An Interactive E-book with an Educational Game for Children with Developmental Disorders: A Pilot User Study

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***Abstract*—Children diagnosed with Autism spectrum disorder (ASD), as one of the most complex neurodevelopmental disabilities, are characterized by different brain and functioning development, distinct interaction with the environment and different learning patterns, language and social skills impairments, and repetitive auto-stimulating restricting behaviors. It has been shown that computer-assisted intervention is much more attention captivating and interesting to children compared with a classic approach to teaching, allowing for faster acquisition of skills. This makes these tools and the technology highly suitable for teaching children with autism basic developmental skills. In addition, interactive electronic books showed positive outcomes for comprehension and information acquisition in children with ASD, while decreasing inappropriate children behavior in the classroom. In this paper a pilot user study on an e-book with an embedded educational game for children with developmental disorders was presented. The results show that the e-book can be efficiently used for teaching children with ASD basic developmental skills and that the learned skills can be efficiently transfered to new media and environments. The framework will provide preschool children with and without disabilities with appropriate educational software, to build up their early cognitive abilities and school readiness skills, and promote incorporating technology as part of the educational and pedagogical process in schools.**

I. Introduction

Children diagnosed with developmental disabilities account for a large spectrum of (neuro)developmental disorders like autism, ADHD, intellectual disabilities, etc. The main characteristic of this neuro-atypical development is that these children and later adults, interact with the environment in different ways, their brains develop and function differently, so they learn in a different way. Autism spectrum disorder (ASD) is one of the most complex neurodevelopmental disorders, which characteristics like impaired language and social skills development, and repetitive auto-stimulating restricting behaviors, interfere with ones overall functioning [1]. The spectrum means that overall functioning of the individuals with ASD can be anywhere between high functioning or mild severity, when only some language delay or lack of social skills is apparent, to severe disability with no vocal verbal communication skills or eye contact and interest in social interaction. This, in turn, greatly affects the way individuals on the spectrum learn and the way learning environment and curricula need to be designed and arranged.

Computer science contribution to this population has been great already, but there is still a vast land of research opportunities barely tapped into. Applications of technologies like eye-tracking [2], [3] and skin conductivity sensors [4], [5] have just begun to shed the light on the way people with autism, for example, visually scan their environment and learn, and what levels of anxiety they feel during those interactions.

Numerous studies have demonstrated that children with ASD acquire skills faster when instruction is delivered via computer vs. the traditional teaching strategies, and are more interested and motivated to learn through computer-assisted instruction [6], [7]. In recent years, significant amount of work in serious games community has contributed in this domain [8].

In this work a pilot user study on teaching effectiveness of the previously developed interactive electronic book for children with and without autism [35] is presented. The study was based only on the game portion of the interactive e-book. We wanted to test whether children with disabilities like ASD will acquire basic learning concepts (i.e. pointing to colors and numbers or basic vocabulary from the story) by going through the e-book and playing the game and will they be able to transfer that knowledge, i.e. is it generalizable.

There are several contributions of this work. The results of the pilot study indicate that this highly motivating and engaging game-based environment can be used for teaching children with ASD basic developmental skills. Furthermore, it has been shown that the learned skills can be efficiently transfered to new media and environments. Finally, this work promotes incorporating technology as part of the educational and pedagogical process in all schools.

II. Related work

It has been shown that computer-assisted interventions can provides children with developmental disorders an opportunity to work on building of basic developmental skills. In addition,

it allows them to practice these on their own time, with or without supervision, and to adjust the appropriate pace while at the same time receiving feedback in form of reinforcement and correction. Bosseler and Massaro developed and tested via two separate experiments a computer-animated program for teaching children with ASD vocabulary and grammar. They found that children with ASD learned novel vocabulary with a computer-animated agent and they noted the active participation of children in the process of learning, transfer and use of the novel language in a natural, untrained environment, which is the key of learning any skill [9].

Kebritchi and Hirumi in a comprehensive educational games review pointed out that this type of games are designed taking into account several learning theories such as learning by doing, discovery learning or constructivist learning [10]. Skinner [11], looking from a point of view of the science of learning, pointed out how in video games players behavior is guaranteed to be reinforced, because the player contact salient and immediate consequences, and are almost guaranteed to be successful. The importance of the immediate feedback a teaching machine can provide vs. teacher teaching a large group of students and never being able to do so, was emphasized by Pressy [12] in the 20's as a main contribution of computerized instruction to the education. In addition, enabling students to advance through curricula at their own pace, permitting them to play an active role in learning vs. passive listener role is shown to be highly motivating for a learner [12], [11]. The feedback, being a correction and leading or prompting a player to a correct response or being a positive reinforcement to strengthen the responses in the future, seems to be a key to learning [13], [11], [14], [15]. The consequence, a component of the three-term contingency or a learn unit is what effects the behavior in the future. The appropriate and immediate consequence based upon student behavior, when properly delivered will increase the likelihood of future correct responding to the same or similar stimuli. Therefore, the intact learn units (LUs), complete antecedent-behavior-consequences, should be the aim of all instruction, computer assisted or not. The interlocking three-term-contingency has been a proven measure of a teacher (i.e. machine)-student interaction upon which all learning is based on [16], [14], [15].

The notion of serious games and its definition are not new [17]. Generally, they are defined as games designed for purposes other than leisure and entertainment, such as education, health, training, simulation, cultural heritage and other. There are many examples of serious games that have been proven to be efficient in achieving their goals while providing a fun, engaging and informal, game-like environment. Game-based learning and educational serious games combine gaming and learning, and are proven to be effective way of computer-aided learning [18][19]. A study by Kebritchi et al. showed that modern mathematics computer games have positive effects on mathematics achievement and class motivation [20]. In another example, the *Re-Mission* serious game allows young people with cancer to learn about it and its treatment [21]. A systematic and extensive review of serious games, with an emphasis on the positive aspects of gaming on learning and skill enhancement, has been presented in work by Connolly et al. [22]. In their paper they showed that playing computer (serious) games can have multiple positive cognitive, behavioral and motivational effects. Another study by Annetta et al. showed that such games can enhance engagement and motivation in children with learning difficulties or attention disorders [23].

Another, closely related, subcategory of serious games are those mainly used for health treatment. These serious games are not used only for treatment of diseases, but also for physical, mental, and social well-being treatments. These include obesity [24], [25], phobias [26], [27], diabetes [28], [29], autism [30], [31], [32] and many others. A complete literature survey on serious games for health can be found in work by Wattanasoontorn et al. [33], that also classifies them by game purpose, functionality, stage of disease and by player's wellness and analyzes each game based on different functionalities. Serious games for ASD treatment are mainly aimed at teaching basic developmental skills, including communication, social behavior and conversation, imaginative skills, sensory integration, emotional expressions, etc. [30], [31], [32], [34], [35]. An extensive overview of serious games for treatment of ASD, along with a classification according to technology platform, computer graphics (2D vs 3D), gaming aspect and interaction type, is presented by Zakari et al. [8].

One of the Electronic picture storybooks often include motion pictures, sounds, and background music instead of static pictures, and hotspots that label/define words when clicked on. Smeets and Bus examined whether these animated e-books aid word learning and story comprehension by comparing outcomes for kindergarteners across four experimental groups: static e-books, animated e-books, interactive animated e-books, and a control group that just played non-literacy computer games [36]. They found that children acquired most vocabulary after reading interactive animated e-books, followed by non-interactive animated e-books and then static e-books. In a similar study [37], but with children with ASD, reading interactive e-books (on iPads) vs. printed books was compared base on the comprehension and information acquisition. They found positive outcomes for each participant in a group using interactive e-books and teachers survey reveled that the students found iPads motivating, asked to use them as reinforcers, which in turn decreased their inappropriate behaviors in the classroom.

III. E-BOOK DEVELOPMENT

The main objective of this project was to develop an educational interactive e-book for early childhood stimulation and to evaluate its effectiveness on learning numbers, colors, novel vocabulary, identification, counting and responding to inference questions. The e-book introduces children with and without ASD a fun, enjoyable, interactive and educational game-based environment. The e-book has been developed for the web using the following technologies: HTML5, CSS3,

JavaScript, jQuery and AJAX, which makes it suitable for practically any device (desktop/laptop computer, tablet, smart phone) that has internet access.

A. Theoretical background

In order to create serious games that foster learning there are some core principles of design in addition to understanding and applying principles of the learning theory. In the design of the interactive e-book with an embedded educational game, there are several important principles: immersive storylines, goals based on targeted skills to be taught, feedback about progress, progressing through levels of difficulty, individualization, and provision of choice [38], [39], [40]. These studies showed that learning opportunities need to be integrated with the story content, a narrative needs to be built to support learning goals and encourage players to develop emotional connection with the characters, so that they will be motivated for learning. In developing the e-book, we paid close attention to these guidelines, and worked with the children story writer to create a main character, a wolf who falls in love and becomes a boy, while learning goals of recognizing colors, numbers, letters, counting, vocabulary building, etc. were embedded within the story, see Figure 1. Throughout the story narrated by children in two languages, players can choose the language of narration and game questions, whether to hear a narrator or to rely only on the text, and whether to start the game portion on the page or to only explore embedded interactive functions within the story. Yet another level of individualization is achieved by three levels of difficulty all game instructions/questions have. Some are selection responding, just pointing to the color or the picture, while others are abstract and inference questions like interpreting the feelings of the character in the scene, see Table II.

TABLE I
THREE GROUPS OF QUESTIONS IN THE E-BOOK.

Question group	Question type / Educational goal
1	Selection-based questions with varied antecedents (i.e. "point to", "find", "where is", "touch")
2	1:1 correspondence questions for teaching children to count objects
3	Production responding, inference questions, where the child reads a short text and makes conclusions based on the story comprehension

B. Web-based implementation

The interactive e-book was developed using web technologies, allowing an easy-to-use, real-time interaction through the web-based front end. The game contains 13 screens (a cover plus 12 playable), corresponding to the same number of pages in the printed book. All scenes are displayed through a wrapper *index.html* page, into which the requested corresponding page is loaded. The *index.html* page contains all the logic for the questions and answers, the language selection and for scene traversal, while the individual scenes' *html* files contain event listeners which are responsible for the page interaction, such as playing the sounds, hiding/showing the page elements, selecting the questions, and initiating the corrections. All the styling, including visual appearance, sizes, positions and effects, is done using *Less elements* preprocessor.

The whole game is implemented bilingually, in Bosnian/Serbian/Croatian (native) and English, so that the language can be toggled at any point withing the game, allowing for learning a foreign language. Each scene contains three question, two of which have three predefined answers displayed in a random order. Other questions, e.g. "where is" or "point to", require interaction with the active scene elements, see Figure 1. For each correct answer the *applause* sound is played and one of the text responses ("Great job!", "Excellent!", "That's correct!") is randomly provided. In case of the incorrect answer the correction is invoked. More details on the game implementation can be found in [35].

IV. A PILOT USER STUDY

The creation and the interdisciplinary design of the interactive e-book was described in detail in the paper published by Hulusic and Pistoljevic [35]. It was designed to attract and keep attention of a learner, to engage him/her by features additional to the text that a player can choose to be read in two languages. Additional features, for example, were auditory stimulation when clicked on a certain object in the scene: naming the object or making a related sound, or a multi layered questions about the scene or story read for comprehension and vocabulary building. There were three questions that went along with the text of the story on each page, increased in difficulty to accommodate different levels of learners (a preschooler or a child with a disability, pre-reader vs. elementary school age typically developing child, a reader). With the embedded game, our educational goals were to teach children basic vocabulary, foreign language vocabulary and school readiness concepts like identifying target objects (i.e. learn the vocabulary), counting objects from 1 to 10, identifying numbers 1-5, colors, and responding to inference questions (i.e. comprehension of the text). First question on each page was the easiest level question, a selection-based question with varied antecedents (i.e. point to, find, where is, touch). Second question was related to teaching children to count, using the scene from the book and objects in it. The third level was the production responding, an inference or an abstract thinking question like whether someone was sad based upon the text on that page the child read/heard being read. These questions were based on the comprehension of the story, so for older children it would require reading skills. The overall goal of the interactive e-book was enriching the reading/listening to narration, experience for children functioning on different levels and to provide an engaging learning environment to children with disabilities, especially multisensory needs of children with ASD. This pilot user study focused only on the 36 questions embedded in the e-book. Following the reading of the page, student was able to select to engage in the game portion on the bottom of the screen (Figure 1) and to respond to 3 questions per page base on the page visual and

Fig. 1. Three scenes from the e-book with the narrated text displayed and different question groups/layers: counting (left), pointing to (middle) and inference question (right).

TABLE II
THE INSTRUCTIONS USED IN THE QUESTIONS, SORTED PER E-BOOK PAGE. THE ACTUAL QUESTIONS WERE DIFFERENTLY FORMULATED TO REFLECT THESE INSTRUCTIONS, E.G. THE FIRST QUESTION ON THE FIRST PAGE WAS: "HOW MANY BIRDS CAN YOU FIND?", WITH FIVE BIRDS ON THE PAGE AND THREE PROPOSED ANSWERS: "4", "5" AND "6" IN A RANDOM ORDER. *PT* STANDS FOR "POINT TO" / "WHERE IS".

Pg no.	Question 1	Question 2	Question 3
1	Count 5 objects	PT bird	PT color red
2	PT wolf	Count 6 objects	PT Goldilocks
3	PT to number 4	PT millipede	Boy/Girl Y/N question
4	PT water bucket	Count 7 objects	Select Wolf (inference)
5	PT letter C	ID action waving	PT color red
6	PT bush	Count 8 objects	Si the wolf sad Y/N
7	Count 9 objects	PT mirror	Does the fairy flies Y/N
8	Count 10 objects	PT keyboard	PT wolf
9	Count 4 objects	PT popcorn	Wolf has fullmouth Y/N
10	PT blue car	PT glass	Count 5 objects
11	PT yellow	PT wolf	PT glasses
12	Count 1 object	PT heart	Is a boy wearing glasses Y/N

TABLE III
GENERALIZATION PROBE: THE QUESTIONS / TASKS, PERFORMED IN PICTURES AND/OR BOOKS AND IN THE CHILDREN'S NATURAL ENVIRONMENT. *PT* STANDS FOR "POINT TO".

No.	Question / Task	No.	Question / Task
1	Count 10 objects/manipulatives	14	PT "B"
2	PT RED	15	PT "C"
3	PT BLUE	16	PT boy
4	PT YELLOW	17	PT girl
5	PT "1"	18	PT bucket
6	PT "2"	19	PT Bush
7	PT "3"	20	PT mirror
8	PT "4"	21	PT Computer keyboard
9	PT "5"	22	PT popcorn
10	PT bird	23	PT glass
11	PT wolf	24	PT glasses
12.	PT millipede	25	PT heart
13	PT "A"		

textual input. Following the mastery of the game, we assessed the transfer of the vocabulary and concepts learned through playing the game by asking children to use the vocabulary and concepts in their natural environments.

A. Participants

In this pilot user study, we tested only the game component of the interactive e-book. Ten students, one girl and nine boys participated in the pilot study, ranging in age from 4 to 7 years old. All students were diagnosed with autism and/or other developmental delays with autistic elements. Children attended a specialized evidence-based model of instruction "EDUS-Education for All", provided through public preschool program for children with developmental disorders. Children attended an evidence-based program that applied behavior analysis to all aspects of teaching, for 5h daily and all had individualized education plans and programs. Seven children attended a classroom with a student to teacher to teaching assistant ratio of 10:1:1, while three attended an 8:1:3 ratio classroom. All students in EDUS programs were grouped according to their levels of verbal behavior, so it would be safe to say that seven participants were speakers and listener, emergent readers and writer, while three were on a lower level of verbal behavior and were emergent speakers and listeners. All instruction across all EDUS classrooms was done via learn units, teacher delivering instruction, reinforcement and corrections while continually taking data on all students responses and behaviors. Same rules were applied during the game playing while children sat at the computer table with the teacher who had a data collection sheet and read the questions from the game to the participants. Due to the age and level of functioning, children were not able to read the questions in the game to themselves. A teacher working with them was instructed to only get their attention to the game, read the questions and record student behaviors. He/she was not allowed to help students in any way or to prompt or explain any questions.

B. Design

The participants played the game with a teacher reading the questions and taking data on the LUs (antecedent-behavior-consequences). Only data on the game playing, not interacting with the e-book, were recorded for the purpose of this study. The instructions used in the data sheets during the data collection for all 36 questions in the game is shown in Table II.

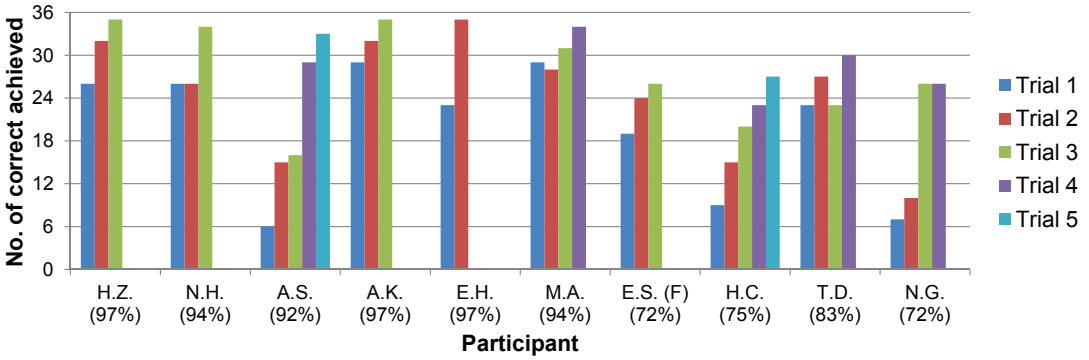

Fig. 2. The number of correct answers achieved per participants across the trials. Bellow the participants' initials the percentage of correct answers is presented. Last for participants did not achieve the mastery. Participant *E.S.* was the only female (F) participant in the study.

Following the mastery, generalization probes were conducted. They were conducted on non-screen media, that is across different school environments and as responses to pictures in other children books. Criterion for mastery of the game was set at playing it once at a minimum of 90% accuracy, that is 33 out of 36 correct responses to the game tasks. The data were looked at as total numbers of LUs (i.e. trials) required for mastering the game, that is reaching the predetermined criterion level. Numbers of LUs to criterion were calculated as well, to tell us on average how many LUs children needed to master the game. Comprehension and vocabulary were only post-tested, to prevent that a repeated exposure to target words in tests could explain the outcomes, to avoid practice effect [41], [42], [36]. During the generalization probes, a total of 25 vocabulary questions were tested. They were conducted in children's natural environment, during instruction and free play, children were asked to point to or show target vocabulary from the game from their environment or in hard cover books and pictures in the classrooms. The questions/tasks from the generalization probe data sheet are shown in Table III.

C. Interobserver agreement

Interobserver agreement or reliability observations were conducted with an independent observer for a total of 25% of all sessions of game playing, with a mean of 98,5% (ranging from 92% to 100%). While the teacher was reading the antecedents to the student and recording the students' responses on a data sheet, an independent observer was doing the same on a separate sheet without any communication with the participant or the teacher. The interobserver agreement scores were calculated by dividing the total numbers of paired observer agreements by the total numbers of agreements plus disagreements and then multiplying that number by 100 [43].

V. Results

The results of the pilot user study with 10 participants showed that the created software in native (Bosnian/Serbian/Croatian) language was completely clear and user-friendly for kids with special needs, and that it is systematically and developmentally appropriately sequenced for learning, see Figure 2. Additionally, it was found that children were able to generalize learned skills, through a transfer to new media or environments, by using the vocabulary in other hard cover books or by labeling 3D objects in their environment. Their teacher also reported that children were very motivated and enjoyed playing the game. For many of them, the game became a reinforcer, i.e. they asked to (re)play it. After an average of playing the game 4 times, all children showed a significant increase in correct responding and reached levels of over 72% accuracy, see Table IV. Six children mastered the game, reaching the 90% or more correct responses. Due to the objective limitations, such as time and access to the children, the other 4 participants did not complete the game. For 3 out of the 6 who completed, we conducted the post-probes, maintenance probes to test for the transfer of learned concepts to the natural environment. All students demonstrated high transfer of vocabulary learned to other, non-computerized settings.

Testing such games with children with ASD is highly time and resource demanding, as the children is tested the game only once per day and testing a game with one child has to be performed by two teachers in an isolated environment and in a suitable time of the day that complies with the children's daily teaching routines. Nonetheless, those that have not so far, and other students not included in the study, will continue playing it and will master it as part of their daily instruction.

VI. Conclusion and Future Work

The e-book was designed to engage children with its auditory-visual stimulation, related to the storyline presented bilingually, with multi layered questions about the story. Our educational goals were to teach children novel vocabulary, counting, identifying numbers and colors, and responding to inference questions.

According to National Center on Educational Statistics from 2001, approximately 90% of children ages five through seven use computers in the USA [44]. Video games in particular provide an interactive, self-paced and motivating tool that presents concepts in a way that are engaging, informal, and fun for children [45]. Education of children with disabilities is

TABLE IV
THE SUMMARY OF THE RESULTS OF THE PILOT STUDY.
* INDICATES THAT PARTICIPANTS G-J HAVE NOT MASTERED THE STUDY (SEE "% CORRECT ACHIEVED" COLUMN)

Participant	Age at the onset of the study	Verbal/behavioral (VB) level	Number of times game played to mastery (36 LUs)	% correct achieved	Generalization probes (25 LUs)	IOA%
A	6.6	Listener Speaker Emerging reader and writer	3	97%	100%	100%
B	4.5	Listener Speaker Emerging reader and writer	3	94%	n/a	n/a
C	6.11	Listener Speaker Emerging reader and writer	5	92%	n/a	92%
D	4.10	Listener Speaker Emerging reader and writer	3	97%	96%	n/a
E	7.2	Listener Speaker Emerging reader and writer	2	97%	n/a	100%
F	5.3	Listener Speaker Emerging reader and writer	4	94%	88%	100%
G*	6. 8	Speaker and Listener	3	72%	n/a	n/a
H*	4.2	Emergent speaker and Listener	5	75%	n/a	n/a
I*	4.3	Speaker and Listener	4	83%	n/a	n/a
J*	6.10	Emergent speaker and Listener	4	72%	n/a	n/a

an existing field and computing sciences are just barely being introduced to aid this process, from interactive educational software, e-books, educational video games, interactive lesson plans, assessment based curricula, etc.

The e-book contained the multisensory stimulation, where extratextual explanations of word meanings were present, e.g., presenting a concept using the visual (image and text/word) and auditory (narration and sound) stimulation, and asking a child to click on a target object in the picture. This concept has been reported to have positive effects on word learning in kindergartens [46].

The results from the pilot study showed that this and similar computer game-based environments, when designed properly, could be used for fast and effective skills development and knowledge acquisition. The six children with *listener, speaker, emerging reader and writer* VB level mastered all the questions withing 3.3 trials on average. In addition, all three of them tested managed to transfer learned skills to new media or environments. This framework will provide preschool children with and without disabilities with appropriate educational software, to build up their early cognitive abilities and school readiness skills.

There are several studies on assessment of the learning outcomes, including both the feedback on user progress and the teaching effectiveness. Although most of the games provide some output on user performance, usually it does not directly indicate if the learning goals have been met. Recently, a methodology for effectiveness of serious games as educational tools has been proposed by Serrano-Laguna et al. [47]. In addition, Chaudy et al. developed a serious games assessment engine [48]. In the future, we are going to embed such a module in the game, so that the data collection and descriptive analysis of learning outcomes is performed automatically in the background during the game-play. Furthermore, we plan to extend the e-book with additional questions for teaching other skills and concepts within the same game environment. Finally, a more extensive user study is being conducted at the moment, which will provide with a better insight in the game effectiveness on skills development and knowledge acquisition, and more evidence-based conclusions.

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