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Technology-enhanced ABA Intervention in Children with Autism: A Pilot Study

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Abstract Purpose: This study investigates whether ICT technology can enhance Applied Behaviour Analysis (ABA) rehabilitation therapy for children with autism.

Method: A technology-enhanced rehabilitation system to support the daily work of ABA tutors, parents and teachers was created, involving ABA experts and parents of autistic children in the entire design phase, in order to better understand the system's functional requirements and enhance its usability. Thus, combining the ABA programs with a learning analytics tool, an open source Web application, ABCD SW, was implemented for teaching and monitoring learning in low-functioning autistic children. In a small pilot study the

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system was tested on seven children with autism enrolled in an intensive intervention lasting 9 months. The children were assessed before and after the pilot test, using Vineland Adaptive Behavior Scales to measure their personal and social skills.

Results: Test participants showed improved communication, especially in the expressive category ($p<0.05$). Subjective feedback from the ABA team involved in the user test confirmed the children's improvement in socialization, communication and behavior. ABCD SW expedites the intervention (thus increasing its efficiency), and makes it more pleasant for the children. Furthermore, ABCD SW enables caregivers to easily conduct and personalize the intervention, reducing its cost.

Conclusions: The study seems to suggest that ABCD SW, and ICT technology in general, can enhance ABA rehabilitation therapy for children with autism, encouraging further investigation of this promising research field.

Keywords Autism · ABA · Technology · User Interface · Tablet · Didactic software

1 Introduction

The Diagnostic and Statistical Manual of Mental Disorders [5] and the International Statistic Classification of Mental and Behavioral Disorders [40] define autism as delays or anomalies appearing in children before 3 years of age in at least one of three areas: social interaction; communicative and social use of language, and symbolic or imaginative play. Autism spectrum disorders (ASD) comprise autistic syndrome, pervasive developmental disorder not otherwise specified, Asperger's, Rhett's and childhood disintegrative disorders. Since the severity of symptoms varies significantly from individual to individual, a personalized educational intervention that can be adapted to each child's needs and learning pace is needed. Concerning autism prevalence, the CDC's Autism and Developmental Disabilities Monitoring (ADDM) Network estimated that in 2010 in the USA about 1 in 68 children aged 8 years (14.7 per 1,000) had been diagnosed with autism spectrum disorder (ASD) [13]. Due to the high incidence of autism, it is very important to act quickly in the first 2 years of life to take advantage of the exceptional plasticity of the child's brain [6,39]. Since the 1970s, different approaches have been proposed to deliver effective learning to children with autism, including ABA (Applied Behavioral Analysis), TEACCH (Treatment and Education of Autistic and related Communication-Handicapped Children) and recently DIR (Developmental, Individual-difference, Relationship-based model) [57] and Early Denver Model [56]. Early detection of symptoms (12-18 months) enables early intervention [11,32–34,47]. According to several studies [2,9,10,48] early therapy in children with autism is more effective than later interventions, especially for mastering skills and developing social abilities. Therefore, our project focuses on delivering young children (2-6 years old) an early intensive Applied Behavioral Analysis (ABA) intervention, since evidence supports its effectiveness [16, 18, 21, 50, 59]. ABA intervention observes the subject's behavior and models it using several strategies, including motivators. One of the main principles is the use of reinforcements: a child showing an adequate-to-the-context behavior is immediately rewarded with something (s)he likes very much, increasing the probability of positive behavior in the future. Furthermore, analyzing and modifying what happens before (antecedents) or after (consequences) an undesired behavior (e.g., self-stimulation) enables tutors to implement strategies for its progressive reduction and, possible extinction. The ABA intervention delivers DTT (discrete trail training). Each task is split into basic steps of increasing difficulty (trials). Each trial is repeated several times until the child (initially guided by the therapist's prompts to avoid errors) is able to accomplish the task successfully and autonomously. In order to keep the child's attention, the sequence has a quick pace, compatible with the child's needs, but sustained in order to avoid or limit self-stimulation [53]. Success requires all the tutors (therapists, teachers, and parents who are fully involved in the intervention) to guarantee the coherence of programs both at school and at home. Intensive, coherent and early ABA intervention (25-30 h/week) supports the child's learning [18, 49, 50, 59]. Monitoring of child actions and behaviors is a pillar of ABA intervention: paper forms are filled out by tutors during sessions of the ABA programs, when reinforcement is provided. This allows measuring the intervention's success and, if needed, reshaping it.

In this study, we aimed to investigate whether ICT technology can in some way enhance ABA rehabilitation therapy for children with autism. Our idea was to develop a technology-enhanced rehabilitation system, working alongside traditional ABA intervention to support the daily work of ABA tutors, parents and teachers. In order to better understand the system's features, we involved ABA experts and parents of children with autism in the design phase to better understand their needs. The analysis identified both the scope of the system, highlighting the need to combine the ABA programs with a learning analytics tool, and the main requirements:

1. Efficiency: to minimize tutor effort in setting up (articles are automatically arranged according to ABA program progress) and execution (the default workflow progresses automatically).
2. Flexibility: if the proposed trial is not suitable for the child, it is possible to change the items (by pressing the R key a new trial is proposed) and modify the default workflow, allowing the tutor full control.
3. Accessibility: the discriminative stimulus is adapted to the child's ability (receptive/expressive or not) using the Augmentative and Alternative Communication (AAC) assistive technology.
4. Engagement: The DTT assures the success of initial mass trials (i.e. the matching of two twin elements). The use of reinforcement sustains the learning over time. Personalization of images motivates the children: specifically articles of Places and People categories are added by parents/tutors to spur learning through well-known items.

5. Scalability: articles and categories can be added via Web interfaces without changes to the app code.
6. Cost saving: ABA requires one-to-one sessions with specialized personnel which is expensive and families might not be able to afford it over time; the software could help parents and caregivers perform technology-enhanced ABA sessions, supporting an intensive intervention.
7. Accuracy: evaluation of the trial (level of prompt provided, or child's behavior) is mandatory, ensuring the complete collection of performance data. Pressing a number from 5 to 0 defines the level of prompt provided (from 100% to 0%); otherwise it is possible to record self stimulation (S key) or problem behavior (P key). If the trial is successful with no prompt, the tutor may reward the child with a visual reinforcement (key 0).
8. Usability: the user interface (UI) are simple and easy to use. Furthermore, the software guides the intervention, aiding non-skilled people.

Fulfilling these requirements, we developed a Web application for teaching low-functioning children with autism: ABCD SW (Autistic Behavior and Computer-based Didactic Software, http://abcd.iit.cnr.it). Furthermore, we performed a small pilot study with seven children with autism to verify some main hypotheses:

H1: The use of ABCD SW during ABA therapy sessions helps make the intervention more rapid.
H2: The use of ABCD SW during ABA therapy sessions helps make the children's intervention more pleasant.
H3: The use of ABCD SW during ABA therapy sessions helps make the intervention easier for caregivers.
H4: ABCD SW allows much easier personalization than do traditional ABA sessions.
H5: ABCD SW can help reduce the cost of ABA interventions.

In the following, we will present our study and the results obtained. The paper is organized in seven sections. After this introduction, Section 2 introduces the background focusing on ABA applications for autism. Section 3 describes the ABCD SW architecture, interfaces and functions. Section 4 and 5 describe the results of the user test involving seven children during a scholastic year as well as problems encountered providing suggestions for further studies. Section 6 presents the discussions of the whole study, summarizing the answers to our hypothesis. Conclusions and future work end the paper.

2 ABA Intervention

There are several treatments available for the rehabilitation of children with autism. Of these, ABA has shown evidence of effectiveness in experimental trials, also with low-functioning people [16, 21, 49, 50, 59, 55]. Low-functioning people may have little or no receptive and expressive language, behaviour inadequate for the context, little awareness of people and expectations, or some degree of mental retardation or hearing loss, making their disability even more severe. Usually, they manifest stereotypies such as repetitive gestures and rituals and sometimes they may present problem behaviours (such as self-injury or aggressive behavior) [7,24,52]. Early Intensive Behavioral Intervention (EIBI) implements ABA for the rehabilitation of young children with ASD [16,35, 46]. Noticeable progress has been observed applying the EIBI model 25-30 h/week in one-to-one interventions for 2 or more years, beginning before age 5. Moreover, ABA has shown effectiveness in addressing challenging behaviors and skill deficits in older children and adolescents [21]. Several models of ABA intervention in autism are applied, sharing common elements [16,21,55]:

(a) Adaptation: intervention proposes individualized programs addressing all skill domains (motor, language, cognitive, logic, educational) and behavior.
(b) Analytic behavior procedures are used to both create new knowledge and reduce problem behavior interfering with learning. They include differential reinforcement, prompting, discrete trial training, natural and incidental teaching, activity-embedded trials, task analysis, etc.
(c) The intervention is carried out by skilled ABA tutors experienced in teaching children with autism.
(d) Objectives: intervention goals and short-term objectives usually start from basic programs (e.g., on categories such as colors, animals, shapes).
(e) Parents become active co-therapists for their children.
(f) Teaching: intervention starts with a one-to-one approach, with gradual transitions to small peer groups and larger groups.
(g) Places: intervention usually begins at home then is generalized to other environments (such as schools).
(h) Intensive intervention is year-round, and includes 25-30 hours of structured sessions per week in addition to general education.
(i) Duration of the intervention is 2 or more years.
(j) Early intervention in the preschool years is crucial for obtaining the best results.

ABA programs progress in steps of increasing difficulty. Initially basic programs such as object discrimination and basic autonomy skills are conducted. Depending on the child's response, the ABA analyst assigns the most suitable programs. Activities may include simple requests; imitation of gross motor skills; object matching; playing with puzzles; sorting shapes or blocks; performing basic daily living actions; using pictures, gestures, or vocals for communicating needs. Once basic skills are mastered, advanced activities may include fine motor exercises, oral motor movements, and imitation of sounds and words. Then the intervention can move on to academic skills such as logic and academic sequences, numeracy and literacy, discriminating questions, conversing and building peer friendships. All procedures apply operant conditioning techniques that include reinforcement, shaping, chaining, and prompt fading. As intervention progress, more natural approaches than DTT could be introduced. The aim is to help the child acquire skills that support learning in natural settings, analogously to typical development of children [17]. Reichow

[45] conducted a review of five Meta-Analyses of early intensive behavioral intervention for children with autism, observing that four of them supported the effectiveness of ABA/EIBI [16,35,46,55]. However limitations emerged: lack of a strict definition of the treatment intervention, the use of quasi-experimental design, small sample sizes, non-random assignment to groups, inadequate participant characterization, narrow outcome measures, lack of reliable data, and lack of standardized treatment methods for group control [45]. Overall, analyzed data indicate that ABA intervention in young children with ASD produced on average large increases in IQ and lower (but still significant) increases in adaptive behaviors. Behavioral approaches have shown efficacy in treating children with intellectual disabilities, reducing challenging behavior and teaching communication skills, toileting, and social skills [17]. Significant adaptive deficits were found in individuals with ASD, particularly in comparison to the higher IQ of high-functioning individuals, considered a strong predictor of adaptive behavior. Significant adaptive delays were found in high-functioning individuals: the greatest in socialization skills, moderate delay in communication and daily living skills [29]. However the use of IQ scores for measuring the effectiveness of treatment is not unanimously accepted, since people might autonomously make improvements in performing the test [31].

2.1 Technology-Enhanced Intervention

The use of new technologies for people with autism mainly addresses communication – through AAC and PECS (Picture Exchange Communication Systems) – as well as the analysis of behavior, self-stimulation, problem behavior and social interactions [15,25]. Putnam and Chong investigate the home use of software (SW) specifically designed for autism, carrying out an on-line survey for associations. Results showed the low adoption of specific SW (8%), while applications for cognitive disability were used by 25% of participants [43]. Several inexpensive apps are currently available in IOS and Android app stores. This was a big step forward in helping families: old-generation communicators (e.g., GoTalk, Tango, Dynavox, Activity Pad) have been recently replaced by mobile apps that are more usable, flexible, scalable, adaptable and easy to learn from, as well as considerably less expensive [25]. However, some apps still require considerable effort (e.g., for configuration) so usability must be a key factor guiding the design of learning tools. AAC increases the user's perceptions, taking advantage of multiple communication channels [27]. It is used with success in learning disabilities and neurological pathologies. Hirano et al. [27] created a visual system (vSked) for planning and organizing children's daily activities, and observed increased efficiency for therapists and improvements in communication, both student-student and student-teacher. ITHACA is an Open Source framework for building adaptable, modular, multilingual, inexpensive AAC-based applications [42].

Participatory design defines principles that actively involve all stakeholders from the early stages of the design process in order to ensure the usability of the artifact or product [37]. Participatory design is essential when designing tools for people with autism and is increasingly applied [12,25,27,36]. ABCD SW was designed by a multidisciplinary team, applying participatory design principles since its conception [3]. Kientz et al. [30] created systems for facilitating efficient child monitoring (progress and behavior): 1) Abaris, for Discrete Trial Training therapy, enabling easy search for therapy videos; 2) CareLog, for collecting and analyzing behavioral data. Recording therapy videos provides more information about child behavior; however, although technology-supported, the analysis of sessions is time- and resource-consuming. Conversely, using ABCD SW the tutor may record behavior data enabling graphic representation and the possibility of making a more thorough analysis, including ABC (antecedent, behavior, consequence) analysis charts and/or video recording [1]. Hailpern et al. [23] investigated the behavior of nonverbal children, using the computer for capturing parameters such as attention, engagement and vocal behavior. Monibi and Hayes implemented a library of virtual cards for the activities of autistic children on a smartphone (Mocoto prototype) that may be customized (e.g., size and number of cards, audio cues, etc.) [36]. Sampath et al. created a system for handheld devices using AAC, which enables bidirectional communication child/caregivers (receptive and expressive communication), converting pictures into spoken language [51]. Pervasive technologies are also increasingly used for monitoring user behavior. Kaliouby and Goodwin used wearable technologies (cameras, microphones, sensors) for capturing, analyzing, and sharing social-emotional interactions of people with ASD, with a fun and engaging approach [15]. Regarding functional communication, Hetzroni and Tannous [26] explored the effects of the app "I Can Word It Too" with five children with autism, observing effective improvement in communication and the possibility of transferring the new skills from classroom to daily life. Current research has developed systems that aid communication, support analysis of behavior data, organize activities, and monitor sessions, but there are few studies on the systematic application of ICT tools for ABA teaching. An ABA software program that enables continuous progress in the intervention, classroom activities as well as daily activities, is Trial Trainer (Accelerations Educational Software), which showed its efficacy with several autistic people [8]. Unfortunately, this tool comes at a price, burdening families with additional costs, while ABCD SW is designed to be free of charge. There are many learning applications designed for touchscreen mobile devices. Sometimes this abundance can confuse the caregivers, due to the lack of guidance in selecting what would be best for their children. Many applications are designed to respond to one specific learning need at a time: social-skills, self-care, language, communication, etc. Although helpful for the specific need and attractive to children, they do not contribute to more comprehensive learning. ABCD SW has been designed with a more holistic vision in mind, showing some aspects that make it different from any other:

1. ABCD is a Web application that runs in any device with a browser (Chrome, Explorer, Opera, Firefox, etc). This makes maintenance easier

(compared to having multiple native apps iOS, Android, WinMobile, etc.) since the single code may be executed on mobile devices or desktop PC.
2. Most existing applications are designed to be used by the child autonomously, while ABCD SW is designed to implement the one-to-one ABA intervention: it can only operate if the child and tutor work together. The tutor has an active role controlling and triggering the flow of an exercise's execution, entering real-time evaluation, enhancing the discriminative stimulus provided by the software and activating a reinforcement for positive behavior when necessary.
3. The learning environment is quite innovative because the software offers two fully separate interaction environments (tablet for the child and laptop for the tutor) synchronized via Internet.
4. Other applications (i.e. ABA find it! or Jacob's Lessons) implement exercises offered by ABA programming, but only ABCD SW is fully ABA-compliant: a) Educational goals are delivered through DTT. Each program provides (seven) increasing levels of difficulty that can be modulated by the tutor, according to child responses. b) Safety, implementing the errorless learning principle, i.e., it prevents the child to perform errors. c) The child is reinforced for each positive behavior. d) It uses the AAC to convey information. e) It ensures coherence of the intervention carried out by different tutors/caregivers, starting a learning session with the last trials performed by the child f) It ensures accurate and real-time data collection, enabling easy monitoring over time of the child's performance through graphics, facilitating the tuning of the ABA programs.
5. ABCD SW is multilingual. This important requirement is usually offered by commercial software, while free or low-cost apps usually require an extra effort to re-insert all the content in a personalized language.
6. It is the result of a multidisciplinary project that included expertise in different contexts: educational, therapeutic and computer science. The participative design of the software, allowing a synergic effort of the multidisciplinary team, was crucial for creating an innovative and more usable tool. The UIs are designed to be easy to use for both tutors and children. The child interaction is fast and accurate, in order to minimize the frustration that may occur if the application does not promptly respond to the child's action. Free applications are often implemented by parents of children with autism but do not always fulfill usability criteria.
7. ABCD SW includes recording all child interaction, allowing accurate data collection that can be analyzed through an embedded learning analytics tool.
8. Safety. The child UI of ABCD SW is a native desktop interface in full screen version without any navigation element, preventing the child from closing the application, changing the URL and moving into the web unsupervised.

To the best of our knowledge, only a few software programs satisfy all these requirements (i.e. AB Pathfinder, http://www.abpathfinder.com/) and are quite expensive, while our application is completely free.

3 ABCD Software

Parental surveys reveal that the Internet is the best friend of families with children with autism [22]. Free software is a great economic relief for families of people with autism who require costly assistive technology. Moreover, ubiquitous technology-enhanced and self-rehabilitation tools might help transfer skills from caregivers to the person with autism [20]. ABA discriminative programs are conducted by tutors in a simple environment that offers no distractions for the child. A session usually takes place on an empty table using cards, photos or real objects. An ABA analyst evaluates the child and assigns a set of programs, suitable for her/his abilities and needs. The tutor selects one of the assigned programs, sets up a trial using DTT, and asks her/him to execute a task (i.e. match/give me, etc.), providing a prompt, if necessary. The trial set-up occurs very quickly in order to keep the child's attention, avoiding inactive periods that could trigger non-collaborative behavior or self-stimulation in the child. The trial set-up requires time, as does preparing/buying all the objects beforehand. ABCD SW is a freely available, dynamic, rich Internet application. It is based on a distributed Web architecture offering two fully separate interaction environments for the child and tutors/caregivers that implements the one-to-one ABA intervention; using a laptop, the tutor defines the exercises dynamically activated on the child's touchscreen tablet. Synchronization between the two devices occurs via an Internet connection, obtaining and inserting data through a database. A real-time summary of the actions performed by the child is available on the tutor's laptop, simplifying decisions about the intervention. No physical connection between the devices is required, making interaction more natural and suitable for children with autism, eliminating the possibility that they may be attracted to plug in/out cables (Fig. 1). We aimed to creating the most comfortable work environment where tutor and child could jointly perform an ABA session simultaneously. In order to verify the best kind of touchscreen devices to use with ABCD SW, we tested two different large touchscreen monitors and five types of touchscreen tablets, actively involving the children in the testing phase. The use of big touchscreen monitors was quickly discarded because they are not very sensitive, so do not provide ready feedback on the child's actions. Along with frustration, the lack of immediate feedback could cause serious difficulties and delays in the child's learning. In addition, the use of large monitors required USB cables, and children with autism could be distracted by their presence. Conversely, a touchscreen tablet has a very sensitive touchscreen, does not require cables and guarantees the system's portability, allowing an ABA session to be carried out anywhere and anytime. We selected the iPad tablet since it was more responsive than Android and Windows tablets in both touch and drag user actions, offering a more effective and pleasant interaction. The children participating in the pilot test showed a high level of collaboration and an interest in the novelty introduced by the iPad, which has proved to be a work environment and a reinforcement at the same time [15,38,59].

Fig. 1 ABCD SW environment: tutor and child's devices

Fig. 2 ABCD SW: Tutor User Interface

3.1 ABCD SW main user interfaces

To access the software, the tutor performs a login phase (with user/password) and selects one of his/her children. Then the Tutor User Interface (Fig. 2) appears where it is possible to select the category/program to work on. ABCD SW includes 17 categories (Fig. 3) and about 350 articles, so it currently implements 17 x 7 = 112 ABA programs (i.e. matching image/image colors, matching image/image shapes, etc).

The main goals of ABCD SW are to facilitate and speed up the three main phases of the ABA intervention while actively engaging the child via appealing and clear graphic items: i) guidance in the correct workflow of the ABA educational programs, helping caregivers to easily provide ABA sessions even by themselves (Fig. 2); ii) faster trial set-up of the exercises on the child's tablet (Fig. 4) iii) easy recording and analysis of the child's performance data (Fig. 5). The Tutor Interface proposes in every program/category to continue from

Fig. 3 ABCD SW categories

the last DTT level performed by the child (the concept of session is persistent between different tutors/devices since it is synchronized by the server). There is no ambiguity since in every ABA program it is possible to work only on one article until it is mastered. This automation facilitates the task of the tutor, who in the traditional approach has to read the report written by previous tutors working with the child in order to know how (s)he is progressing in programs and to continue accordingly. Also, in the case of problems with an article the tutor points it out in the same book, while the ABCD SW allows the tutor to mark this element as temporary, suspended or excluded. In this way the software excludes the element until a tutor decides to put it back in the articles Not Mastered.

On the top left side of the tutor interface, programs are sequenzialized as required by ABA, i.e., when selecting a category for the first time, the "matching image/image" program is proposed. Then the tutor selects one item clicking twice on it, or drags it into the On Acquisition box and the DTT flow starts. The DTT levels (left bottom of Fig. 2) include: 1. Mass Trial (MT) that assures child success (i.e. matching two equal articles) 2. MT with one neutral (i.e. different in shape, color, and category) distracter 3. MT with two neutral distracters, 4. MT with one distracter, 5. MT with two distracters, 6. Extended Trials (the item in acquisition with mastered elements, randomly rotated). To maximize the session pace, a random function is utilized by ABCD SW for selecting both distractors and mastered articles. As previously mentioned, the tutor can press the key 'R' to reset the trial, if not suitable for the child. The center of the Tutor Interface is organized into three areas. At the top, the category and the article on which the child is working (animals/butterfly) are displayed; in the middle, there are the mastered items (goose and ladybird), and at the bottom, there are all remaining items to work on. When 80% of items (articles) of this category have been mastered by executing all DTT levels, the child can move to the next program, i.e., "matching word/word animals", and analogously when completed this program can move on to the next: "matching word/image animals", then "matching image/word animals". When the matching programs are ended, the child can move to "Receptive Image animals" and then "Receptive Word animals" and finally move to the "Expressive animals" program. Mastering all programs in this category would allow the child to discriminate between animals and to recognize images and

Fig. 4 ABCD SW Child Interface: non-receptive subject (the instruction is shown on top)

words associated to them. To consolidate mastered skills, the "random rotations" between all mastered articles are executed over time (button ROT in the right side). The child works on more than one program at the same time. Usually intervention starts from simple categories of shapes, colors, and animals to progress toward more complex ones (numbers, body parts, etc.).

The Child Interface is very simple and shows the trial activated by the tutor. Fig. 4 shows an example of the Child Interface for working in the "matching image/image animals" program, on the article "butterfly". It shows an "extended trial (ET)" for a non-receptive child in the "image-image matching animals" program. Personalization adapts the discriminative stimuli as a string (PUT TOGETHER) shown on the UI. The child has to drag the butterfly at the bottom of the interface onto the one at the top. The Child Interface is controlled by the tutor who selects the proposed trial. To enforce the collection of learning data (crucial for evaluating the efficacy of the ABA intervention), the next trial only starts when the previous one is evaluated by the tutor (pressing one key from 1 to 5). Learning and communication development often rely on the visual channel, usually the most effective in children with autism [25,44]. For this reason, graphic images were carefully designed to be clear and easily recognizable, using pictures or photos without background. The interface is organized to make the task clear to the child, avoiding confusion. All items are presented in the user interface (UI) inscribed in rectangles, like two-dimensional cards, that recall the traditional ABA sessions. The software adapts the visual prompt to the child's abilities, i.e., "not receptive" or "not verbal", using labels in addition to images. The element positions try to simplify the interaction. For example, in matching programs the target element is placed at the bottom, closer to the child, and it is the only element of the UI that can be moved.

Different programs require different types of interactions, e.g., "point and touch" in expressive and receptive programs, and drag and drop in matching programs. These interactions simulate the actions the child performs in traditional ABA sessions. For example, in matching programs the child has to match a cardboard picture the tutor gives him/her with the same target image, with a movement that brings the first one onto the second. The use of ABCD SW is also a way to generalize tasks familiar to the child, if (s)he had previously carried out a traditional ABA program (at the table). When the tutor presses the DTT level and the trial starts on the child interface,

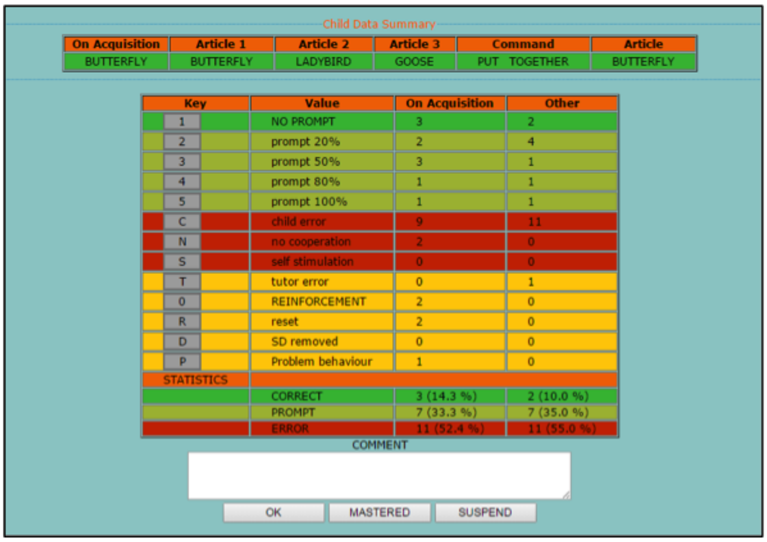

Fig. 5 ABCD SW: the Tutor control panel

a new tutor interface overwrites the previous one, showing a control panel (Fig. 5). The panel gives real-time statistics on the trial and shows the key for specifying the prompt provided (1: ”no prompt”, 2: ”20%”, 3: ”50%”, 4: ”80%”, 5: ”full prompt”), or recording behavior (n ”no cooperation”, or s ”self-stimulation”). The bottom of the panel shows statistics on the trials of the current program: the percentage of correct answers, prompted trials as well as potential errors (that have been impeded by the software). This facilitates tutor decisions, such as whether the article can be mastered, or has to be suspended in the event of a high percentage of errors. An ABA computer-assisted session can last up to three hours, depending on the child’s interest, but should have one or more pauses to allow the child’s eyes to rest. ABCD SW has been designed to guarantee the coherence, completeness and efficiency of ABA intervention. The guidance to the correct workflow of the ABA educational programs helps not-trained caregivers to easily provide ABA sessions even by themselves. However, to assure flexibility and avoid rigidity, the tutor can change the proposed trial sequence in order to proceed in a different way.

3.2 Personal content

A simple user interface enables ABA professionals and caregivers to create new elements for the Places and Relatives categories, which need to be personalized with element familiar to each child, such as the house, the school, the park, etc. and Mum, Dad, sister, etc. that he/she knows and can recognize. The interface requires inserting a little information describing the new element and uploading an image of the element. The software automatically adds the

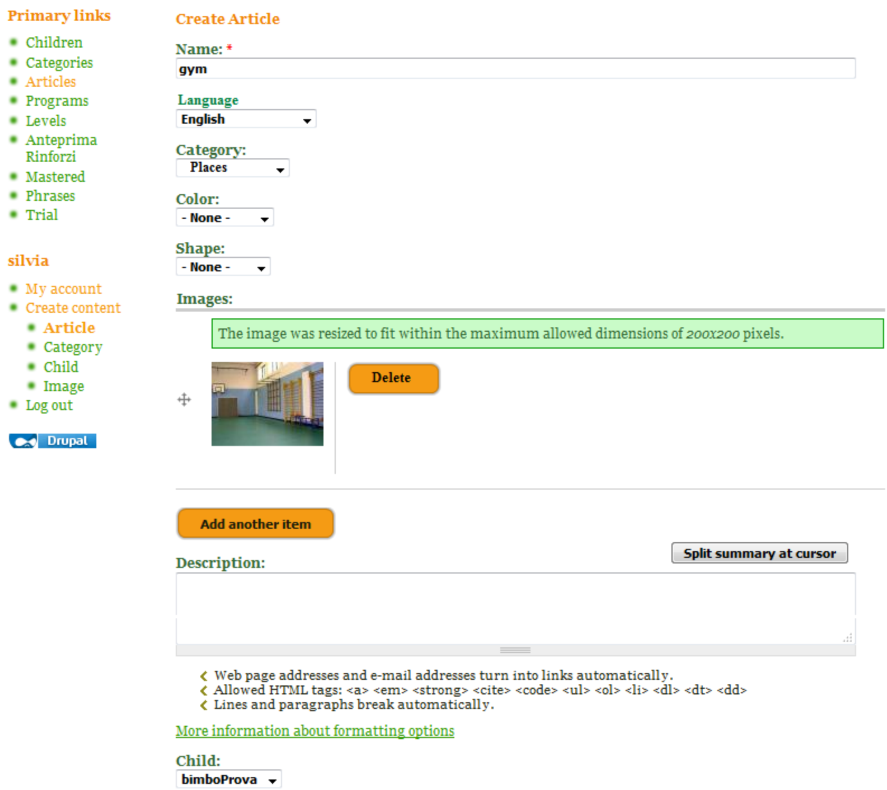

Fig. 6 ABCD SW: Personalized content UI

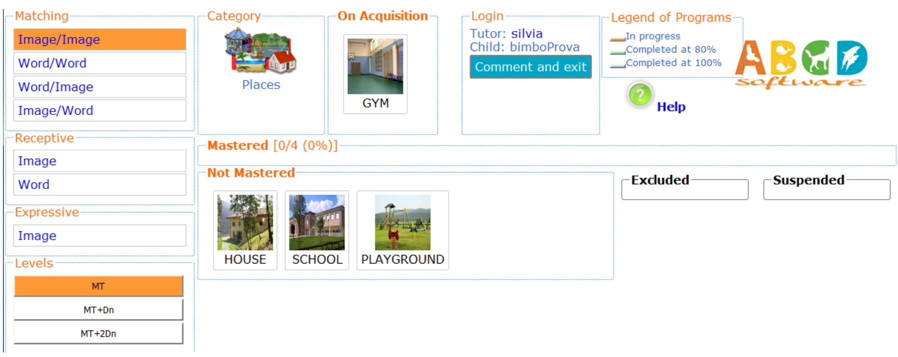

Fig. 7 ABCD SW: Personalized content usage - Places category

new element to the database and uses it when it shows the category's elements. In the following an example is shown of personalized content as it appears in ABCD SW.

Summarizing several ABA principles implemented in ABCD SW:

Errorless: The software prevents a child from making an error by having a zone of attraction or repulsion around each target. A correct target has a zone of attraction. An incorrect target has a zone of repulsion. If the child is making a correct match, the element is attracted to the target. If the child is making an incorrect match, the element is pushed back to the initial position. All actions (dragging, touching, errors) performed by the child are recorded in the database in real-time and instantly available on the tutor's panel. In this way, the errorless principle is implemented but the error attempts are recorded.

Learning by increasing levels of difficulty according to DTT.

Flexibility, adapting the presentation of the proposed trials to the child's needs. For instance, a label supporting the tutor's vocal request to the child, such as "put together", "touch", etc., is activated to facilitate learning for a non receptive child who needs major visual support.

Comprehensibility: the UIs of the software are minimal in order to be very clear. Furthermore, ABCD SW uses AAC (images, labels, animations) to aid those with impaired production or comprehension of spoken or written language.

Monitoring the child's progress: for each trial, ABCD SW stores performance and evaluation data, allowing the intervention to be measurable, thus favoring the tuning/set-up of the teaching strategy according to a personal learning path.

3.3 The ABCD SW architecture

ABCD SW is a PHP, AJAX, and HTML5 Web application that relies on the Drupal Content Management System (CMS) and the mySQL database. Use of the Content Management System enhances data management, offering native scalability and support for internationalization (multi-language application). Most of all, ABCD SW enables managing of application content independently from the code: tutors can add/remove content in a user-friendly way. Objects are drawn in the Web browser with the JavaScript Library Raphael, which uses SVG (Scalable Vector Graphics). Technical members of the software design team observed ABA sessions to better understand the natural environment where the application had to run. The involvement of the ABA team in the design phase helped us build a more usable software that is fully ABA compliant, enhancing efficacy, efficiency, and user satisfaction [3]. The ABA team and parents expressed positive evaluations concerning the usability of the ABCD SW through an online questionnaire, as described in the following. Concerning maintenance and system scalability, the software provides user-friendly interfaces (facilitated by the CMS) to add new items or categories, sharable with the community. Furthermore, the CMS favors personalization, crucial for people with autism, allowing tutors and parents to insert photos of articles familiar to the child, such as relatives or places. In this way, the personalized articles are used as target items for the child trials.

4 Materials and Methods

4.1 Participants

Seven children with autism were enrolled during the school year in an intensive ABA intervention at school and home ranging from 25 to 29 h/week. Children were recruited by LASA (Lucca Associazione Sindromi Autistiche), a no-profit association promoting ABA for the care of children with autism, which contacted and set up specific agreements with the children's families, also including privacy and ethical aspects. Children's inclusion criteria were:

1. Age between 30 months and 72 months, with the exception of one low-functioning child 10 years old with cognitive estimated age in that range. We decided to accept one child out of the age range in the sample in order to gather observations about the possible engagement of older subjects with the SW.
2. Diagnosis of autistic disorder or pervasive developmental disorder not otherwise specified according to the Diagnostic and Statistical Manual of Mental Disorders criteria [5].
3. Autism classification confirmed by the ADOS-G (administered by clinicians). The mean age was 50 months (standard deviation, $\pm$ 8.82 months; age range, 25-36 months).

An evaluation based on standard Vineland Adaptive Behavior Scales (VABS) was administered by a psychologist to the children before and after the intervention, in order to compare their development and assess any progress in the user test period [54]. The VABS measures the personal and social skills of individuals from birth through adulthood. In order to determine the level of an individual's adaptive behavior, someone who is familiar with that individual, such as a parent or caregiver, is asked to describe his activities. Those activities are then compared to those of other people the same age to determine which areas are average, above average, or in need of special help. Learning about an individual's adaptive behavior helps provide a total picture of that individual. When adaptive behavior information is combined with information about an individual's intelligence, school achievement, and physical health, plans can be made to address any special needs that person may have at home or in school. The VABS assesses adaptive behavior in four domains: Communication, Daily Living Skills, Socialization, and Motor Skills. It also provides a composite score that summarizes the individual's performance across all four domains.

4.2 Methods

An intensive ABA intervention was delivered to the participants by an ABA team performing 15 h at home in the afternoon and from 10-14 h at school in the morning each week, assuring at least 25 h per week (25-29 h/w). The user test was carried out for 9 months during the school year. ABA intervention

Table 1 Child profiles, before starting the pilot test

Child	ABA intervention	Receptive	Verbal	Severity (Legend: Y=Yes; N=No; H=High; M=Medium; L=Low)
E.	5 years	N	N	H
Em.	More than 2 years	Y	Y	L
G.	Less than 1 year	N	N	H
M.	Less than 1 year	N	Y	M
S.	No	Y	Y	M
Si.	No	N	N	H
T.	More than 1 year	Y	Y	M

requires a high level of attention from the children, so the first few months were spent bringing all children to a homogeneous level, since only three of the seven enrolled children had already received an intensive ABA intervention (more than 2 years) as shown in Table 1. The severity of the syndrome varied between low (L, 1 subject) to medium (M, 3 subjects) and high (H, three subjects who are non-receptive and non-verbal).

The intervention delivered two 3-h sessions a day: one in the morning at kindergarten and one at home in the afternoon. The younger participants received the two sessions at home. Each session had one or two short pauses according to children's age and their ability to maintain their attention. Each child was assigned more than 10 programs involving skills, language, motricity (arts&crafts, gym), autonomy, etc. The user test included two intervals of 4.5 months: in the first one, each child performed intensive traditional ABA sessions while in the second one each child was enrolled in a mixed educational intervention including both approaches (traditional and technology-enhanced ABA sessions). We observed the seven children involved in the test, collecting the ABA team observations and requests in order to refine the SW and better adapt it to their (and the children's) needs. The older child, E., had been receiving traditional ABA intervention starting from age 5. Since both age and ABA program experience were not homogeneous with other participants, his collected data was not included in the data analysis but the observations and results of his involvement will be presented in the Results Section.

Calling X our independent variable (composed of X1= traditional stimulus and X2= technology-enhanced stimulus) and Y the dependent variable (represented by the resulting behavior), in our study it was not possible to discriminate with certainty the effect on Y due to the action of the individual components of X because they cannot act as a single variable at any time. An ABA requirement is the intensive intervention implying that children had to be exposed to the training for several hours per day but, as safety guidelines suggest, computer-assisted therapy should be limited to 2 (maximum 3) h per day (to prevent problems with eyestrain and socialization of the child, also depending on age). Therefore, the use of the tablet was alternated with the traditional ABA intervention. Moreover, the main aim of the pilot test was to refine the ABCD SW, enhance its functions, improve the user interfaces and investigate the effect of the technology-enhanced approach in behavioral intervention as a generalization of the traditional ABA intervention.

This pilot study observes the effect of introducing ICT technology in the ABA intervention. By offering to a target group an educational intervention including both traditional and technology-enhanced ABA sessions, it is possible to collect the children's responses and evaluate the impact of changes in the ABA routine process. Medicine often distinguishes between effectiveness and efficacy. The first relates to how well a treatment works in practice, the second measures how well it works under ideal circumstances in clinical trials. As a consequence, the effectiveness of an intervention is the degree of beneficial effect under "real world" clinical settings and it could be measured through hypotheses and study designs formulated according to conditions of routine clinical practice and outcomes essential for clinical decisions [54]. Not being an experimental method, our pilot test did not need a control group, and we can proceed to estimate the correlation of our variables using methods of non-experimental research, as illustrated below.

4.3 Survey

An online post-test web survey was created using Google Drive. The questionnaire's URL was sent via email to parents and the ABA team of the participants. The questionnaire, comprising two parts evaluating both the traditional ABA intervention and the one supported by ABCD SW, was designed according to a Liker-type scale, and for each question it offered an optional free text comment. The evaluation of the overall behavioral intervention investigated qualitative data concerning skills and progress achieved by the child, and the degree of satisfaction of participants, therapists, teachers and parents involved in the training. The results showed as frequency distributions are described in Section 5.

4.4 Qualitative assessment: paper and ABCD collected data

A qualitative assessment of participants was carried out using both data gathered with ABCD SW, and those manually recorded on paper forms in the traditional sessions. The traditional ABA learning analytics model consists of (1) paper forms for recording trial data in daily sessions and (2) a notebook to record progress of ABA programs, periodically updated according to the children's progress. For each trial the daily form records program, category, article, discriminative stimulus, DTT level and prompt, date and tutor name. The notebook contains the programming designed specifically for the child: the list of programs and articles assigned, with dates of the introduction and the mastery of each article. These data are periodically copied from the notebook to an electronic spreadsheet for creating learning graphs, but this process is time-consuming and error-prone. ABCD software totally retains information expected on the paper forms such as category, program, article, number and percentage of the prompts, correct trials, errors and occurrence of inappropriate behaviors (self stimulation or problem behavior). Moreover, it may include additional information such as the time needed to carry out a trial and potential child errors (avoided by the software to maintain the errorless ABA principle).

4.5 Vineland Scales

As mentioned before, another source of data comes from a multi-informant perspective through professional interviews using the Vineland Adaptive Behavior Scales (VABS), second edition. The VABS were administered as parent interviews to assess the children's ability to perform the daily activities required for personal and social self-sufficiency. The VABS uses four specific domains (Communication, Daily Living Skills, Socialization, and Motor Skills) and the subscale scores are added up to yield an adaptive behavior composite score [19, 53]. A pre/post study was performed on the participating children. Two evaluations were performed before (Time 1) and at the end (Time 2) of the intervention. The study was approved by the Local Ethics Committee, and at least one parent of each child provided written consent. Mean scores at intake and after 9 months of ABA were computed for the outcome measures (VABS). Two-tailed parametric and non-parametric statistics (t-test and Wilcoxon) were performed to determine whether treatment led to a better outcome scoring in the four domains scales and for each related subscale. Statistical analyses were performed using SPSS software version 20.0. An alpha level of 0.05 was used for all statistical analyses. Results are presented in Section 5.

5 Results

We collected 47 questionnaires; of these, 70% were from trained ABA professionals (tutors, senior tutors and consultants), 6% from teachers and the others from parents. All questions were assessed with a 5 Likert scale (I do not agree at all .. I fully agree). Not everyone answered all the questions, i.e. problem behavior was not present in one child, so their caregivers could not answer. The first part of the questionnaire investigates the usability of the ABCD SW showing a high evaluation by participants on its efficiency, efficacy and user satisfaction, as described in [4]. Here we focus on evaluating children's performance and behaviours, as shown in Table 2.

Table 2. Survey proposed to the ABA teams of children involved in the pilot test

Nearly the entire sample of users (91%) was satisfied with being part of the ABCD SW project (s15); three participants (6.3%) expressed partial satisfaction preferring other approaches, such as video modeling, respect to ABA

Table 2 Survey proposed to the ABA teams of children involved in the pilot test: statements s1-s15

Statement
s1. The child progresses from the beginning of the intensive ABA intervention
s2. The child has increased frequency of correct behavior, appropriate to the context
s3. The child was more collaborative (during the intervention) than before
s4. The child has increased the number of communicative intents
s5. The frequency of problem behaviors have decreased during the intensive intervention
s6. The child was more sociable at end than at the beginning of the intervention
s7. The frequency of self-stimulation behavior has decreased during the intensive intervention
s8. The child appreciated the ABA intervention during the school year
s9. I find ABCD SW useful
s10. I find ABCD SW easy to use
s11. ABCD SW is an effective tool for delivering the ABA intervention
s12. ABCD SW improves intervention efficiency (greater speed/time saving) vs traditional ABA intervention
s13. I find it useful for my child to repeat this experience in the future
s14. My child likes using ABCD SW with a touchscreen (iPad) tablet
s15. I'm satisfied my child participated in the ABCD SW project

considered too 'rigid'. Regarding children's progress during the intensive ABA intervention (s1), 98% of the participants declared that their child showed progress in different abilities (72% significant improvement and 26% some improvement). More than half of the participants observed positive changes in the child and great pleasure in executing assigned tasks (s3), in general with a good degree of collaboration from all the children (97% of the sample: 57% = absolutely yes, 40% = yes). Significant improvements in the child's communication (s4) were observed by 98% of participants (60% strongly agree, 38 agree). The use of AAC and PECS favors communication (visual, gestural, spoken) [24, 27]. Overall, 98% of the sample declared that children increased the number of communication intents. The primary goal of any behavioral intervention is to modify a child's responses to environmental stimuli, encouraging a greater occurrence of correct behavior, appropriate to the context. Of the sample, 98% observed for their child an increased frequency of adequate-to-the-context behaviors (s2).

At the beginning of the intervention only six (out of seven) children manifested problem behaviors. Participants agreed that the frequency of their children's problem behavior decreased: 23% greatly reduced and 58% reduced (s5). We also investigated the perception of participants regarding frequency of stereotypies and self-stimulation in their children; 66% of users observed that children showed reduced self-stimulation during the intensive ABA intervention (s7). The increased frequency of correct behavior observed by participants might be due to a greater communication and comprehension, which could favor child cooperativeness. A total of 91% of the subjects thought that their child was more collaborative during intervention than at the beginning of school (absolutely agree = 38%, agree = 53%). Moreover, ABA intervention also seemed to improve the subject's social attitude, according to previous results [14, 29, 58]. A great percentage of users (absolutely agree = 57%, agree =

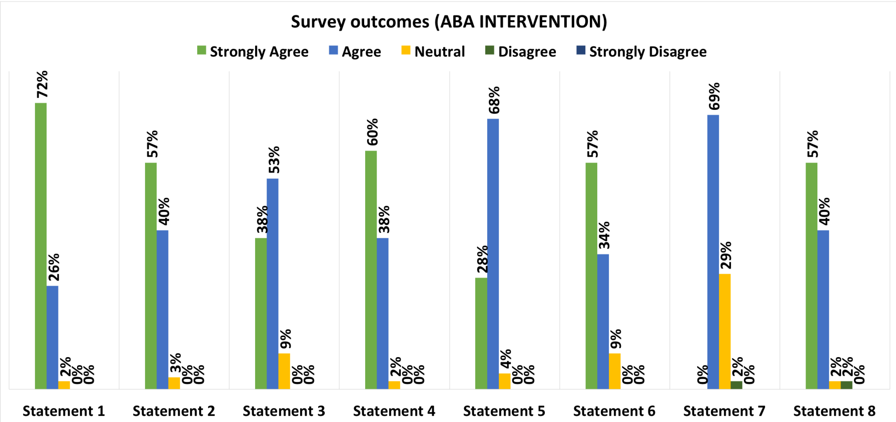

Fig. 8 Survey results, statements from 1 to 8

34%) thought that their child expressed more sociability during intervention than in the previous period (s6). The second part of the questionnaire focused on ABCD SW; we collected fewer questionnaires (33 users instead of 48) since mainly ABA tutors utilized the software while parents and consultants might not have worked with it. Indeed, each tutor took away own touchscreen tablet after the intervention, using it with all the children involved in the pilot test. In this way, we intended to use the tablet as a learning tool and a motivator, so the child would not use the tablet inappropriately, compulsively or as a self-stimulatory tool. Children greatly appreciated using the tablet as shown: more than 50% appreciated it very much (s8). One child who was unable to focus attention on using a computer or watching TV showed great interest in and increased attention to using the tablet as a personal learning environment. The reasons could be several: the natural interaction of the touch, the clear and attractive images, and full control of the small-size device, more suitable for little hands. Overall, concerning their participation in the project users acknowledged great satisfaction (55% fully agree, 36% agree) and would repeat this valuable experience in the future (55% fully agree, 36% agree (s14).

5.1 Data Collected via ABCD SW vs paper-based model

ABCD SW ensures data accuracy and immediate availability. In traditional ABA sessions data are recorded on paper. This process requires time and organization: since recording depends on the child's behavior, data is not always complete and accurate. In the pilot test we observed some gaps in the traditional ABA: not all trials were recorded. This impedes a fair comparison between the timing of the articles mastered in the traditional vs technology-enhanced sessions. Table 3 shows some of the information collected by ABCD SW, which enables accurate tracking and monitoring of the child's learning path.

Table 3 Medium value of learning path indicators in Matching I-I and Receptive I programs for the entire group

Program	Matching Image Image Average	SD	Receptive Image Average	SD
Sessions	97	60.43	7	3.1
Introduced articles	316	82.6	43	14
Mastered articles	133	89.7	8	2
Introduced categories	13	0.9	2	0.5

Since programs evolve hierarchically, only the matching Image/Image and the receptive programs gathered a number of significant data by all the children of the sample during the pilot test. All children worked differently according to his/her own learning needs and paths, leading to a non-homogeneous number of observations. All children completed the above-mentioned programs at 80% but only started or did not explore at all the more advanced programs. The matching Image/Image is the simplest program introduced at the beginning of the intervention. If the child is unable to work with written words (due to age or ability), all matching programs involving text are bypassed and the student moves on to the Receptive program based on images. This explains why these two programs were the most frequently used. Several articles had already been mastered in traditional ABA sessions, so the work was carried out to generalize the learning. Tutors started the training with the mass trial with one non-neutral distracter, shortening the full DTT workflow. In about 5 months, each child performed an average of 97 sessions. The high SD (Standard Deviation) indicates that children did not work uniformly, reflecting their personalized learning paths.

To be meaningful the number of sessions has to be connected with the results in terms of articles introduced and mastered. Each child had 316 items introduced, about 3 items per session, considering that the child works with one article at a time and moves to the next one only if (s)he completes the DTT levels with at least two different tutors. About one-third of the introduced articles were mastered. Both the SD values of the introduced and mastered articles are high since children worked in different ways (number of articles introduced) producing non-homogeneous results (number of articles mastered) due to their different personalized learning paths. The average number of categories introduced (13 for matching image/image and 2 for receptive image with SD of 0.9 and 0.5 respectively) is homogeneous among the children. Comparing data sessions and articles introduced, more performing subjects worked more (greater number of sessions and articles introduced) within the same larger category (such as animals and labels). Matching programs involving words were carried out by only two children, also due to young age of participants.

We compared the children's learning times by analyzing data of the two models (traditional and technology-enhanced). In traditional ABA, the average time for mastering an article is 2-3 days (from 2 to 6 sessions). Since each child has a personal learning pace, the time needed to master an article in the

Table 4 Child mastered articles with ABCD SW

Program SD	Matching Image Image Average	Receptive Image SD	Average
E	1-3 days	75%	2.3
Em.	1-2 days	80%	4.2
G.	1-3 days	40%	2.5
M.	1-3 days	42%	3
S.	2-3 days	21%	1.7
Si.	2-4 days	10%	2
T.	1-2 days	73%	2.1

Pre- Post-intervention Vineland Adaptive Behaviour Scale/Subscale Scores

	Time 1		*Time 2*			
	Mean	*SD*	*Mean*	*SD*	*p-value t-test*	*p-value Wilcoxon-test*
Communication	101,0	50,4	118,5	55,6	< 0,05	< 0,05
Receptive	30,7	6,4	32,7	3,7	ns	ns
Expressive	57,7	33,6	69,3	37,7	<0,05	<0,05
Written	12,83	15,39	16,50	17,4	ns	ns
Daily Living Skills	129,7	56,4	136,2	45,7	ns	ns
Personal	99,8	28,2	104,0	18,7	ns	ns
Domestic	15,7	15,7	16,7	12,7	ns	ns
Community	14,17	15,98	15,50	16,7	ns	ns
Socialization	93,5	41,7	99,7	47,5	ns	ns
Interpersonal Relationships	37,7	20,0	37,8	20,2	ns	ns
Play & Leisure Time	37,3	16,4	39,7	18,0	ns	ns
Coping Skills	18,5	9,5	22,2	14,3	ns	ns
Motor Skills	116,3	26,2	123,5	14,3	ns	ns
Fine	41,8	18,5	48,0	10,1	ns	ns
Gross	74,3	9,4	72,2	8,4	ns	ns

Fig. 9 Pre-Post intervention Vineland Adaptive Behavior Scale/Subscale mean scores

same or comparable programs can vary from child to child. ABCD SW seems to empower participants, since on average it took from 2 to 4 sessions for one article to be mastered in a specific program via ABCD SW compared to the traditional intervention requiring from 3 to 6 sessions. Table 4 shows the ratio articles/sessions for each child. It is remarkable that two children starting ABA with the project, S. (the younger participant, medium severity) and Si. (high severity), who mastered only a few articles in the X1 period, had the ratio articles/sessions 1.7 and 2.0 respectively. These values are not far from E. (high severity) and T. (medium severity) ratio articles/sessions 2.3 and 2.1 respectively of children who have received more years of ABA intervention, and used the software mainly for generalization of previously mastered articles. It is presumable that the technology-enhanced process is faster since the DTT path is usually shortened by the tutor (as discussed before). More details are available in [4].

The older child, E., had received traditional ABA intervention starting from age 5. Since both age and ABA program experience were not homogeneous with other participants, we have excluded his collected data from the data analysis. Nevertheless, during the pilot test this child was participative and motivated to work with ABCD SW since he was very attracted by the technology. He interacted easily with ABCD SW performing all the tasks without difficulties. He easily performed most of the discriminative programs in the common categories (shapes, colors, animals, numbers, vehicles, etc.). He appreciated the reinforcement provided by the software as rewards for the work done. He seemed to be more involved in the ABA training and he often requested to work at home with his parents using verbal attempts that previously were unusual for him before the pilot study. He appreciated the reinforcement provided by the SW as rewards for the work done. He seemed to be more involved in the ABA training and he often requested to work at home with his parents, using verbal attempts that previously were unusual for him before the pilot study.

6 Discussion

In the following, we analyze the answers to our main hypotheses, provided by results of the small pilot study.

H1: The use of ABCD SW during ABA therapy sessions helps make the intervention more rapid. We refer to the increased rapidity observed for: A) materials preparation, B) trial setup, and C) data collection. A) Basic materials are automatically provided by the system and can be used for all the children. Furthermore, as previously described, personalized content may be easily added to ABCD SW. B) Objects are automatically arranged, saving time. Shortening the trial set-up (and evaluation) time allows increasing the number of trials/exercises performed in the same time slot compared to a traditional intervention, as confirmed by the collected data analysis, which showed that for each child, mastery time was shorter using ABCD SW than the traditional ABA sessions. Furthermore, the software automatically implements errorless teaching (avoiding child errors), reducing the tutor/caregiver's time spent in preventing errors. C) Data collection is one of the main features of the ABA intervention. Automatic real-time data collection offered by ABCD SW allows a tutor to gather rigorous complete data on the learning trends, while paper-based data collection could miss information since tutors might have no time for the sustained pace of the training delivered or might forget to insert data. Furthermore, data analysis of paper-based data is complex, time-consuming and error prone, while ABCD SW data are immediately available.

H2: The use of ABCD SW during ABA therapy sessions helps make the children's intervention more pleasant. The child's enjoyment when performing ABCD SW is important because it increases the child's motivation. In the previous sections we had already presented results recording this hypothesis, e.g.:children greatly appreciated using the tablet, they increased time spent in ABA sessions using ABCD SW, they increased requests for ABA sessions through ABCD SW, etc. Especially, the use of the tablet motivated the children to work, acting as an intrinsic reinforcement. The tablets used in the project were equipped with special shock-resistant shells, but unexpectedly the children involved took good care of their mobile devices. This attraction to technological devices experienced by children with autism has already been reported by several studies [28,38,60]. Williams [60] for instance showed that children with autism spent more time on reading material when they accessed it through a computer and were less resistant to its use. Among technological devices, the tablet has enhanced attractiveness since it is portable, responsive and usable (offers a very intuitive interaction).

H3: The use of ABCD SW during ABA therapy sessions helps make the intervention easier for caregivers. By default, ABCD SW progresses level by level, increasing the difficulty according to Discrete Trial Training, and thus helping tutors perform ABA sessions correctly. In this way, ABCD SW increases the ABA sessions' usability not only for therapists but for caregivers in general: parents and unskilled caregivers can perform ABA sessions with their children under the ABCD SW guidance, permitting a more intensive intervention, anyplace, anytime.

H4: ABCD SW allows much easier personalization than do traditional ABA sessions. The system adapts to the user's needs, e.g., visual prompts such as labels and images are provided in the user interface if the child is not receptive or non-verbal. Furthermore, simple interfaces allow caregivers and parents to quickly insert personal content, achieving personalization more easily than by using handwritten, professionally prepared training regimens.

H5: ABCD SW can help reduce the cost of ABA interventions. The software is free, available at no cost. It helps caregivers to easily provide ABA sessions even by themselves, reducing the cost needed for professional ABA personnel.

Summarizing, ABCD SW helps make the ABA intervention more rapid, so increasing its efficiency, and more pleasant for the children. Furthermore, ABCD SW enables caregivers to easily conduct and personalize the intervention, reducing its cost, and easily monitoring child's progress. Concerning statistical indexes, our study highlights that participants showed improved communication skills in general. The two children who reached the expressive program during the test period specifically improved expressive communication. This is in line with previous findings. A meta-analysis of scientific literature conducted by Ospina et al. [41] provides some evidence of improvement regarding special education on adaptive behavior, communication, interaction, comprehensive language, daily living skills, expressive language, overall intellectual functioning and socialization, when delivering behavioral treatment. This benefit increases by increasing the intensity of the intervention [45].

6.1 Lessons Learned and Study Limitations

We addressed many challenges during the entire project. The most demanding in terms of economic effort and time was to coordinate and deliver the intensive home-school intervention that required setting up agreements with the children's schools and training the teachers and parents regarding ABA and ABCD SW. In countries such as Italy where the state education program does not support this kind of intervention, it is recommended to set up these agreements as early as possible. A crucial factor for the most successful behavioral intervention is the close collaboration of parents. In our test period, their involvement was not completely sufficient for the protocol's needs. For future work, we suggest previously providing specific parent training. Each child with autism is unique in the sense that improvements in abilities are very subjective, especially in low-functioning subjects. The amount of data collected is so vast that new indicators could be defined to verify any other statistical significance of collected data. On the other hand, additional data could be recorded to enable correlation analysis between apparently different parameters. Regarding problem behavior, it could also be useful to record its duration and not only its occurrence. In that way, we could observe whether increases or decreases in frequency and duration could be correlated with delays in the learning process.

This study presents some limitations. First, the small size and the non-homogeneity of the sample; this is due to the difficulty of enrolling low-functioning children sharing similar functional and behavioral profiles. As with any research based on informed consent and voluntary participation, a degree of sample bias cannot be excluded. A parents' association carried out the enrolment of the study population and tutors, leading to an informal selection. A rigorous enrolment of participants by medical staff according to inclusion/exclusion criteria, a control group, the definition of metrics and indicators, and a follow-up study would scientifically assess the impact of the technology-enhanced ABA intervention vs the traditional one, shedding light on its effectiveness.

Since each individual with autism is singular and has specific abilities, progress and learning trends are very subjective and could depend upon external factors such as family, health conditions, environment, etc. Being narrow, our findings are not representative of the population with autistic syndrome at preschool age. Certain types of behavior may have been overexpressed or otherwise not expressed in our sample. This makes it impossible to generalize these results. In addition, some measurement bias could have been introduced. It would be important to take into account what kind of treatment, if any, the child and/or family are undergoing in a public or private health structure. In our sample the only intervention was performed in the pilot test. We also need to consider that training with software was conducted by ABA tutors who were part of the project and expert in the correct use of the software. The flexibility of the ABCD SW carries the risk of sessions being improperly conducted, for example changing level or program at the wrong time, with respect to the needs of the child; thus the present pilot study did not report on treatment fidelity. However, it is important to evaluate progress child by child since this can provide indications for future research. In our test, all children progressed steadily during the school year, while a decrease in their performance was suddenly noticed after school ended and the intensive intervention was over. The effectiveness of ABA intervention documented by literature has shown some limitations on maintenance and generalization. Recent research then focuses on a systematic integration of social interventions within a comprehensive and long-term context of high-quality ABA intervention for all developmental needs [16]. Rigorous long-term studies in this field would introduce models for effective education for pre-schoolers with ASD.

7 Conclusion

This study investigates whether ICT technology can enhance applied behaviour analysis rehabilitation therapy for children with autism. More specifically, we designed with ABA experts and parents and then developed an open source customizable software program for teaching low-functioning children with autism: ABCD SW. Accessibility guided the design of the software: it uses Augmentative and Alternative Communication and the learning programs follow Discrete Trial Teaching; images and user interfaces were carefully designed to avoid distracting elements; it minimizes possible errors by automatically discarding trials where the shape and color of the articles are too similar; it supports the comprehension and feasibility of the task by adding labels for non-receptive children or providing visual elements to help non-expressive children; it implements the errorless principle in order to avoid children's errors, since they are very difficult to correct. The careful design and implementation of ABCD SW maximizes the tool's accessibility, making it usable by autistic children. Lastly, personalization (crucial for people with autism) is easily implemented by adding items via a web user interface. The personalization helps children to familiarize themselves with places, persons and processes in a technology-mediated way, electronically introducing change of contexts. Adapting the child's environment to his/her abilities allows delivery of more accessible content. The pilot study confirmed the simplicity and usability of ABCD SW – all the children quickly learned how to use it and enjoyed working with it. Our work confirmed the observation (previously described in literature) that children with autism are attracted by technology for several reasons: interaction with the technological tool does not require emotional involvement; the answers are repeatable and coherent; the small size of the tablet (in our study) made it fully controllable by the child; the simple touch interaction and very rapid feedback as well as the game challenge with immediate reinforcement might increase motivation. Previous work in the field dealt with ABA programs and learning data analytics as separate components, while ABCD SW integrates both features in one tool. This allows easy maintenance of the code, and high accuracy of data collection since the tutor must evaluate the trials otherwise the child' exercise is blocked. Consistency and coherence of the intervention is fully assured; each tutor can automatically continue the intervention of the previous ones (3/4 tutors rotate), without needing to read the paper reports used in the traditional ABA sessions. Time saved using the more rapid set-up, personalization and data monitoring ABCD SW functionalities affects the overall effectiveness of the ABA intervention because more time can be devoted to the learning intervention, allowing mastery more items in the same time slot.

The pilot test with seven children showed that all subjects experienced great satisfaction using the software with an iPad. The qualitative evaluation performed by the psychologist using the Vineland Adaptive Behavior Scale before and after the ABA intervention showed improvements in all children participating in this intensive program, in both communication and socialization areas. The VABS gives valuable information for developing educational and treatment plans. In particular, the Parent/Caregiver Rating Form is a valuable tool for progress monitoring. Children with autism benefit from intensive, early intervention that focuses on increasing the frequency, form, and function of communicative acts. Highly structured behavioral methods have important positive consequences for these children. Fluency and flexibility of expressive language are key components of the distinction between "high-functioning" and "low functioning" autism in school age or adolescence. Because of the centrality of communicative deficits in the expression of ASD, amelioration of communication problems in children with this syndrome is one of the most important areas of educational service. An approach that results in an increased use of communicative and expressive behaviours is required to assess the efficacy of high-tech aids like these in this population. The comparison of mastered article ratio in both technology-enhanced and traditional ABA intervention enriched with ABCD SW proves increased efficiency when using ABCD SW. Helping tutors with intervention workflow, optimizing their time, is vital for ensuring a correct and effective intervention. Furthermore, the ability of the software to support better decision-making through data collection, processing and visualization (graphs) facilitates the work of the ABA analyst in controlling and reshaping the intervention. Concerning ABCD SW's acceptability, the natural interaction and immediate feedback along with the possibility of managing small devices offered a pleasant experience. All the children were attracted by the iPad and accepted the novelty introduced by the technological tool, requesting to work with it by themselves. The iPad worked as an intrinsic reinforcement. Furthermore, they maintained their attention for longer sessions. Surprisingly, all the children showed special care using the tool, avoiding any physical damage. Our work confirmed the observation (previously described in literature) that children with autism are attracted by technology: interaction with the technological tool does not require emotional involvement; the answers are repeatable and coherent; (in our study) the small size of the tablet made it fully controllable by the child, the simple touch interaction and very rapid feedback as well as the game challenge with immediate reinforcement might increase motivation.

In conclusion, free open source ABCD SW is a tool that can help parents, tutors and psychologists perform basic ABA programs, improving rapidity and accuracy compared to traditional intervention. Moreover, it can also be used by non clinical personnel, thus sustaining families in their daily burden in rehabilitating children with autism. Since the software is designed as a rehabilitation tool, it is meant to be employed in a one-to-one intervention. The pilot study provided us with an unexpected result: a child with attention problems, unable to watch TV or use computers, with a high number of self-stimulation behaviors, and who had severe learning difficulties, began to learn quickly and easily through the ABA program mapped on ABCD SW. This is a promising result regarding the actual learning abilities of children with autism using tablets, suggesting that it would be worthwhile to investigate technology-enhanced learning in a fully controlled safe (impeding self-stimulatory interaction with the technology) environment, with the aim of verifying whether the free interaction could further aid their progress over time. These data would be extremely interesting both for designing teaching methodologies and for creating accessible and usable technology-enhanced teaching environments. Future research will be oriented in this direction.

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