Participatory Design of Technology for Inclusive Education: A Case Study

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Abstract. Regular school must be for all, and technologies used in educational activities should match the learning and development potential of each student, as well as the possibilities of teachers to insert these technologies into educational activities. However, not all technologies promote inclusive learning and teaching. Tangible User Interfaces (TUIs) promote sensory engagement involving various senses. TUIs can provide more accessibility for users and thus be powerful tools to promote inclusive education. This paper investigates the hypothesis that Participatory Design with inclusive education teachers facilitates the creation of technology for inclusion in the classroom. We report on a series of Participatory Design activities, and illustrate and discuss how these resulted in the creation of a technology that is relevant in the situated context of inclusive schools in a Brazilian municipality. The design process can be described as a process of mutual learning, also contributing to continuous in-service training of the teachers. A preliminary prototype evaluation indicates that the created technology can be adopted by involved teachers and students.

Keywords: Inclusive education · Participatory design · Tangible user interfaces · Makey Makey®

1 Introduction

Regular school must be for all, and consequently, materials and technologies used in educational activities should match the learning and development potential of each student, as well as the possibilities teachers have to insert these resources in their daily activities. Materials such as paper notebooks, books, games, communication boards, pencil grips, magniers or switch inputs are well-known examples

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of technologies that have been incorporated into school activities and that promote the participation of students who listen, see, move, think, act and bond in different ways. A look at scientific literature reveals ongoing research efforts for new technological artifacts to promote the development of the human condition and the construction of knowledge in the school.

A growing body of literature describes the development of new technologies that can be used by students with different cognitive, motor, sensor, psychological and social characteristics (e.g. [3,4,15]). Of the different technologies used in research within the context of education, Tangible User Interfaces (TUIs) stand out for two reasons. When inserted into the user's environment, TUIs promote sensory engagement involving various senses. According to Zuckerman et al. TUIs can provide more accessibility for users [17]. Thus, TUIs can be powerful tools to promote inclusive education.

However, not all technologies promote inclusive learning and teaching. Many technologies have been created for a specific special need or a specific activity, e.g., teaching traffic rules to students with visual or hearing impairment. Within the context of the classroom, it is not feasible to create artifacts for each combination of educational content and singular student characteristics. Furthermore, creating artifacts targeted at the needs of some might result in segregation of these students, since their activities in the classroom become individual and different from those of their classmates. Finally, teachers might feel reluctant to use unfamiliar technology they do not dominate completely.

In a context in which the teacher acts in a way that students feel challenged and continue to follow their different learning paths, the hypothesis of this paper is that the participation of inclusive education specialists during the process of design, development and evaluation facilitates the creation of differentiated and comprehensive materials and technologies that consider the individual characteristics of students, promoting their inclusion in the classroom.

To evaluate our hypothesis, we conducted a Participatory Design process to create a tangible technology that has the potential to promote inclusive education in regular schools, to the greatest possible extent, independent of cognitive, sensorial, physical or social characteristics of students. The tangible technology is based on Makey Makey®[1], a platform that permits creating TUIs without requiring advanced knowledge or skills in programming or making. The design process was conducted in a collaboration between researchers at the University of Campinas (Unicamp) and inclusive education professionals of the city of Amparo in São Paulo state, Brazil. In this paper, we present a case study of this design process.

The objective of this work is to evaluate how Participatory Design activities involving teachers, students and researchers can result in the creation of more accessible and relevant technologies that can be used by different students in regular school in a variety of different situations.

The remainder of this paper is structured as follows. Section 2 presents inclusive education in Brazil and in the municipality where this study was conducted.

[1] http://makeymakey.com/about/.

Section 3 presents related work. Sections 4 and 5 present the method used and the results obtained. Section 6 discusses our findings, Sect. 7 concludes.

2 Inclusive Education in Brazil and in the Municipality of Amparo

The Specialized Educational Service (SES; from the Brazilian-Portuguese "Atendimento Educacional Especializado (AEE), literally "specialized educational attendance") "identifies, elaborates and organizes pedagogic and accessibility resources that eliminate barriers to the full participation of students, considering their specific needs" ([1]; translation by the authors). The SES complements or supplements the formation of students, aiming at their autonomy in and outside of school, constituting a mandatory offering of the Brazilian school system. SES is different from school reinforcement, tutoring or other assistive services. It has particular functions of special education that are neither targeted at substituting regular classes nor at adapting curricula, activities or performance evaluations.

SES attends students that live situations of:

- **Disability:** students with long term impairments of a physical, intellectual or sensorial nature which might obstruct or impede full and effective participation in society due to barriers society imposes when these students interact in equal conditions with others [12].
- **Autism Spectrum Disorder:** students with alterations in neuropsychomotor development that affect social relationships or communication, or that result in repetitive, restricted patterns of behavior. This includes students with diagnoses of autism, Asperger syndrome, Rett syndrome, childhood disintegrative disorder and pervasive developmental disorder not otherwise specified [1].
- **Intellectual Giftedness:** these students must have the opportunity to participate in activities developed in collaborations between the students' schools and higher education institutions and institutes that develop and promote research, arts, sports, etc.

An SES teacher works to support the development of these students:

- providing teaching of languages and specific codes for communication and signing,
- offering contemporary technologies to promote accessibility,
- adapting and producing didactic materials, considering students' specific needs,
- facilitating curriculum enrichment for students living situations of intellectual giftedness.

This research was developed in collaboration with the municipality of Amparo, situated in the interior of the state of São Paulo, Brazil. Within the municipality, studies about inclusive education were initiated in 2001. In 2006, the program “Education has many faces – educating and learning in diversity” (from Brazilian Portuguese: “A Educação tem muitas faces – educando e aprendendo na diversidade”). The objective of this program is to guarantee to all students the right to high-quality access and permanency in public schools of the municipality. Since then, the professionals of the municipality strived to align their work with the Brazilian National Policy of Special Education within the Inclusive Perspective [1].

Over the years, four so-called “rooms with multifunctional resources” have been implanted. Four SES teachers attend the target audience of all schools within the municipality in these rooms equipped with pedagogic and accessible materials. The target audience includes students in preschool and primary school. To attend all students in their respective schools and thus provide a higher quality SES, with teachers able to more effectively articulate actions to promote accessibility and inclusion, the municipality plans to build these rooms in all schools, starting in 2018. More rooms with multifunctional resources enables the SES teachers to conduct more research and acquire, adapt or produce materials that promote accessibility. Although the municipality identified the need to expand the SES offering, all students in the program already have access to an SES close to what was proposed by the aforementioned special education policy [1].

3 Related Work

Technology is increasingly used to support teachers and students in the teaching and learning process. One of these technologies is the TUI, which has gained prominence in showing itself more and more present in the school environment, providing new means for acquiring knowledge and even for the inclusion of children and adolescents in the school environment.

As an example, Leong and Horn developed a TUI, called BEAM (Balancing Equations by Adapting Manipulatives), to assist primary school students in teaching mathematical concepts such as equality, multiplication and order of operation [8].

Another work using TUI in education consists of the Combinatorix application, created by Schneider et al., whose main objective was collaborative learning of probability and combinatorics by high school students. By using tangible tokens on an interactive table, the students could learn through presentation of effects and graphics on the table when making combinations between different tokens [14].

Cuendet et al. used a system based on a TUI, called TapaCarp to help train carpenter apprentices. In order to be integrated into the pedagogical practices of the school, TapaCarp was designed in a participatory way with carpentry teachers and apprentices [2].

Regarding inclusive education, Starcic et al. targeted students of a regular class including thoses with learning difficulties and low motor coordination.

The developed TUI helped these students to design geometric shapes. The students, through the manipulation of physical tokens on a table, could draw geometric shapes, which were identified and presented on a monitor [15].

Jafri et al. developed a TUI-based software solution for visually impaired children, to teach tactical shape perception and spatial awareness sub-concepts in small-scale space. The solution was comprised of 3D printed geometric objects used as tangible tokens, a tangible tracking system, and a spatial application. The spatial application was developed to enable the child to learn by manipulating the 3D printed objects [7].

Another example of an application in the context of inclusive education was presented by Hamidi et al. [4]. In this study the authors aimed at a group of students from a classroom who did not use or rarely used verbal communication. Thus, these authors developed a tangible communication board, to allow these students to communicate with their teachers by touching the board.

Lin and Chang showed how tangible interfaces can be used to motivate students to perform certain tasks [9]. The authors developed a system – using Makey Makey® as a base technology for their development – to increase the level of motivation of children with cerebral palsy in performing physical activities. In this work, students should challenge themselves to trigger a stick positioned in front of them, which then generated an animation on a TV.

Using the Sphero[2] as a tangible device, the researchers Oliveira et al. focused on creating games that use a ball as the main object of the game, such as football or bowling. Using a user-centered design approach, this study presented a game for people with cerebral palsy [11].

Analyzing these works, we realized that they were designed for a specific need and predefined activity, for example, to help children with cerebral palsy in the performance of a certain physical activity. This factor limits the use of such technologies in the inclusive school, because in this teaching context, teachers work with different pedagogical contents and in a process in which they must consider the development and learning possibilities of all students. This would require a considerable number of TUIs in the school environment.

Considering the principles of Design for All [16], and based on ergonomic principles, Goya et al. proposed the development of a gamepad with more accessible design that could be used by different people with diverse capabilities and limitations [3]. The authors developed a fixed device that was fixed to the user's legs, allowing people with different motor conditions to use the tool. Analyzing the work of Goya et al., a limitation regarding the device's use in games-related activities is its small number of commands.

In the scientific literature about the production of more accessible technologies to be used by different students in inclusive schools, the works where teachers participated in the process of creation and development of TUIs (e.g. [2]) did not make clear how this participation occurred. In an interview with the participants of our research, a teacher stated that "*often the technology may even be helping the student in his development, but the teacher does not have the knowledge*

[2] http://www.sphero.com/sphero.

or ability to use it, which causes its no-use". The consideration made by this teacher alerted us to the fact that the process of creating and developing a new technology to be used in the inclusive school can be facilitated if built on a Participatory Design dynamics [10] with teachers and researchers working together to design the technology, thus allowing stakeholders to know, understand, use and, above all, to appropriate the newly created technology.

4 Method

Based on the principles of Universal Design [16] and using methods and techniques of Participatory Design [10], we conducted a series of one to two-hour workshops, following an iterative design process consisting of the phases understand, study, design, build, and evaluate [6]. The eight workshop participants included two Human-Computer Interaction researchers of Unicamp, four inclusive education teachers, a coordinator of the inclusive education program of the city of Amparo, and a pedagogic advisor.

These eight participants participated in the process from its beginning including the design, construction and evaluation of the created technology. Furthermore, at the time of writing this paper, one student who participates in the SES program acted as the evaluator of a functional prototype. The participation of this student, as well as others in the future, is essential, since teachers and students, as part of the regular school, will make use of the constructed technology. Thus, the design of the technology needs to consider the challenging trajectories of students and the problems they face during each school day.

Participatory Design ideally gives a voice to all stakeholders impacted by a design and design decisions, and results in technologies that make sense to the stakeholders and are relevant to its users. In our case, this means that the created technology must contribute to the work teachers develop with students in regular schools. Furthermore, teachers should be able to appropriate the technology for their individual practices to provide a better teaching and learning quality.

Giving a voice to stakeholders in this work is manifested by its multi-authorship. Two authors are HCI researchers and two authors represent the stakeholders within the municipality of Amparo. This paper talks in multiple voices: each author contributed with text content besides commentary and suggestions, and we avoided to homogenize the writing style to make the multiple voices more explicit.

In the following, we describe the main stakeholders, the data collection and interpretation, as well as the design process.

4.1 Stakeholders

In the context of the SES, stakeholders comprise all people directly or indirectly involved in the development of a child as a student and citizen: the very student affected by the developed technology, SES teachers, teachers in the regular classroom, school faculty, parents, and relatives.

In this work, we involved two stakeholder groups: SES teachers and students who participate in the SES program. SES teachers are directly involved in the search and creation of technologies that highlight the abilities of a given student to permit this student to conduct scholarly activities. Students are directly affected by the technology use. Respecting the characteristics of each student, the participants of the design process decided together to include students only as evaluators in this stage of the design, potentially giving them less voice than a codesigner, but allowing them to participate in the process of improving the designed technology.

Teachers of regular classrooms participated as informants, discussing during interviews how the developed technology might be inserted into teaching and learning activities and what might be limitations. Furthermore, some teachers participated in a workshop during which we explained the concept of TUIs and elaborated with them practical examples of how to use TUIs in the regular classroom.

Parents did not directly participate. We explained the research project to the parents of the participating student and that it was approved by Unicamp's Ethics Committee; and they signed a consent form authorizing the participation of the student.

The levels of participation of each stakeholder group reflects the levels of participation already present in the SES program in the municipality of Amparo. Usually, SES teachers design (non-computerized) technologies, and evaluate them with students and teachers of regular classes.

4.2 Data Collection and Interpretation

Collected data were qualitative data, and included observations of workshop activities, interviews, informal conversations, and posters and other written material created during workshops. These data were captured by video recordings and manual annotations. Additional data included prototypes created during and between workshops. Videos were transcribed by one of the HCI researchers after each workshop. Some written material was created to facilitate data interpretation by promoting clarity and succinctness compared to sometimes parallel and imprecise oral communication.

The interpretation of video transcriptions and material created during the workshops was done by the HCI researcher for practical reasons: all participatory activities occurred during working hours of the education professionals, and it was thus deemed infeasible to schedule additional time for participatory interpretation. However, all interpretations were synthesized and then discussed among participants.

4.3 Design Process

We conducted a series of participatory one to two-hour workshops with the participants available at each time, and some activities between workshops. During the activities between workshops, only the HCI researchers participated. These activities included mostly follow-up and preparation of workshops, but also some design activities. The whole design process had a research objective, a practical objective, and an educational objective. The research objective, pursued by the HCI researchers, was to evaluate whether and how the Participatory Design activities might result in the creation of more accessible and relevant technologies. The practical objective, pursued by all participants, was to create a new technology that might be used within the context of SES or regular teaching and learning activities. The educational objective, pursued by the education professionals, was to contribute to the continuous in-service training of the participating teachers.

Before planning the design process, the HCI researchers made some exploratory visits to different schools in Amparo to better understand the SES program, how the SES teachers work, what activities they conduct and what materials and technologies they use. During these initial visits, all participants gained an initial understanding of each other's practices and objectives. These understandings evolved continuously throughout the process.

The scheduling of the workshops and other activities was mostly defined by the availability of the participating teachers. Activities that involved all eight primary participants occurred usually monthly, during one of the teachers fortnightly Friday encounters at one of the participating teachers' school. The workshops usually started after the coffee break that marked the end of the encounters among teachers, program coordinator and advisor. The content of the activities was planned by the two HCI researchers, to be better aligned with the research objectives and since the other participants had no experience in planning a Participatory Design process.

The sequence of activities followed an iterative process with the phases understand, study, design, build, and evaluate [6], whereas most iterations of the "study" and "build" phase and few iterations of the "design" phase were conducted by only the HCI researchers. Employed techniques included braindrawing, interviews, group discussions, scenario writing, storytelling, and the Wizard of Oz technique. Although the HCI researchers defined which methods to use, we tried to choose simple and accessible methods, often using materials that were already available at the respective school.

Explaining the Design Space. To explain to the participating education professionals what is a TUI, we initially conducted three encounters during which we explored three TUI prototypes created by one of the HCI researchers: the communication board, the tangible vest, and the "ludic carpet" (Fig. 1). These TUIs were inspired by activities and materials the researchers observed during the exploratory visits. The TUIs replicated or extended non-computational technologies already used by the SES teachers, and might be used during activities such as storytelling about daily routine.

During these three encounters, the SES teachers acted only as evaluators of the TUIs. Since they did not have any previous contact with TUIs, an objective of these encounters was to permit them to get familiar with this technology and get

Fig. 1. Low-fidelity prototypes presented during the first workshops.

a first impression of how it might be used for the SES. The HCI researchers tried to show diverse possibilities grounded in the teachers' existing practices, as well as to "break the ice" for future encounters. To this end, the prototypes were built with low-tech material such as cardboard, cloth, Velcro® and Styrofoam®. As hardware platform, we used Makey Makey®, and as software platform Scratch. A preoccupation of the HCI researchers was to create prototypes that did not focus on a disability but that were usable by students with diverse abilities.

We discussed the prototypes' potential to reduce barriers the students that frequent the SES program experienced in school. Although we conducted no formal evaluation, the HCI researchers tried to explore by guided questions to what extent the prototypes were accessible to students with different needs, and how the prototypes might be improved to better adapt to the teachers' practices and the students' needs.

Participatory Workshops for Designing a Tangible Technology. During the first encounters, some important aspects of design had already been uncovered and discussed. The technology should support the student in communication without negatively affecting other activities. It had become clear the high-level guiding ideals for design had to include:

- autonomy of the student, i.e. the student should be able to use the technology without requiring assistance of an additional intermediary between student and teacher; and
- conscious use of the environment, i.e. the technology should be able to be inserted into reality of the classroom with its furniture including tables that already contain other school supplies.

The following workshops initiated the creative process of thinking about and creating this technology. During the first workshop, the HCI researchers asked the participating teachers to “dream up” tangible technologies that considered the individual students each teacher worked with. In previous activities not reported in this paper we had perceived that during creative group techniques such as brainwriting, the teachers often put ideas on paper that already appeared previously. To get more diverse ideas, we thus opted to ask each teacher to individually create their ideas, either in writing or in drawing.

At the next workshop, we discussed the ideas presented during the previous workshop more formally, asking the SES teachers to prioritize strong and weak points regarding their application to inclusive education. Subsequently we created a joint proposal together with all participants and conducted a braindrawing session to materialize the ideas in graphic form.

One HCI researcher then created a non-functional cardboard prototype of a physical input device, and the HCI researchers and an SES teacher evaluated whether the prototype dimensions were compatible with the students’ chairs and tables, and whether they could be easily adapted to be used ergonomically by different students. To this end, we visited preschool and elementary school classes during class-time attended by two different SES students and asked them to use the physical controls of the prototype.

During the following workshop, we evaluated how the technology might be inserted into teaching activities in the regular classroom. To this end, one HCI researcher created an architectural cardboard model of a classroom with movable pieces, and a miniature table, a computer screen, tablet, speaker boxes and a representation of the device to be designed. The SES teachers then discussed different configurations of the device, possible accessories, and how these could be used in the classroom, including the physical location as well as class dynamics.

In the subsequent workshop, we employed an enactment technique with a prototype of the physical input device and paper cutouts to discuss how the technology might be inserted into the classroom and to understand how a student might interact with it. For the enactment, we used mathematics as an example school subject and an activity adapted from an activity one of the SES teachers already conducted using pen and paper. One SES teacher acted as teacher, the other as student.

To gather more requirements for the accompanying application to create activities to be used with the physical device, we conducted another braindrawing session, in which in each iteration, each participant moved to the next table that contained an evolving drawing of an activity within the context of a specific school subject (mathematics, Portuguese, arts, music, history, geography, science and physical education). The objective of specifying school subjects was to cover different dynamics in class.

To evaluate whether the functional prototype could be employed during real activities in the classroom, we conducted an evaluation with one of the SES teachers and one of her students. The student was six years old, had cerebral palsy, was a wheelchair users with limited upper limb mobility, did not communicate orally, but could express herself with facial and body expressions. The informal evaluation consisted in two steps. First, teacher and student used the prototype in an activity that resembled an activity the two usually conducted using a desktop computer and a mouse switch (the student was not able to use the mouse, but could press a mouse switch; the mouse pointer was placed by the teacher). One HCI researcher acted as facilitator, the other as observer, and the activity took 15 min. Immediately after, the HCI researchers and the teacher discussed the activity.

5 Results

After the first activities during the exploratory visits, the SES teachers commented that "*the way the application was presented, it is only a different form of conducting the activity, not being any different [from the existing techniques] and not bringing any advantages*". They also put forth the question of "*how could we improve [these applications] so that the children can use them?*" The pedagogic advisor asked the teachers "*What would you need to produce this material in accordance with [the needs of] your students? Thinking about producing an actual [functional] technology. If you would like to change the content of [the prototype], what would you have to do?*" (Fig. 2).

Fig. 2. Teachers and an HCI researcher discussing a TUI prototype.

We interpreted these manifestations as evidence that the participants understood the concept of TUIs and saw their potential for inclusive education. These and similar comments also marked the point of SES teachers beginning to effectively act as codesigners.

During the ideation activity, the SES teachers presented the following ideas: a table with physical buttons and a tablet, a pedalboard for interaction using the feet, a wall-mounted device with sensors to communicate with gaze and eye movement, and an application "*with animations, since the student feels more interested by activities that have animations*". In a subsequent activity, the ideas were discussed and their main elements prioritized. The consensus of prioritizing ideas and elements was that the technology to be designed should involve a tabletop with buttons and a pedalboard below the table, to permit use by students with different abilities and preferences. Furthermore, applications controlled by these physical input devices should make use of animations. Based on these ideas we conducted a braindrawing session to externalize the participants' different ideas (Fig. 3).

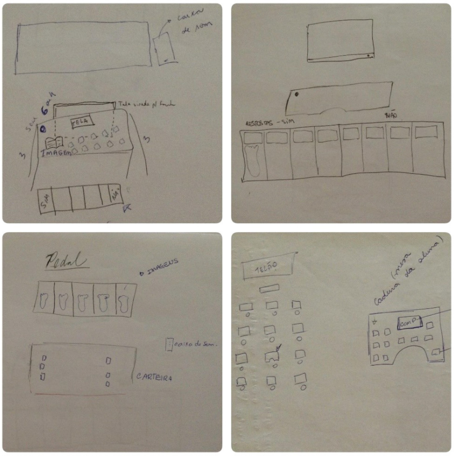

Fig. 3. Different ideas for the tabletop and pedalboard, generated during a braindrawing session.

The subsequent activities with cardboard prototypes and architectural models clarified details about the physical and spatial configuration of the physical input devices and additional accessories. For example, ideas such as additional screens or tablets, a projector as well as speaker boxes, mounted in different locations in the classroom, were discussed with respect to aspects such as the possibility to facilitate the communication between the students using the technology and the rest of the classroom. The SES teachers participated differently in these activities: two involved themselves actively, interacting with the prototypes, the other two preferred to only contribute to the discussions. In the end, we decided to have a small number of buttons on the tabletop as well as the pedal board, a laptop on the table, since this is already used in the classroom, as well as a projector to share contents with teachers and students.

The first high-fidelity prototype had five buttons on the tabletop, and five on the pedalboard, following a suggestion of the teachers to be able to work with digits from zero to nine. A discussion revealed that five pedals would be difficult to use for many students, and that four pedals would be easier to use and sufficient for many activities. The physical design of the tabletop buttons was also revised to facilitate the use by students with less physical strength. Together with the physical prototype we discussed some initial ideas about the accompanying applications. Important points included the limited internet access in some schools, as well as general metaphors of an activity list, and whether this should be organized by school subject, by author, or by students' abilities.

The main result of the activity including the three teachers of inclusive classrooms was that the two groups could create a low-fidelity prototype of a TUI to be used in the classroom within only 30 min, after only having been exposed to the concept of a TUI for less than one hour. The two proposals used physical arrows to navigate within an application. This indicated to us, that technologies such as the one described in this paper make sense and are relevant in the classroom, and that teachers might be able to appropriate this kind of technology for their own teaching activities.

Although we tried to encourage some diversity in the braindrawing session for generating ideas for the application for creating and organizing activities by specifying different school subjects on each station, we observed that most participants only replicated their ideas when arriving at the next table. The main aspects of the application that emerged were the use of different media to be able to work in different contexts, i.e. videos in sign language, sounds for visually impaired students, and images. This result indicated, that although the SES teachers already could imagine how to use the designed technology, they still had difficulties imagining the creation of own content.

After activities and workshops spanning one year, the ideas had converged towards an "interactive table" with five buttons on the tabletop and a pedalboard with four pedals to be put under the table. Figure 4 shows an earlier version of the prototype, with a higher fidelity tabletop and a low-fidelity pedalboard, still with five pedals. In the prototype of the proposed technology, tabletop and pedalboard are connected to a laptop computer, which would be available at each school of the participating teachers. The reasoning behind designing a technology with buttons and pedals was that some of the students that frequent the SES program have limited or no mobility in the upper limbs while others have limited or no mobility in the lower limbs. For the teachers, it was important that the designed technology could support students in their development, providing challenges that stimulate the advance of abilities during school activities.

During the evaluation (Fig. 5), we used only the tabletop part of the prototype, since the student was a wheelchair user. In comparison to Fig. 4, the prototype had already evolved and included different buttons to be accessible to students with less strength and coordination in arms and hands. The activity consisted in matching animal drawings. In the center of a screen, the animal to be matched was presented, for example a lion. Below, two smaller drawings were presented, one of the matching animal and one of a different animal, in varying order.

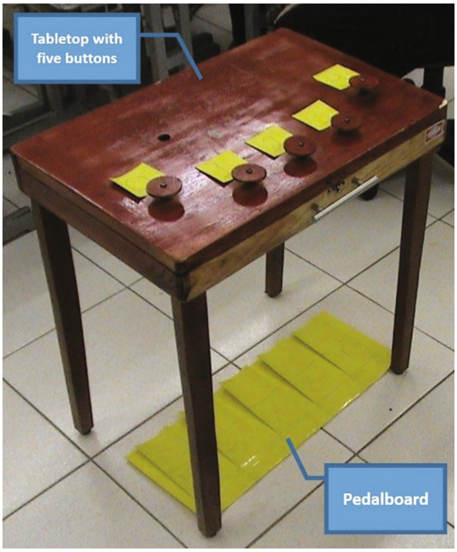

Fig. 4. Iteration of the prototype of the proposed technology.

Fig. 5. Prototype evaluation with an SES teacher and one of her students.

The student was motivated, and despite her limited mobility and the fact that the prototype was configured to also use the buttons closest to her, she made efforts to reach the farthest ones. When the teacher explained that she could also use a closer button, she made clear that she wanted to use the farther button using an unmistakable facial expression. This and other behaviors that showed the efforts of the student and thus hinted at the potential of the technology promoting the development of the student, was commented by the teacher as very gratifying.

In the follow-up discussion with the teacher, the main positive point she mentioned was the autonomy the student gained in comparison to the similar activity were the teacher placed the mouse pointer and the student pressed the switch: "*She felt comfortable, acted alone. She had freedom. The autonomy and possibility of choice allowed [...] was rich*".

The teacher also contemplated the use of the prototype in the regular classroom, believing that "*it will make life easier in the classroom*". Besides the benefits for the student, the SES teacher recognized benefits for the teachers in the classroom: "*[The prototype] will give more options to the teacher, for example, she will be able to work with syllables, words, and others*".

6 Discussion

In this section, we discuss three main themes that are related to the three objectives of this work: we first discuss mutual learning along the process, which is related to the research objective (evaluate the Participatory Design process) and the educational objective (continuous in-service training), then reflect on the Participatory Design process, and finally on the design of the prototype.

For researchers and designers that do not have a profound knowledge about areas such as inclusive design and programs such as SES, Participatory Design is essential to understand the context in which research and design are inserted, and to design a product or service that is relevant to the target community. The same can be said about the participating teachers. At first, they had little knowledge about TUIs and processes of design. Participatory Design enabled the teachers to learn about these topics and to thus contribute effectively as codesigners within the project.

This mutual learning process was implicit and did not require formal training; it occurred along the process by sharing questions, doubts, preoccupations or proposals among equals, avoiding hierarchy, supervision or judgment that could stifle participation. In each subsequent activity, all participants felt more "in control". We consider mentioning this important, since when the researchers initially participated as facilitators and observers, the SES teachers felt more inhibited. To give an example, we quote one of the teachers: "*At the beginning, when you [the researchers] arrived, I didn't understand your language. I couldn't imagine anything [...]. But this process of construction was very good.*" Regarding the design process, mutual learning was probably facilitated by explicitly including moments for "understanding".

At some moment, the teachers might have had the preconception that their acts and ideas were being judged by the researchers. Another fact that might have contributed to feeling inhibited is that the researchers were experts in digital and tangible technology. The teachers might have believed that, by extension, the researchers were also experts in tangible technology *for inclusive education.* On the contrary, the researchers were experts only in digital and tangible technology, while the teachers were experts in inclusive education. The purpose of conducting Participatory Design was to join these different kinds of expertise.

The experience of creating a new technology together with researchers might also contribute to revise the existing processes of continuous in-service training of teachers, to avoid hierarchizing knowledge and practice. Our research provided evidence that some practices tend to inhibit teachers' creative processes, leading them to adopt a behavior that makes them ask their "*superiors*" what they should do when working with students, instead of creating and proposing collaborative and participatory actions.

These reflections show that, like the students, the teachers also require practices that are challenging and promote critical thinking to create and innovate their ways of teaching, abandoning practices that segregate and exclude.

In the previous paragraphs, we discussed mutual learning within the design process. In the following, we briefly discuss other dimensions that characterize this process [5]:

The SES teachers participated in the design process from its outset. Two exceptions are the choice of Makey Makey® as the base technology and the creation of some prototypes by an HCI researcher between participatory workshops. Since this was the first contact of the teachers with the design of a computerized technology, the researchers chose the base technology to start design activities without requiring an extensive pre-evaluation phase of alternatives. Now that the teachers have become more familiar with the possibilities of digital technology within the inclusive school, they should actively participate in the choice of future technologies. In fact, during some ideation activities, one teacher already suggested to investigate the web camera as a tool to increase accessibility to teaching and learning. Some prototypes were created between workshops by an HCI researcher, because the time of the teachers to participate in the project was limited by fortnightly one to two-hour meetings.

During the participatory activities, teachers acted as equals with the same power to influence and take decisions as the researchers. All critical decisions were discussed among the present participants. As described in the previous paragraphs, during some initial activities, the teachers were more guarded, partly possibly because they did not yet know the power they had at the outset of the project, and partly because during some initial activities the researchers participated more as facilitators and observers, thus possibly giving the impression of evaluating and judging the teachers.

Regarding the stance that "people play critical roles in design by being experts in their own lives" [5, p. 89], one could argue that students should have played a more active role in the design process, e.g. by participating as codesigners and not only as informants or testers. We opted for not including children or other stakeholders more actively into the process for the following reasons. The abilities, limits, preferences and needs of the students are so diverse that including a limited number of students would inevitably have missed important points, or put an unduly focus on specific special needs, which might have countered the ideals of Design for All. Furthermore, the participating teachers spent intensive time with different students and can thus be seen as deputy experts.

Finally, involving students only as testers and informants was more faithful to the process the SES teachers used to create materials and activities.

The focus of our work was not to develop a technology applicable in a general variety of educational contexts, but a technology that made sense and was relevant in the concrete context of the participating teachers' schools. To achieve this goal, we had to create a design process that considered the peculiarities of the situated context of SES in the municipality of Amparo. The different involvement of different stakeholders discussed in the previous paragraph is a consequence of these considerations. This was consistent with the teachers' current practice of creating low-tech materials for students they are intimately familiar with. Interestingly, the teachers' practices are well aligned with practices of Design for All in HCI. Hence, the technology was not created for specific "disabilities", but considering every student in the classroom should be able to use it. The new technology designed by the participants is not intended to replace any existing materials and practices, but might enrich the possibilities of access to what is taught and shared during class, supporting both teachers and students.

Although a common guideline for design is to use non-functional low-fidelity prototypes in early stages of design to promote the deconstruction of presented ideas and generation of more diverse new ideas, we believe the use of more functional prototypes in a mid-level fidelity was adequate for this design process, since it helped the participating SES teachers, who were accustomed to traditional desktop or mobile technology, to understand what a TUI-based device might be able to do. With the intention to making them feel more confident and encouraging them to engage in critique with the prototypes we reverted to lower fidelity prototypes during subsequent activities, using materials the SES teachers themselves used in their practices.

Based on the principle that a "disability" is no property of a student but of a technology that inhibits a student to grow, the participatory activities tried to explore how technology might support students in their development without focusing on their "impairments". The participating SES teachers contributed with specific individual knowledge, e.g. one was a specialist for SES with visually impaired students, another for deaf and hard of hearing students. The participatory activities promoted the sharing of these different kinds of knowledge and thus the creation of a technology that supports students' development lowering barriers of access. The development of the technology strived to enable students to leverage their abilities while enabling teachers to challenge students to develop additional abilities. For example, for students not communicating orally, the designed technology permits a different kind of communication, for students who cannot use the hands, the technology permits interaction with the feet.

7 Conclusion

The reports of the teachers and the involvement of the participants in the design, development and evaluation of a new technology showed that this participation benefits the process of inclusion in the classroom of the regular school, since it enables thinking about how to eliminate barriers that prevent students from access to knowledge, the school environment, and the people there.

Our work aimed at creating a technology that makes sense and is relevant within the context of the inclusive classroom. The participatory approach to design has shown its strength: the participating SES teachers knew their students and their needs very well and were thus able to better think about technologies that facilitate the development of students' abilities and learning possibilities. This knowledge promoted the incorporation of the new technology, and thus new practices, within the work of teachers in the regular classroom.

The knowledge construction of the teachers reminds us that, per Piaget [13], the process of knowledge acquisition is driven by imbalance, and occurs when the subject enters into contact with the object of knowledge, then encounters difficulties to assimilate and perform an action on this object, subsequently assimilates new information about the object and finally accommodates this information, thus returning to a state of balance. This process can be called adaptation. Hence we are continually changing, constructing ourselves with the relations between the individual and the environment.

Initially, the researchers explained the concept of TUIs to the other participants by means of different prototypes created based on and inspired by materials already used by the teachers. These prototypes were discussed with respect to their potential to eliminate learning barriers, stimulate inclusive practices, as well as possible limitations. During the subsequent workshops, we conducted Participatory Design activities using techniques such as braindrawing, semi-structured interviews, group discussions, as well as different prototyping techniques.

The technological artifact resulting from the workshops was a tabletop interface with five buttons and a pedalboard with four foot pedals that can be used instead of or additionally to the tabletop interface. Based on the discussions during the workshops as well as on preliminary evaluations in an inclusive kindergarten, an inclusive elementary school class, and during an individual activity involving one student and one teacher, the prototypes have been iteratively refined.

The participants of the design process could gradually construct shared meanings of concepts related to HCI and inclusive education. This process was facilitated by the facts that the practice of creating low-tech material for inclusive education is similar to participatory and inclusive design in HCI, and that Makey Makey® as a platform permits to create physical prototypes and educational activities that have a technological complexity similar to what teachers are already used to.

The workshop and classroom activities showed that the design process resulted in prototypes that make sense in the educational contexts of the participating teachers, and that these prototypes can be used in a variety of different activities as well as by a variety of different students. For example, during an evaluation that replicated an activity in which a student with cerebral palsy previously had used a switch input device, the respective teacher found that the student gained more autonomy, and the teacher more flexibility.

The results of the work presented in this paper provide evidence that Participatory Design together with an adequate technological platform can produce technologies that can be used by a variety of different students in a variety of different situations. Our next steps involve the creation of an application for authoring educational activities to be used with the physical prototypes. Furthermore, it is necessary to investigate the use in different educational situations as well as to what extent teachers can create their own physical prototypes and respective educational activities.

Future work includes activities with students with different abilities who frequent the SES program. Another important question is how teachers in the classroom use the technology and whether they can include it in their existing activities in a relevant way. Since an important goal of the design project is to enable the teachers to use the physical prototype – and possibly other devices they create in the future – during their own scholarly activities, other future work involves the design of an application to create, manage and adapt activities to be executed with physical input devices such as the prototype presented in this paper. Some design goals and concrete requirements could already be elicited during the presented participatory activities, e.g. promoting the development of students' abilities and permitting the use of custom images, sound and videos. This application is instrumental for our long-term goal: facilitating the appropriation of technologies like the one presented in this paper by teachers during their individual daily practices in the inclusive school.

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