Designing *ReduCat*: Audio-Augmented Paper Drawings Tangible Interface in Educational Intervention for High-Functioning Autistic Children

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ABSTRACT
This paper describes the design of *ReduCat*, an audio-augmented paper drawings tangible user interface (TUI) system intended to support educational intervention for high-functioning children diagnosed with autism spectrum disorder (ASD). The system records audio snippets on standard paper drawings using a tangible user interface that can be shared between the therapist and the child. *ReduCat* is designed as a tool for the therapist to engage the child in a collaborative storytelling activity. We used a progressive design method based on a dynamic process that merges concept generation, technology benchmarking and activity design into continuously enriching actions. The paper highlights the qualities and benefits of using tangible audio-augmented artefacts in educational intervention for children with ASD. Finally, we reflect on three main qualities of our system: exploring the qualities of children's written and oral narrative; framing children's attention; and supporting therapist appropriation and child differences.

Author Keywords
Audio-Augmented paper; drawings; high-functioning autism; tangible user interface; prototyping; interaction design.

IDC '16, June 21-24, 2016, Manchester, United Kingdom
© 2016 ACM. ISBN 978-1-4503-4313-8/16/06…$15.00
DOI: http://dx.doi.org/10.1145/2930674.2930675

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

1 INTRODUCTION
Autism spectrum disorder (ASD) is a developmental, neurobiological condition that affects the ability to communicate, interact socially and be imaginative [18,19]. The severity and range of disordered thought processes, communication interactions and behaviours vary from one child to another. Children on the low-functioning (LF) end of the spectrum usually have little or no language use, severe intellectual disability, and little awareness of other people and their expectations. Children on the high-functioning (HF) end of the spectrum typically exhibit functional social and communicative abilities along with higher cognitive abilities compared to other children with autism, but still typically experience social, sensory, and learning deficits. The syndrome is lifelong, and its causes are still unknown.

Interventions for individuals with autism typically begin early in life and are usually aimed at teaching social and communicative strategies. These interventions often include the use of visual supports such as images and drawings to represent both concrete and abstract real-world concepts [9]. Among the various techniques and approaches, the social story intervention is commonly employed to address the acquisition of new social skills and improvement of existing social behaviours [14]. In social stories, visual cues are often used to assist children in their understanding of oral language; the use of pictures, drawings and written words combined with spoken language fosters children's ability to abstract meaning from information [29]. The strengths of social story treatments are that they can be implemented in informal environments, are extremely flexible and adaptable to individual children's needs and characteristics, and stimulate and enrich children's experiences during rehabilitation sessions through the use of physical artefacts (i.e. drawings, pencils and other materials).

Our aim is to provide a novel tool and a new approach for caregivers (therapists, special education teachers or even parents) to present and discuss social stories or similar materials with HF children on the autistic spectrum. This paper presents the development of a tangible user interface for situated authoring of custom audio-augmented paper drawings social stories. We examined the utility and effectiveness of the *ReduCat* system for children, educators, logopedists and therapists. An important contribution of this work is a long-term field development of the *ReduCat* educational authoring system, involving a diverse range of stakeholders, and centres in two countries. This allowed us to study how educators and children might incorporate audio-augmented paper drawings technology into their daily educational activities, and in turn, we identified ways in which *ReduCat* might be improved to support social skills development and language instruction.

The paper first introduces a preliminary framework for future development of this research area, and then it reviews related projects and previous studies. Next, the design process used in this work is presented. Then the research method used in a preliminary ecological study is described, and research findings are discussed. Finally, conclusions are drawn, and suggestions are offered for further study.

2 RELATED LITERATURE AND WORKS

In recent years, numerous technologies and systems have been designed to support educational intervention for children with ASD. Many of these computer-based interventions are grounded on the cognitive-behavioural therapy (CBT) procedure, based on applied behaviour analysis principles [15,25]. Computer-based interventions include virtual reality [22,26], robotics [10,21], tabletop computer interfaces [16], tangible artefacts [3,11–13,23], mobile applications on tablet computers [16,36], and wearable devices. For the purposes of this work, we only report literature focusing on tangible interventions for autism or with a strong tangible component, such as the audio-augmented paper system [3]. For a more general review, refer to Hourcade et al [16].

Researches have reported an increase in cooperative behaviour by children with ASD using tangible technologies. LeGoff [23] used LEGO© as a therapeutic medium and found that it improved social competence amongst children with autism. Similarly, Farr et al. [12] highlighted the advantages of Topobo, a 3-D constructive assembly system embedded with programmable kinetic memory [30], in fostering collaborative and cooperative behaviour among children with ASD. Alessandrini et al. [4] explored the role of audio-augmented paper for supporting cooperation educational activities with children diagnosed with ASD**.** Garzotto and Bordogna [13] found the utility of 'talking paper' in supporting children with disabilities to associate physical objects with multimedia resources. Additionally, Farr et al [11] highlighted the positive impact that augmenting configurable objects with the child or therapist's own voice could have, indicating the positive and reassuring role played by the child's caregivers.

Several works in the existing literature incorporate paper as an active medium. Back et al [6] described an augmented book that uses radio frequency identification. TinkerLamp [37] used fiducial markers to build paper-based interfaces for tangible simulations. LuminAR also uses fiducial markers to build tangible interactions [24]. Piper et al [27] proposed the use of a digital pen for audio annotation of paper-based materials. Raffle et al. [31] Jabberstamp tool allows for repeated audio imprinting on a sheet of paper, enabling children to attach recorded audio cues to drawings and encouraging users to communicate, create narratives, and even devise games outsiders can interact with, whether singly or collaboratively with other children. Such studies should be considered in light of Prieto et al. [28] review of augmented paper systems in educational settings, where their ability to accommodate a variety of classroom settings and activities were noted. For a review of prototyping interactions practices and challenge in designing tangible user interfaces, refer to [1,2].

Although these studies demonstrate a vibrant field of study and present interesting opportunities to design future TUI technologies, scarce information exists regarding the benefits of using located and situated audio-augmented social stories for the educational intervention of children with autism. In order to address this gap, we have designed an audio-augmented drawing, tangible interactive environment to support and promote paper locate audio, narrative and descriptive activities for children diagnosed with ASD. In our research, we investigate the roles and benefits of using located and situated audio recording in narration and description tasks, as well as the advantages of using our prototype to support educational sessions. The rest of this article describes the design process for the prototype development and the results of our ecological study with children and therapists.

3 DESIGN PROCESS

In order to come up with the system, the users and stakeholders were at the centre of our design process since the beginning. Our design process, which was grounded on user-centred design (UCD) principles and on scenario-based design [7,8], uses an iterative methodology which combines concept generation, technology benchmarking and activity design into continuous enriching and gradual actions.

3.1 Field Research

Our project began with a field research study conducted via participant observation at three centres across Scotland and

Italy for the education of children with autism**.** We observed that all the centres regularly use variations of the social story approach, organized around a drawing and story sequencing activities done by child and the therapist collaboratively. Observation participants were children (7-14) ranging from mid to high functioning, and therapists ranging from new (less than two years) to expert (more than five years). We observed that the therapists often use these activities to build a framework to introduce and discuss examples of social problem circumstances. We observed that often either the child or the therapist wrote down on the sheet of paper or on the child's notebook a description of the contents of the social story cards. These descriptions were intended to act as a memory aid for continuation of the activity at a later time, or for parents to become aware of their child's educational rehabilitation activities. Subsequent to observation, informal interviews were also conducted with the therapists involved regarding their activities with the children. We observed that the project stakeholders appreciated the use of the paper component because of its simplicity and ease of use, for its expressive potential, and for its ability to be shared.

The research team (composed of an interaction designer, a senior human-computer interaction researcher, a cognitive science researcher and a product designer), starting from the data coming from the field study and the experience gained from a previous project [3], sought to use the tangible properties of the paper and physical-digital artefacts. According to the project stakeholders, handling physical-digital artefacts rather than digital computer representations offers several benefits for children with autism and their therapists.

3.2 Design Objectives & User Scenario

The research team, informed by the field research study, investigated the design space by focusing on sheets of paper, defining the following design objectives:

Design objective 1: augment standard paper drawings with the possibility of recording audio from the child and therapist's oral narration. Therapists could then create educational activities involving the child's voice presenting the stories on paper without the need to write on the paper (although writing may still be a possibility if needed).

Design objective 2: embed computation capabilities into tangible artefacts, making the "computer" disappear from the child experience. This would maintain the natural interaction between child and therapist, thus reducing child distraction.

Design objective 3: ensure ease of use. The therapist should be able to easily use and configure the system.

Parallel to the field research, we began to look at potential appropriate enabling technologies for the project and inspirational recent projects. We focused in particular on easy embeddable small form factor voice recording audio chips that enable high-end voice audio quality with an adequate duration for the purpose of our project (ranging from 20 sec. to 5 min.). Concurrent to this, the research team conducted concept generation sessions inspired by the field study and informed by our enabling technology review. The multidisciplinary research team engaged in iterative creative design sessions which bring us to the generation of seven major concepts. At this stage, the concepts were produced and visualized into concept scenarios [7]. Designing a mobile app for tablets was considered, though it was rejected as being incompatible with our designs objectives. The research team finally selected the *Call-Out* concept for further elaboration within the design process, as it was deemed compatible with our stated design objectives.

The *Call-Out* concept is a physical-digital interactive tool that enables the child or the educator to augment an ordinary sheet of paper drawing with their own voice. The idea enables the use of one's own voice to augment paper drawings for narrative and descriptive activities for rehabilitative and educational exercises. We created a concept scenario to further guide our design process.

The child and the therapist collaborate to draw with standard pens on a standard blank sheet of paper. When the system is placed over a sheet of paper drawing, it captures and understands the sheet's content drawn under it. The child starts recording the story with their own voice. The system couples the drawn captured section with the child's own voice. The therapist moves and records their voice on another area of the drawing. The child listens to their own voice by replacing the system where they recorded their voice and activating the playback of the audio.

3.3 Proof-of-concept Prototype

We produced a proof-of-concept prototype to understand the interaction between the audio and pictorial contents of common sheet of paper. We stressed the fact that our model of interaction exploited the tangibility and expressive qualities of paper, this should foster child and therapist sociality and it might support cooperation and turn-taking during the educational activities.

Our proof-of-concept used a few sensors, several electronic components, and a sheet of paper with a social story printed on it. The sensors were used to recognize the drawing on the sheet of paper. At this development stage the electronic was rather simple and consisted of a speaker and buttons to activate the recording and playback functionalities. In our proof-of-concept the recording and playback functionalities could only be operative when the system is detecting a drawing "context" on the sheet of paper (Figure 1 – Left).

During the process we faced the following challenges. The prototype's form factor was inadequate in terms of aesthetic design and physical graspability. Smaller circuit boards were tested in order to make the prototype more compact and able to fit inside dedicated casing. In addition, our system design had to be entirely embedded in a unique

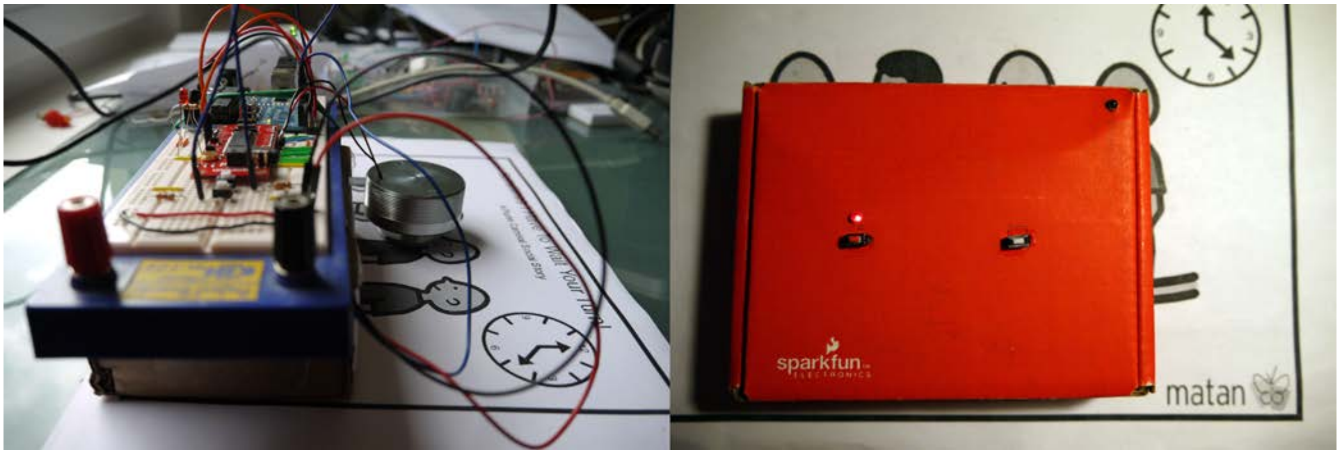

Figure 1 First Prototype (Left – circuit board; Right – interactive mock-up)

shape in order to avoid external distractors for the child and to enhance ease-of-use with a single prototype, rather than requiring additional interaction with a PC or other system for the therapist. Speakers that could offer better audio quality were also tested, and code refinements that could improve the accuracy of drawing detection were implemented. These latter improvements were considered of high importance due to the necessity of propagating the audio in the tabletop space.

We presented the proof-of-concept prototype at a workshop with a multidisciplinary audience (including a psychologist, educational centre personnel, a designer, a computer scientist and an engineer). The workshop was intended to focus on getting insights and feedback for our proof-of-concept prototype from diverse audience. The feedback from the workshop made us understand that our model of interaction enhanced the imaginative expression of the paper medium, and could better support the collaborative interaction between the therapist and the child. To better support cooperative interaction between the child and therapist, we redesigned the interaction model to enable multiple anchor points and sharable controls by users. We revised the system to support more dynamic and expressive interaction based on tangible artefacts for the fruition and creation of the audio contents. The new model of interaction introduced a new dimension related to the space of interaction, requiring social abilities to use the system.

3.4 First prototype refinement

We refined the proof-of-concept prototype using a dramatized prototyping approach [5], introducing a new method for the recognition of drawing on paper anchored with the audio hot spot propagation properties. The refined model of interaction reorganized the space of collaboration in several ways. Firstly, an anchor artefact in the form of a sheet of paper was required to initiate interaction with the system. Secondly, the interaction artefact affected the user-selected sheet of papers' areas. Thirdly, the physical-digital artefact enables privileged behaviours between the users and those areas of the paper they selected.

In other words, to record on the sheet of paper drawings, the child or the therapist should cooperate to determine which area on the paper to place the tangible artefact. The child or the therapist then activates the recording over the area; stopping it or removing the physical-digital artefact ends recording. Moreover, the playback functionality allows the users to create a sequence, enabling the concatenation of audio files just by successively placing the tangible artefact over the previous audio enriched user-selected sheet of paper's areas. The research team hypothesized that freeing the users to create multiple anchor points of interaction could give the child and therapist greater opportunity for negotiation, thus stimulating cooperative interaction, imitational learning, and consciousness of each other's actions.

The system refinement was followed by two activities run in parallel; the creation of the storyboard and video scenario, and the development of the wireframe and an interactive prototype. With the first two, we highlighted three key aspects of the model of interaction. Firstly, the system requires a sheet of paper, whether blank or with pre-drawn content, which must be free of vision based tagging techniques. Secondly, system functionalities must be easy to control by the child in collaboration with the therapist. Thirdly, users should have the possibility of creating an audio sequence by using multiple sheets or a user-selected sheet of paper's areas by placing the physical-digital artefact over the audio enriched areas in successive order.

For the first interactive prototype, the research team sub-divided the activities in two phases. An informative phase based on a state machine and an interaction wireframe described software, hardware components and their implementation first, and user's interactions secondly. The making of the prototype required the definition of the shape (Figure 2 – Left) and the redesign and integration of electronics enabling components. The new prototype was based on redesigned miniaturized electronics embedded on an engineered 3D printed "cat head" shape (Figure 2 – Right). The software's system, running on the embedded tiny microcontroller, detects and captures drawing scenes and generates events in their presence. This functionality was implemented by using vision sensors. The software running the system reduced the incidence of missed detection, increasing the stability of the drawing-detecting process. The Arduino Integrated Development Environment (IDE) was used for combining components with specific functionalities, such as audio, tracking and user interface.

Several challenges become apparent at this stage. Although a casing shape had been printed and engineered that was capable of holding all the embedded electronics, reducing volume in order to aid graspability was still a concern. This ran alongside concerns over the prototype's power system, in which different electronics components required their own separate batteries. This negatively impacted the prototype's efficiency, presented poor space management, and increased its weight. It was therefore decided that all the electronics and consequently the power system had to be refined. Furthermore, the definition of the ratio between audio quality and recording time had to be settled. It was decided, through several iterations, to settle upon 8 kHz and 1 minute respectively, privileging audio quality over recording time. This was due to the importance of the listener of being able to recognize and distinguish voice sources. The contact point made by the prototype's base with the tabletop also presented a challenge for the requirements of different components. The sensors, to better read the drawing traits, required millimetric space between them and the surface, while the speaker had to be in contact. The balance was found through several iterations with the surface speaker transducer, which had a power rating of 3W, and compelled a balance to be found between the different components such as the board, speaker, and material for the basement. Finally, user safety issues were considered in light of the prototype's components being prone to overheating.

The new prototype was subject to a heuristic evaluation by experts on autism from different backgrounds, consisting of psychology, engineering, design, and computer science. Two new challenges to be overcome in the subsequent design were identified by them; the visual recording feedback was unclear and should be brighter for children, and the audio was too weak and sometimes inaudible for children. However, they believed that the system was simple enough to be explored and learned quickly, and that the shape and form factor was appropriate, attractive and not distracting for the children and for the therapist. Based on the heuristic evaluation's findings the research team addressed the prototype's shortcomings by introducing more visible and consistent feedback about the system status; refining the shape of the prototype in aid of volume, graspability and weight; improving the audio quality by using material with more resonating quality; and by refining the user interface.

The challenges identified were addressed in the following ways. Visual LED feedback of the prototype's recording status was shifted from the cat's head ear into the prototype's main shape, thus improving perceivability from all angles and overall aesthetic quality. This entailed reengineering of the top of the prototype's head. Additionally, graspability was improved by reducing the prototype's volume by 20%. A new high-powered electronic board was implemented in order to boost audio quality from the attached speaker. In order to assist audio propagation, different base materials that could influence propagation were explored in an iterative process. Finally, the user interface was defined to be more consistent, fluid, and error-resistant.

3.5 The final prototype

The system embedded within the shape of a cat head has sensors placed under the base of its body in such a way that the field of view of the sensors matches with the front view of the "cat head". A small microcontroller is connected to the sensors where a program detects the drawing on a piece of paper, provides feedback (recording and drawing context), reacts to the user interface (record and play buttons) and communicates with the voice recording electronic board, which in turn records, stores, and plays back audio files. The sensors are used to recognize the presence of a specific drawing section.

The drawings, traits or sections which are drawn (or printed) with a standard dark marker or pen on any standard sheet of paper enable the sensors to recognize the presence of a sheet with a drawing under the base of the cat, and assign a unique state to each drawing section located under the prototype before recording audio. The latency of recognizing drawing line traits is almost instantaneous and was not found to impact upon the user experience. The

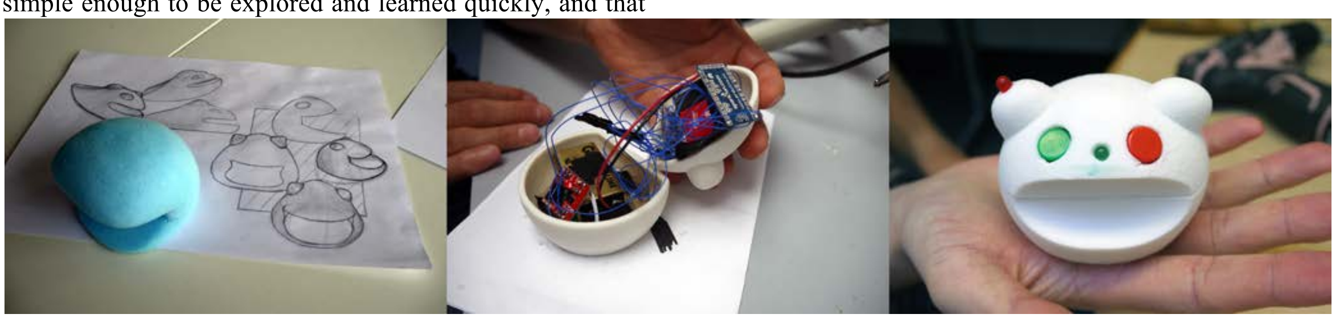

Figure 2 Second Prototype (Left – Blue-form model of 'cat head'; Centre – Embedded electronics of interactive prototype; Right – First interactive prototype)

accuracy of reading is dependent on the line weight being at least 1 point, and on the material of the surface on which the prototype is placed, with plain white paper achieving the best accuracy when compared to other surface types such as laminated paper or plastic whiteboard.

Recording a snippet of audio is performed by placing the cat head onto the drawing and, once the “drawing context” is captured by the system, pressing the record button. If a sheet of paper already contains audio – that is, upon drawing a new section, an audio recording is already associated with the overall drawing context of a sheet of paper – the new audio is appended to the end of the previous one. In this way, a longer audio description can be added to a drawing section piece by piece.

Audio content on the prototype can be erased in two ways. If the prototype is placed on top of a drawing which has associated audio content, then the record button can be pressed for over two seconds in order to erase that particular content. If the prototype is placed over an empty section of the paper and the button pressed for more than two seconds, then all audio content contained in the prototype memory will be erased.

The final prototype (Figure 3) was further evaluated by stakeholders composed of four therapists, two psychologists, three centre directors, and other personnel of the aforementioned three centres for the education of children with autism. During the evaluation, stakeholders explored the prototype by simulating and speculating on possible use in a rehabilitation situation. The explorative session was not only helpful for the stakeholders to explore the prototype’s functionalities, but it also favoured brainstorming sessions in which ideas could flow freely. During the evaluation, stakeholders recommended enhancing the audio qualities (because children with autism might be immersed in a noisy rehabilitation environment), but also suggested having a more readable set of cards (reducing the scene complexity and increasing the dimensions of the cards). The next section describes in detail the results of the pilot study.

Figure 3 Final prototype

4 PILOT STUDY

The prototype was evaluated in an ecological pilot study done in two different countries; the first at a centre for the education of children with autism in Italy, and the second at a school for special needs in Scotland. This study was not intended to comprise a final evaluation, but rather to explore the strengths and weaknesses of our prototype. The following three dimensions were worth investigating: how the therapists use the prototype, how the prototype supports the therapists’ learning objectives, and the children’s level of engagement with the prototype.

4.1 Method

The pilot study was divided into three phases: use of the prototype by the children and the therapists, semi-structured interviews with the therapists, and final focus group discussion with the therapists. In each use session, the therapist used the prototype together with a child for twenty to thirty minutes. The therapists already knew the children, and the former were already conducting educational activities based on social problem solving, story sequences, and descriptions of flashcards with the latter. In the semi-structured interviews, each of which lasted approximately twenty minutes, the study facilitator asked questions about the therapists’ experiences using the prototype. The children’s families were informed about the study and its objectives and gave permission for their children’s participation. The whole study was approved and supervised by the directors of the centres and the psychologists affiliated with the children.

The study in Italy involved two HF subjects with verbal abilities (8-12 years) led by two therapists. The study in Scotland involved two subjects between the ages of 17 and 18. The first was moderately functioning (MF) and the second was HF. Both had verbal ability. Each child was involved in one session, and in Italy, different leading therapists were involved in each session, while in Scotland, the same therapist conducted both sessions. At the beginning of each session, the study facilitator described to the therapist the functionalities of the system. During each session, the therapist was free to choose the activities that best responded to the child’s needs. All sessions were video-recorded. At the end of each session the study facilitator interviewed each therapist involved. The pilot study concluded with selected video clips of the prototype use being discussed in a focus group with therapists and the psychologist. In general, the therapists appreciated the prototype and were able to use it without major problems. However, they most often used the prototype to engage the children in a description activity rather than in a storytelling activity. This preference might be due to the therapists’ limited experience with the system or because the system is too limited for a storytelling activity. The therapists used three different tasks throughout the study: describing pre-printed, social story visual cards; describing pre-printed, social problem solving visual cards; or describing the content of vocabulary-based flashcards.

Figure 4 Use of the social problem solving cards

4.2 Description of Social problem solving cards

In Italy, the therapists showed the children the social problem solving visual cards and created a remarkably rich activity with them. For example, the therapist asked the child to describe the content of the cards, and to explain the social situation depicted on the cards. While the child talked about the contents of the cards, the therapist asked the child to record their voice by placing the prototype on the card and press the recording button to capture the child's own voice. In this activity, located situated audio recording was mainly used to allow the child to listen to their own voice, to verify their statements, and as a reward (Figure 4).

Before starting the educational activity with the cards, the therapist let the children explore the prototype. For example, the therapist explained that the prototype was able to record their own voice if it was placed onto the top of a card and if the red (recording) button was pressed. The therapist let the child make a few exploratory recordings and listen to their own voice using the cards on the table which would be used for the educational tasks. Following this first discovery phase, the therapists created more collaborative and cooperative actions through the cards and the prototype together with the children. For example, the therapists said to the children, "*Put it here*", or "*Now listen to what you said*". In some cases the therapist allowed the child to record their own voice again to get an improved narrative and better-quality recording.

In this first phase, HF children acted on the prototype. The therapists gave them complete control of the system, and the HF children responded well to the therapists' requests and tasks. The therapists used the prototype in a way so that the children weren't distracted from their primary exercise of describing and discussing the cards' contents.

4.3 Description of story sequencing cards

In the sessions in Italy, the therapists chose to use the story sequencing cards with the children. The space on the table was populated by sets of story sequencing cards distributed randomly. It was observed that the therapists easily adapted the use of the prototype to the children's specific needs. The children were highly engaged in this ordering and description activity. Usually, the children have personal notebooks where they transcribe the description of the story sequencing cards to be further elaborated upon. The therapists used the prototype and the personal notebook to engage the children in a comparison activity between the audio of the sequencing card story recorded by the prototype and the written version of the story on the children's notebook. This activity shows interesting use of the prototype, flexibility and easily supports educator's appropriation.

In many cases, the prototype allowed therapists to easily control the pace of the educational activity. The therapists appreciated the opportunity to interrupt and restart the activity to permit the children to elaborate on their tasks better. In many cases, this took the form of the prototype being removed as soon a problem occurred or if the children did not accomplish the educational task correctly. All the therapists used the situated audio recording of the children's own voices to enhance their re-engagement in elaborating upon the description of the story. For example, a therapist said, "*I asked you to describe how the child on the bench feels, but you did not describe it … let's listen again to what you said*". All the therapists found that the children's own voices were a key factor in the reinforcement and re-elaboration of the educational tasks. In this manner, our prototype was recognized as an effective tool for the therapists to "tune" and control the flow and pace of the educational activity during each sessions.

4.4 Description of flashcards

The sessions held in Scotland were conducted in a different environment to those in Italy. The sessions were held in a shared classroom environment, where the educator supervised several students at the same time in addition to the participant (Figure 5). This resulted in moderate levels of background noise and distributed personal attention given by the educators. The educator chose to use flashcards in their task with the student.

The results of the sessions differ according to the participant's degree of functioning. We observed that the MF participant did not engage with the prototype, and the session has issues with the audio quality in the noisy environment. According to our interview data and video analysis, the prototype failed to support learning objectives and child engagement. This may be due to the participant's MF as our design was intended for HF, or to the age of the subject (17). Their age may also have been a factor in their lack of engagement, as our design was intended for a lower age range.

By contrast, the HF participant engaged more readily with the prototype, understood it well by the session's end according to the educator, and even spontaneously explored it when the educator's attention was briefly focusing on other children. These different results may have been a consequence of the participant's high degree of functioning, which falls closer to the prototype's target demographic of

HF children. While the prototype's audio quality wasn't optimal for the environment, its user experience was a point of interest for the HF participant and helped them become more engaged. Additionally, the educator considered it useful that they could control the pace of the exercise. Finally, the therapist pointed out an additional use of the prototype; that it could be applied to written text rather than just pictures in order to augment language development. This additional use of the tool only become emergent upon this study, highlights the tool's flexibility across a range of contexts and uses, and can inform future design choices.

Figure 5 Use of the flashcards

5 DISCUSSION

The study investigates the roles in which audio-augmented paper drawing can be used for support, educational interventions for children with ASD, and the benefits it can bring to children and therapists. Humans have a well-known rich and complex repertoire of physical actions with physical objects. According to Tomasello [32], the actions of passing, grasping and sharing objects emerge very early in the development of children's cultural background. This ties into the unique characteristic of tangible interfaces, as identified by Ihsii [17], of being able to link computational power with a physical object. We employed a progressive design method based on a dynamic process that merges concept generation, technology benchmarking, and activity design into continuously enriching actions. We set our initial goal to design an audio-augmented paper drawing interactive environment based on a tangible user interface to support and mediate collocated cooperative activities for therapists and children. The *ReduCat* environment was intended to stimulate the interplay between social exchanges in a given context coupled with the properties of digital artefacts [33]. Additionally, it was designed with the idea that our tangible interface could foster not only physical manipulation, but also the possibility of being shared and passed among people in an immediate social setting [35].

We were interested to see how the use of *ReduCat* would help children, with the support of therapists, to create narratives of paper social stories. The system was effectively utilised to describe stories and augment the sheets of paper drawings employed during the educative activities with the children's' voices. The children were engaged and amused by the opportunity to record their own voice and listen to the playback. The three main qualities of our system are detailed below.

5.1 Exploring the qualities of children's written and oral narrative

We aimed to augment social stories with audio narrations without the necessity of writing the story on the paper, although writing may still be a possibility if needed. Our *ReduCat* environment enables the therapists and the children to engage in a situated verbal comparison with the contents of written stories. Therapists asked the children to compare the children's own voice with the written stories in their notebook after the audio recording, catching tones of the story and enriching or revising the narration. The system stimulated children's attention in listening tasks. The therapist can use the children's' voice to reinforce the children's awareness of their own answers. In this sense, *ReduCat* functions as a useful tool of comparison between writing styles and oral narration educational tasks. The system supported educational activities that stress the difference between written and oral narratives, and could highlight emotional states and creative discourse. One significant result of this work is that hearing children's voices serves as an incentive to children's attention, which would not be possible with a typical, unaugmented sheet of paper drawings.

5.2 Framing children's attention

The *ReduCat* prototype was used to support the therapists in engaging the children. This aspect was considered interesting and important by the therapists and stakeholders. The *ReduCat* system supported the therapists in holding the attention of HF children. Therapists employed the prototype to fixate the children's attention on the educational activity. Additionally, therapists reported that the prototype was useful for understanding the children's attention on the educational tasks. If the children displayed too much focus on the *ReduCat* prototype itself, this meant to therapists that the children were less focused on the educational tasks. In Vygotsky's perspective of cultural tools [34], our system became a tool that not only supported the therapists, but also empowered the children during educational activities, making the children active participants in the educational activity. Social story cards, problem-solving cards, flashcards, sheets, notebooks and the *ReduCat* prototype became tools to create opportunities that allowed children to participate in the educational activities. With the ReduCat prototype, the therapist and the child could undertake cooperative actions and thus achieve a goal together. Therapists could achieve rehabilitative goals through collaboration with the child, by explaining the functionalities of the prototype and then letting them use it autonomously in determined educational tasks. The ReduCat prototype supported the children in being a protagonist of these actions in collaboration with the therapists, creating opportunities for reciprocal exchange.

During the design process and demonstrations to the stakeholders, it emerged that the length of the higher audio message could be a limitation on the prototype for intended educational activities. Surprisingly, we saw that the brevity of the audio message was perceived as a quality by the therapists for the children's focus. The children were cooperative and focused and they did not diverge as usual. The children's frequent free thinking "escapes" were limited by both the length of the recording messages constrained by the prototype and the children's developing awareness of the length of the message. The focus on description was fostered by the audio length, making the child maintain attention for the important parts of the descriptions.

5.3 Supporting therapist appropriation and child differences

The interface of the *ReduCat* environment was deliberately designed with a simple and flexible user interaction model. The use of the paper, and the simple shape of the tool facilitated the use and understanding of the prototype for HF children. The benefit of a simple design model of interaction was also discussed in Keay-Bright and Howarth [20]. The simplicity and flexibility enabled the therapist to appropriate the environment and have high control and opportunity in adapting to the needs of HF children.

Our design was thought to support a wide number of different uses and to support integration with various rehabilitation centres. The system was flexible and simple enough to understand and to enable therapists to use various tools such as custom drawings on blank paper, pre-printed flashcards, pre-printed social problem solving cards, and story sequencing cards. Moreover, paper in a variety of sizes, shapes, and colours could be used with the *ReduCat* prototype.

6 CONCLUSION AND FUTURE WORKS

Our prototype meets our design objectives and suggests a stimulating line of investigation for the benefits it might bring to rehabilitative or educational interventions. Our *ReduCat* prototype demonstrated the potential to be a highly flexible tool that therapists can easily appropriate. A more formal evaluation along the dimensions discussed in this paper is planned in the near future, as well as the implementation of new prototype functionalities.

7 ACKNOWLEDGMENTS

We would like to thank the children, their families and the therapists of the educational centres. In particular we would like to thank the Istituto di Riabilitazione S. Stefano Filottrano (AN) in Italy; and the Fairview School, Perth, and Kings Park School, Dundee, in Scotland.

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