion and Interpretation of Results

The discussion and interpretation of results will give us the possibility to fulfil the aims specified at the beginning of the paper: to check the improvement in communicative disorders and the advantages obtained by using "Chain of Words" when compared to traditional solutions.

For the first matter, charts (vocabulary and sentences) show an increasing progress during the sessions (Fig.7 and Fig.8). Specifically for vocabulary, a linear trend is observed which is confirmed by these results (p=.01). Progress in sessions is featured by the variability of results in the first ones, due to the typical characteristics of these ASD students and which may change from child to child [13], [39], because, since it is a new environment, it is difficult for them to adjust. In the last sessions, progression leads us to think that the effect will stabilize regarding its increase as the environment is more controlled and, therefore, his or her behaviour is more predictable. Moreover, this progression effect is evident between the first and the last sessions as it is so confirmed by significant statistical differences (p=.03). With reference to sentences, results have shown significant differences regarding progression in the first and in the last session (p=.03). Data behaviour for sentences is similar to that of vocabulary data during the first sessions but it is different in the last ones. In our initial sessions, we have noted a growing progression with variations. Since it is a new app, children get used to it over time and so the learning environment becomes more predictable. During the last sessions, data variations do not follow a linear pattern. The reason may be that the teacher has introduced new words and even though sentences do not vary in difficulty, children do not identify those words with the respective object. In the last session, students identify the objects related to the words for each sentence in a better way, and thus there is a significant difference between the first and the last one. We complement this result with visual analytic techniques in the same line suggested by [40] for exploratory purposes. We show progression in marks obtained by type-case in the sentences and vocabulary sessions (see Fig. 10). Analysing the results taken from this case, we realize that progression in vocabulary is quite steady, with small ups and downs over the sessions. In the case of the sentences, there is an increasing progress but it is not as steady as the one observed for sentences. Said variations are due to the difficulty to adapt to the changes introduced by the teacher over sessions but, nevertheless, the child finishes with a significant improvement when comparing the first and the last sessions.

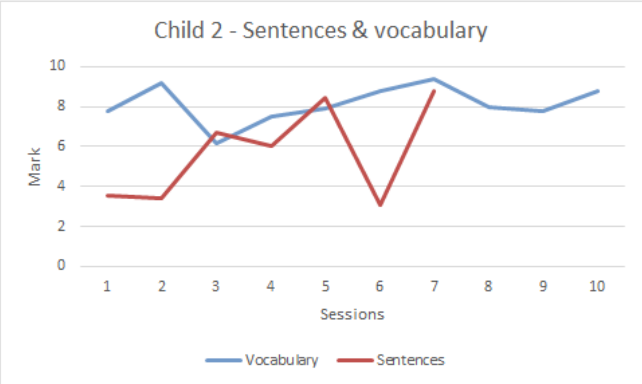



Figure 10. Chart which shows mark progression over sessions for both, vocabulary and sentences, considering only one child of the study

The results obtained on improvement in communicative disorders have shown us that tablets may be another supporting device for teachers who work with autistic children with communication problems. Experiences similar to "Chain of Words" and based on communicators and pictograms [13], or systems which use symbols and text-to-voice [20], [24], but without reaching the level of building grammatically correct sentences, have proved that mobile devices are useful tools for the receptive and expressive language, fostering acquisition of vocabulary and, therefore, improving the lack of communication shown by some ASD kids, which may cause them anxiety [41].

The analysis of the surveys show that "Chain of Words" improves some of the aspects considered by the traditional systems. The child is more motivated the first time he or she uses "Chain of Words" than when using other systems (question 1). Besides, the child prefers to use "Chain of Words" rather than traditional methods (question 3). This result is in line with other works such as [20] building on the stimulating and motivating effect technology has on children with autism. Here it is even more the case, since these children have already used tablets in other educational activities and, therefore, this motivating effect as something new is not present.

With "Chain of Words", teachers have highly considered the possibility of customizing contents according to the child's specific characteristics and appreciate the way "Chain of Words" can be adapted to the children's needs (Question 6), because each case of autism is unique [42]. The adaptation of materials to daily situations of the child's life, even with his or her own photos, means that "Chain of Words" is more reliable at the time of introducing contents than the traditional PECS card system. Flexibility of contents to customize tasks for each child is a result in the same line as other research studies such as [10]. In such study, teachers can have flexibility of contents, but it does not offer an educational activity with children to verify such flexibility.

Teachers consider that the traditional method is also tailored to their needs (question 7). It is important to mention that teachers in our study use the traditional PECS method and PowerPoint presentations. Miao-En and his colleagues compare in their study the app iCAN to the traditional method of PECS cards. But in our case, this comparison is made with the PECS cards and PowerPoint. We consider this fact causes the minimum significant difference shown in the comparison between both methods.

After using "Chain of Words", the child wants to continue learning (question 4) and using "Chain of Words", is eager to pronounce words/sentences (question 2). We consider that the improvement obtained in communicative deficits thanks to the statistical analysis of vocabulary and sentences supports the result obtained in this case. We believe this result is the consequence of the engagement effect of technology as demonstrated by Venkatesh et al. in [20].

After using "Chain of Words", the child's relation to the teacher is improved (Question 5). Over the interviews, a teacher told us that the relationship had grown closer thanks to the interaction with the tablet device and to the possibility to guide the student's behaviour in some cases. The touch interaction has been used successfully for autistic children with motor disabilities [43] and to engage children with ASD in social activities [44]. In "Chain of Words", the direct manipulation style by using the touchscreen allows children to match up objects and words; the speech technologies improve both learning and new vocabulary and sentence building in Spanish with an emotionally neutral computer [17], aided by visual support complemented with audio and video reinforcement.

## 7 Conclusions and Future Work

Results obtained in this research confirm that mobile devices may be another supporting tool to be used with children suffering from autism and communication deficits. Specifically, dmTEA is a software mobile technology which enables the evaluation and diagnosis of autism spectrum conditions, apart from acting specifically on those communication-related disorders. Said evaluation and action is based on the IDEA inventory, which evaluates twelve characteristic dimensions of students with autism spectrum and severe developmental disorders. On the one hand, this technology implements twelve learning activities adapted to tablet interaction for a specific educational context. Its aim is to work on difficulties to solve them gradually by modelling behaviour. At the same time, students acquire the necessary knowledge and skills.

"Chain of Words" is an app designed for the functional area of communication. All three language dimensions are perfected as well as the communication block of IDEA. In addition, "Chain of Words" offers flexibility for managing different task contents, facilitating the resource management of the activities which may be considered suitable for and adaptable to each child over a period of time.

Research studies based on interventions with the support of computer mobile technology have opened up possibilities for children with ASD. The use of tablet devices allows some portability, mobility and affordability which give rise to individual and customized educational scenarios outside the regular classroom. Within this learning environment, the teacher and the student are working together and technology becomes an extra support to help them. Specifically, in the dimension of receptive and expressive language, it has been demonstrated that they help children with autism to communicate, increase their interest and engagement in the learning of words and sentence building. The touch interaction permits a direct manipulation style with reference to objects matched up with words. Communicator building applications or applications such as ours, "Chain of Words", add the advantage of using oral technology for acquiring vocabulary and, in our case, building grammatically correct sentences in Spanish. As each autistic child is a unique case, the use of tablet device by teachers adds content flexibility. In doing so, experts are able to adapt and even customize the visual support to each specific case, together with the audio and video reinforcement offered by the apps.

Results obtained encourage furthering this study. Directions of future research for the case of diagnosis include both extending the number of users involved in the evaluation as well as including the four existing levels of autism (Kanner, Regressive, High-Functioning and Asperger), in order to be able to generalize the observed behaviour to situations that were not examined. Other future lines of work are: completing dmTEA with all the IDEA dimensions and including more tasks as well as some further development of the diagnosis system to facilitate the present management of the experts' reports and create new activities which can progressively help with disorders. In the case of "Chain of Words", teachers have told us that it is a tool with a high potential to deal with social skills-related communicative problems. Thus, research will be conducted to determine if children begin to communicate by themselves when using the application, as well as to reinforce the capacity to express their basic needs. Besides, we have considered adding a learning analytics module to visualize the gradual progress in the child's communicative disorders which could be helpful to make appropriate and real time decisions along the process.

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In recent years he has studied professional rules of social and educational inclusion and developed project evaluations in social services at local, regional, national and European level.