Interactive and Open-Ended Sensory Toys: Designing with Therapists and Children for Tangible and Visual Interaction

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ABSTRACT
Treating neurological conditions like cerebral visual impairment (CVI) and related disabilities is a complex challenge where the needs of the affected persons have to be considered individually. It is also commonly agreed that stimulating the body's senses, as part of early intervention programs, is a crucial activity in therapy. With this paper, we add to the literature on how tangible and embodied interaction can facilitate such stimulation of the body and provide engaging experiences for children with (multiple) disabilities. Our report entails a detailed description of a co-design process involving early intervention specialists and affected children over the course of six months and multiple prototype iterations. According to our participants, the strengths of the resulting products or therapeutic toys are their open-endedness and versatile applicability, meeting individual needs and making therapeutic sessions both enriching and fun for the children.

Author Keywords
Therapeutic toys; children; disabilities; CVI; stimulation; body perception; playful approach; design case study.

ACM Classification Keywords
• *Human-centered computing ~ Field studies* • *Human-centered computing ~ Participatory design*

INTRODUCTION
Tangible and embodied interaction can leverage the user experience of many applications, for example, by making controls more intuitive and natural [19]. In this paper, we are interested in tangible interaction as a facilitator of stimulating bodily experiences for children with (multiple) disabilities in order to support developmental and sensory competencies. This interest is justified by (a) the strength of tangible interaction design to address the users' full body in interactive applications and (b) the usefulness of stimulating the body in the management of certain disabilities [10].

The results in this paper stem from a six months design-research endeavor with early intervention specialists (abbreviated as EIS from now on) as co-designers. EIS are social care professionals – often additionally educated in related fields like pedagogy or psychology – trained in supporting children with disabilities. In the context of our research, all children had a form of visual impairment (primarily cerebral visual impairment - CVI), in some cases causing only mild problems, in others having a more severe effect on life. In addition to vision problems, most children suffered from comorbidities like cerebral palsy, which can often be found in individuals with these kinds of vision impairments as both are consequences of neurological damage in related brain regions [6].

The EIS' task of supporting and treating these children is complex, because the children's conditions are manifested through a vast variety of symptoms [6; 17]. Hence, individual treatment plans differ significantly and have to be established on a case-by-case basis. Still, it is commonly agreed upon that interventions should start as early as possible and expose the affected child to appropriate sensory stimuli in order to spur growth, either on a cellular level where new synapses are established or on a personal level to foster developmental competencies [10]. Much of the exercising takes place in a playful age-appropriate manner using (therapeutic) toys in the children's homes.

In this kind of setting, our project was established to co-design novel interactive and therapeutic toys. As we will outline in the following, there was a demand for toys with specific but not yet clearly articulated and implemented affordances. We saw an opportunity for interactive and tangible technology to leverage conventional (therapeutic) toys. Thus, we created our own prototype family of therapeutic and sensory toys that we named BoostBeans.

The paper on hand contributes a detailed description of BoostBeans (see Figure 1 for an overview in advance). It constitutes a design case study providing fellow designers or researchers with firsthand insights into a demanding, however, rewarding design space that, in our opinion, deserves further explorations by the TEI/HCI community.

We are *not* aiming to provide summative evaluations of our products involving metrics for success or failure. Rather, we focus on describing the setting, the process and the motivation of the design decisions. A prior publication of the concept without implementation or evaluation can be found in [5].

We go on to briefly provide further information regarding the needs of the children in the project from a therapeutic perspective and review related TEI/HCI works.

THERAPEUTIC CONTEXT

Early intervention programs as offered in many countries support children with neurological issues starting from the first weeks of life and accompanying the children until about aged six years [10]. Within these programs, the primary objective is to prevent or minimize developmental delays [10]. Since the affected children can have a broad variety of symptoms (as opposed to one clearly circumscribed problem), we go on to describe what these programs aim to accomplish on an *abstract level* in order to support developmental and sensory competencies, applicable for most of the affected children.

In the literature, these abstract goals are summarized as *to improve the children's orientation and mobility*, *to build-up play skills* as well as *to develop daily living skills* [8]. Certainly, in practice, there will be different priorities depending on the care providers' philosophy and, of course, on the children's individual needs. Still, these goals clearly resonate with the approach of the EIS who were involved as co-designers in the research project described in this paper.

To accomplish these objectives, it is essential to provide the children with appropriate experiences, that is, stimuli that are geared towards their specific situation, allowing them to progress at the given point of time. The EIS then need to identify and deliver these appropriate experiences and assess the children's progress by maintaining a lasting relationship. A child generally does not change his or her EIS over the course of the six years of intervention.

In the case of our research project, relevant stimuli were often visual experiences, since all children suffered from a form of visual impairment like CVI [11], as mentioned in the introduction. CVI "is clinically defined as a significant visual dysfunction caused by injury to visual pathways and structures occurring during early perinatal development [… and is associated with] a myriad of visual deficits" [11, p.1]. The motivation of the EIS for engaging with the children with CVI is – besides creating an emotional bond and providing warmth and care – to recover visual function, a motivation which is supported by scientific evidence [3]. To this end, it is crucial to provide the children with sensory experiences to stimulate cellular growth and the wiring-up of new neuronal pathways [3]. Similarly, other conditions and comorbidities like cerebral palsy need stimulation for teaching the body to integrate different sensory inputs [17]. Training hand-eye coordination is an important challenge in both supporting children with CVI and/or cerebral palsy.

Having described the broad project setting from the perspective of the needs of the children, we go on to review related works from TEI/HCI that have addressed similar issues. Here, we focus on playful approaches and games, as our objective was to indeed develop novel interactive toys.

RELATED RESEARCH IN THE TEI/HCI LITERATURE

In this section, we highlight exemplary related work and appreciate their contributions to the TEI/HCI community. We start by describing prototypes with a clearly prescribed intention, that is, objects that were designed to be used in a specific way. In the course of the section, we then move on to report research that enables the user to customize parts of the product in order to meet individual needs.

Linehan et al. [9] and Waddington et al. [23] created a videogame for children, which aimed at mitigating the negative effects of CVI. They engaged in a participatory design process to come up with appropriate and interesting visual stimuli for exercising the visual pathway. While their videogame is not a tangible application, it is one of the rare examples in HCI explicitly targeting CVI.

ChillFish [20], in contrast, is a tangible game controller for a health-related computer game that was presented recently at TEI'16. It was created by Sonne and Jensen [20] in order to explore a videogame-based biofeedback application for children suffering from attention deficit hyperactivity disorder (ADHD). ChillFish is operated by a mouthpiece that can sense the players' respiratory rate. In this way a character in a *jump'n'run*-like videogame is controlled. The game constitutes a relaxing breathing-exercise that should make children with ADHD more focused and concentrated.

PhonoBlocks by Antle et al. [1] is also a typical tangible user interface, but not a game. By means of smart and illuminated letters the product supports children with dyslexia in decoding letters utilizing sound and multicolor LEDs. Kiteracy as proposed by Jadan-Guerrero et al. [7] is based on tangibles as well and aims to support children with Down Syndrome in improving their literacy.

Polipo is a research prototype for improving the motor skills of children's hands, introduced recently at TEI'17 by Tam et al. [21]. While not a toy or game per se, Polipo utilized electronic elements to make this hand-held device more engaging and fun for children when fulfilling exercises for fine motor skills. For example, on completion of a task (e.g., positioning a rotary knob mounted to the Polipo), the device rewarded the children with light animations and prerecorded audio clips. The designers of Polipo were careful to implement a "cause and effect model" in their prototype as well as different means that allowed the therapists to customize the device [21]. They could, for example, mount different knobs or handles on it, and they could copy their own audio files to the Polipo system as customized rewards.

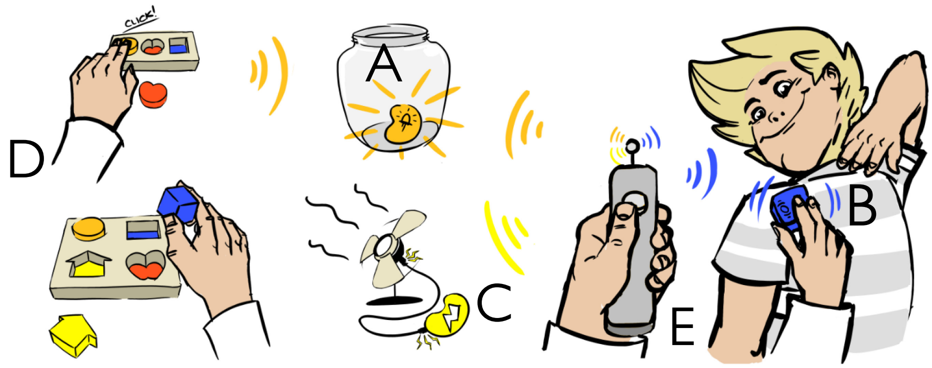

Figure 1. Concept of BoostBeans. The prototype consists of four actuator modules (A: LightBean [in an old jar], B: BuzzerBean, C: PowerBean [with connected fan], and SoundBean [not displayed]) that can be triggered remotely with puzzle remotes (D) or conventional remote controls (E). BoostBeans was designed to be incorporated freely and flexibly into exercises or games, to augment conventional objects and toys, to make exercising more interesting, and most importantly, to address the children's senses.

While the Polipo supported (optional) adaptations, Moraiti et al. [14] created a Do-It-Yourself (DIY) toolkit for occupational therapists which made customization the main feature and a necessity. The motivation of the researchers was to empower therapists to design and create their own tailor-made assistive technologies to be handed to their clients. More specifically, the electronic toolkit enabled the transformation of everyday objects like pillows into tangible interfaces for computer applications such as games.

Verhaegh et al. [22] and Garzotto and Gonella [4] proposed tile-based (board) games for children to support their learning. Both groups of researchers carefully implemented high degrees of adaptability in their tangible applications. While Verhaegh, Fontijn and Hoonhout [22, p.187] supported "fine-grained and wide ranged difficulty levels [... and] address[ed] a range of skills including fine motor skills, cognitive and social skills", Garzotto and Gonella [4] designed their system to be completely open, allowing the users to reprogram or customize all tangible elements.

As evident from previous paragraphs, there is a lot of inspiring research currently being conducted within the TEI/HCI community. We have seen a range of different concepts involving tangible interaction in order to support children with disabilities. We can coarsely divide the reported research prototypes into two groups: devices that have been designed for one particular purpose (e.g., ChillFish [20] to calm children down) and toolkit prototypes that were conceived for customizations (e.g., as proposed by Moraiti, Abeele, Vanroye and Geurts [14] to support occupational therapists).

With the design case study of BoostBeans presented in the next section, we describe a concept that differs from the existing prototypes with respect to customizability, but also regarding tangible interaction design. As we will show, BoostBeans cannot be customized as a device, but the EIS can use it to (re-)frame situations during therapy in custom ways, that is, re-appropriate meaning. For example, our participants utilized it to alter or customize existing objects, and they incorporated it into unguided play activities. In this way, the paper also contributes to discussions about open-endedness and re-appropriation in design (e.g., [15; 16; 18]).

DESIGN CASE STUDY: BOOSTBEANS

BoostBeans were created as part of an applied research project involving four early intervention specialists over a timespan of six months. The project goal was to bring interaction design to therapeutic toys or equipment and to come up with innovative design solutions that can be used to support children with special needs. We found ourselves in the comfortable situation to have no content-related constraints, except that the outcome should be a fully functional interactive and engaging toy or object to be used in therapy. As we will see in the following, not having constraints can, however, also be a challenge as this freedom implies a huge design or solution space.

To tackle the design challenge, we broke it down into three activities (Phase 1-3). Firstly, we familiarized ourselves with the general setting by engaging in observational fieldwork. Secondly, we conducted a number of design workshops with the EIS (e.g., see Figure 2). Eventually, we iteratively prototyped, refined and deployed the final design concept (BoostBeans) in a series of field tests. Figure 1 provides a preview of this concept, but it will also be introduced in the course of this section.

Before we detail these three design phases, we provide some more information about the people who participated in the project and about the recruitment process.

Informants

As stated before, the project involved four EIS. They were recruited through a local special needs organization (partners in the research project) and they received financial remuneration for their efforts. All of the EIS had several years of professional training, and each one had more than ten years of experience in working with disabled children.

The nine children in this design case were affected by CVI and in some cases by additional conditions as described in the Therapeutic Context section. They were recruited by the four EIS. Inclusion criteria for the children were approval by the parents as well as being likely to enjoy the visits of researchers and potentially benefitting from the engagement from a therapeutic perspective. The children or their parents did not receive financial compensation, but the children received free sessions of training. In order not to distract the children or to exhaust them, only one researcher at a time came to the training sessions. All encounters with the children took place in the presence of one or two parents, and all instructions were given by the EIS only. The researcher acted as an observer, taking field notes as unobtrusively as possible, and in rare occasions photos on the approval of the parents. All involved parties, including the researchers, signed a contract. The participants gave their written informed consent, and the researchers guaranteed not to publish any personal information without permission.

During the six months, we visited the homes of nine children and particularly engaged with four of them in the design process (i.e., we visited them multiple times and focused on their needs), because of their suitability and interest as participants. We go on to briefly introduce these four children using pseudonyms.

- Mario is five years old and has a big heart for animals. He regularly meets his horse-friend Henry in hippotherapy. He likes to chat with people and tries to get away from exercising by involving the EIS in a conversation. In addition to low acuity, Mario has particular difficulties in identifying shapes and hand-eye-coordination.
- Monica is six years old. She is always very cheerful, but when she gets frustrated she likes to throw her toys. However, this is not as bad as it might sound. She is happy again in the next second. She has a severe form of cerebral palsy, a cognitive delay and slightly impaired vision.
- Michael is four years old and loves to operate his parents' TV remote control. Switches and buttons are his passion. And he likes to tickle people and being tickled gently. In addition to impaired vision, Michael has a moderate form of cerebral palsy and a cognitive delay.

Figure 2. Snapshot from a design workshop showing several lo-fi props and two of the participating early intervention specialists (abbreviated as EIS in this paper).

- Muhammad is six years old who likes to get people involved in a little chat. His favorite topic is the current weather. Muhammad lives together with his parents and three siblings in a small apartment. Due to increased intracranial pressure, Muhammad suffers from multiple neuronal disabilities like low vision and a general lack of motor-control.

Phase 1: Familiarization with the Setting

Since we, as interaction designers, were not familiar with early intervention with children, we started the project by exposing ourselves to the work environment of the EIS. We began with an investigation of their organization's special needs inventory of therapeutic toys and studied their rooms and additional equipment (waterbeds, light installations, optical assessment instruments, vibrating floor mats, etc.). Then, we accompanied the EIS during their home visits to the children's houses. In this phase, we made a total of fifteen visits, which each lasted between 60 and 90 minutes. We attended three additional sessions, which took place at the rooms of the special needs organization, but usually therapy takes place at the children's homes. Phase 1 lasted about 8 weeks. About four weeks in, we conducted in-depth and semi-structured interviews with the four EIS in order to further capture their work experience and what kind of therapeutic toys they preferred. Moreover, in this phase we talked to twelve additional EIS who worked for the organization and asked them to showcase their favorite toys and equipment for us.

We transcribed the audio recordings of the interviews and analyzed them for salient patterns or observations, which we rendered into a hierarchical mind map. We employed our field notes from the home visits and other observations for the same analysis. Note, the purpose of this analysis was to inform the subsequent design process and not to serve as the foundation for a detailed qualitative research paper. For this reason, we pinned the gathered materials (mind map, notes, photos) clearly visible on the wall of our office as a source for inspiration. We do not provide a detailed analysis of the material as this is out of scope for this design case paper.

Insights from Phase 1 to inform Phase 2

During Phase 1, two facts soon became evident. First, the EIS already possessed a huge stock of conventional and therapeutic toys. Second, the work practices of the EIS were shaped by permanent improvisations to respond to changing situations, all for the good of the children.

Huge stock of toys: The inventory catalogue of the organization featured over 1000 pieces of toys or similar equipment. This stock was approximately split half between special educational materials/toys and conventional toys that could be bought at any toy store, designed without considering special needs. While some of the conventional toys made use of electronics to enhance their experience, for example, by adding audio effects, a lot of the special needs toys were designed according the principles of

Montessori [13]. EIS2 stated: "We have an amazingly huge amount of toys, many of them get lost for years in the storage room until they are re-discovered."

Interestingly, the EIS often favored rather *simple things* in contrast to elaborate and expensive equipment. For example, simple and colorful boxes or cans with slots in different sizes were very popular utensils among the EIS. As they stated, they often instruct children to throw little objects (e.g., old bottle caps) into the cans. This was an excellent exercise for hand-eye coordination and it made insightful accompanying sounds, in particular for children with low vision. They also made use of magnetic objects attracted by the outside of metal cans, inviting the children to "pluck" them before throwing them into the can, hence, adding a more interesting motoric component.

Most of these simple toys and objects were self-made and customized according to the needs of individual children and to make rather dull exercises more interesting. This fact leads to our second observation regarding improvisations in the daily work of the EIS.

Improvisations: As documented in the literature, to work with disabled children can be challenging because of their heterogeneous needs, which moreover can change at a fast pace [4]. Also, most sessions took place at the children's home and consequently the EIS needed to get along with the situation they found there, for example, little space or bad lighting. We have observed this directly at the children's homes and indirectly through the improvisation skills that the EIS have acquired. Often the children did not like or were not able to solve one particular exercise that they were supposed to do, and in this case the EIS needed to find (on the fly) an alternative to train the child. Thus, when the children rejected a particular exercise or toy, the EIS tried to keep the attention of the children by offering variations in form and decoration, which they created and collected over the years. When asked about what kind of tinkering or DIY-practice they would engage in most often to create or upgrade equipment, EIS1 answered:

"Reduction. Reducing a toy is what we do most often in terms of tinkering. Often the toys are too complex, too many functions, too many distracting images. Then we remove stuff, we cover things with tape, we make things simpler so everyone can use them. And sometimes we also enhance things, e.g., coloring old cans and boxes to enhance the contrast and to make them look more interesting." [EIS1]

Overall, from Phase 1 we learned that the EIS already possess a large number of toys, that they have to react to a multitude of different and unforeseen situations, and that they are quite inventive and hands-on in approaching these situations. Consequently, we set ourselves the goal to create a toy that was different from the ones they already had, and that was not realizable by their own DIY skills. In addition, we aimed at creating a toy that would be useful for children with different preferences or interests and disabilities.

Phase 2: Design Workshops

To initiate the co-design phase, we invited the EIS to a hands-on design workshop. The aim of this workshop was to introduce the therapists to interaction design as performed by us and to give them an idea of what kind of designs we were capable to produce with respect to time constraints and budget. We demonstrated and explained tools for digital fabrication like 3D printer, laser cutter, and CNC mill. We initiated a 3D print and let them cut some plywood pieces with the laser. Moreover, we let them interact with prototype designs that we had created earlier in the context of other research projects. These prototypes were selected based on their affordances and represented exemplary work that might also be interesting for the EIS. In addition, we invited the EIS to 'play' with littleBits [2], a platform designed for children for creating very simple electronic prototypes by snapping together magnetic sensor and actuator modules. We concluded the workshop with a discussion of what the EIS would like to create with the tools they learned about that day, if they had an assistant helping them to bring their designs to life.

Following the design workshop, we rendered the impressions we gained as well as the insights from Phase 1 into a number of design proposals. Those were captured in a mix of sketches, storyboards, and scenarios, exploring divergent concept directions. In this course, the initial, less elaborated concept for BoostBeans was formed.

We discussed the proposals with the EIS in another meeting in order to receive feedback and narrow down the space of potential solutions. After two weeks, we scheduled yet another workshop meeting where we brought refined sketches and some lo-fi prototypes and materials for play-acting scenarios. The photo in Figure 2 was taken on this occasion.

Final decision for the BoostBeans concept

We decided collectively with the EIS that the design proposal of BoostBeans should be explored as prototypes in Phase 3.

As we learned from our investigations, one of the biggest challenges for the EIS is to motivate children and to improvise in this course. For this reason, the EIS asked us to come up with a toy, which they can build into their daily exercises with different children and different needs. Interestingly, it was not important to them that the novel toy should be designed for one particular purpose, for example, to improve hand-eye coordination, but to afford a certain degree of versatility. This is de facto what BoostBeans is aiming at as described in the next section.

Phase 3: Conceptual Design, Iterative Prototyping, and Field Deployment

Following the insights from Phases 1 and 2, we decided to focus on the design concept, which is illustrated in Figure 1 (BoostBeans). The activities as described in the following took place over the course of approximately four months. It might be to little surprise that the proposed design is not an interactive toy in a conventional sense. However, in accordance with the EIS, we opted for creating a modular system to be used to *augment* existing toys and everyday objects. That is, instead of adding yet another toy to the stock of 1000+, we designed an interactive and open-ended technology to add extra value to existing materials.

BoostBeans (see also Figure 3) is comprised of small actuator modules that can light up (LightBean), vibrate (BuzzerBean), and record and replay audio clips of six seconds (SoundBean). Later on we also added PowerBean as described subsequently. The kit comes with corresponding remote controls to wirelessly trigger the actuator modules on the push of a tactile button. In the case of the red remote control for the likewise red SoundBean, a brief touch of the button will replay the sound, and a long touch (>5secs) will record a new clip with the built-in microphone.

In the following we describe affordances of BoostBeans. While some of them were implemented by intention, others emerged during field tests.

Augmentation of existing objects and toys
The initial idea of BoostBeans was that the EIS would prepare an object with BoostBeans, for example, by putting a LightBean into an empty jar as illustrated in Figure 1A. Whenever the visually impaired child would reach out for the jar, the EIS would (secretly) operate the remote control acting as a "Wizard of Oz". In this way, the eyes of the child would be exposed to a bright stimulus (wanted behavior for wiring up visual paths), and the jar would show interesting interactive behavior without the need for fully implementing the action-reaction mechanism thanks to the Wizard of Oz/remote control.

Motivational aspects and rewards
Another idea was to use BoostBeans as rewards between training tasks, which might feature boring exercises. Then, the children should be allowed to engage in whatever activity suited them best with BoostBeans. Figure 5 (left), for example, shows a container with old bottle caps collected by the EIS. They placed BuzzerBean between the caps and offered the container to the children to stick their hands and feet into it. The result was a fun sensory impression, which at the same time was an important lesson for the children with respect to body perception. Thus, the EIS made use of the system to create holistic experiences addressing multiple senses, which again had motivational effects due to an increased variation of exercises.

Making up own games
Interestingly, it did not take long until the children wanted to operate the remote controls themselves although we originally created them for the adults. They made up their own games with them. Figure 5 (right) shows Mario using the remote control to locate the SoundBean. The SoundBean was prepared beforehand by EIS2 who recorded funny horse sounds and hid it between Mario's soft toys also shown in Figure 5 (middle). Mario used the remote again and again until he located the SoundBean. He used both his hearing and his poor vision to find the toy, which made the fun game a good exercise, as well.

Cognitive challenges and solving puzzles
Inspired by such observations, we decided, in accordance with the EIS, to create remote controls specifically for the children in the shape of puzzles (Figure 4). The pieces had to be put into place to complete the control, because they represented tactile buttons for triggering BoostBeans. In this manner, the children had to solve a cognitive puzzle involving hand-eye coordination, before they could use the device to trigger the desired action. We were inspired by the design of the LEA symbols [24], a common non-verbal eye-assessment test. The motivation was to prepare the children for the LEA test by introducing them to the symbols in a playful way.

The puzzle remote was well received by both the children and the EIS. Figure 6 (left) shows Monica holding the BuzzerBean to her head and the remote control with the other hand. Since she liked the vibration, she had to use both hands simultaneously to trigger it. This was a good exercise for her coordination and also for motivating her to make use of her "weaker" right hand. Figure 6 (middle) displays Muhammad experimenting with BoostBeans, and Figure 6 (right) shows Michael who liked the tickling feeling of BuzzerBean while holding his foot against it.

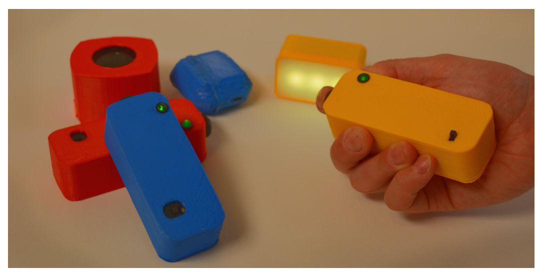

Figure 3. Three BoostBeans (in the background): SoundBean (red), BuzzerBean (blue), LightBean (yellow) and three remote controls for triggering the corresponding BoostBean of the same color.

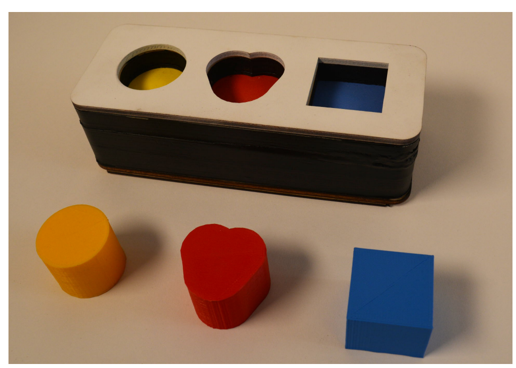

Figure 4. Puzzle remote control for triggering the LightBean (yellow), SoundBean (red), and BuzzerBean (blue). The puzzle pieces are the buttons and have to be put into place.

Figure 5. Container with old bottle caps and BuzzerBean (left; encircled). Mario's soft toys as a hiding place for AudioBean (middle). Mario triggering the remote control while searching for AudioBean (right; indicated with an arrow).

Figure 6. Monica engaging with the puzzle remote control (left). Muhammad examining BuzzerBean (middle). Michael holding his foot against BuzzerBean, because he enjoyed the feeling (right).

Redesign of puzzle remote control

Due to the success of the puzzle remote control and BoostBeans as a whole, we created a redesign (see Figure 7) that was extended by one additional BoostBean. We named it PowerBean (see Figure 8) as it basically constitutes an energy source with connecting port, which can be switched on and off remotely. By this means, the EIS are enabled to connect USB gadgets of their choice like LED strips or small fans to the port and incorporate these gadgets in their training sessions with the children.

DISCUSSION

Since we presented BoostBeans as a design case study, we discussed many of our design decisions as part of the main body of the paper. Here, we want to take some space to address a couple of observations and issues that we found remarkable during the project.

Motivating the children

One important lesson that we learned was about how much work in the daily practices of the EIS was about *motivating* the children to fulfill their exercises. As summarized in the Therapeutic Context section, it is crucial for the children's development to work with all of their senses. However, vision exercises, for example, can be dull as we have learned, since they require a child to iteratively look at abstract and high-contrast patterns [9; 23]. For this reason, the EIS became very inventive to engage the children in their exercises. Hence, we decided to give broad agency to the EIS during the design process and to support their great talent for improvisations and creativity through BoostBeans. This observation about their practices is in line with the literature. Metatla [12] spoke of "maker culture" when reporting on a study of the work of special education teachers for visually impaired children. He explained: "The maker culture seems to be naturally nurtured by two reoccurring factors; first the difficulty of reusing materials and resources; second, by the heterogeneity of needs of children with [visual impairments]." [12, p.5]

Sheer number of toys

To respond to this heterogeneity of needs, the EIS already obtained a large number of therapeutic toys. While a few of their 1000+ toys featured electronic components, almost no toy made use of more elaborate interactive technology or interaction mechanisms. In most cases, electronics were used to illuminate a toy to make it more visible or interesting. Sometimes, toys would also play sounds in certain situations. However, these features were used to enhance the toy, they did not define it per se and with empty batteries, most of them were still useable whilst not that interesting anymore.

These considerations should not imply that we argue "the more technology, the better". We are far from this belief; still, we identified an opportunity to draw on the tangible and embodied interaction paradigm to leverage toys for children with disabilities. Despite the great heterogeneity of their clients [11], the EIS provided beneficial sensory experiences for all of them according to their current needs. To some surprise, these experiences did not only involve encounters with visual stimuli. The reason for this is that the children are treated in a holistic way addressing all senses, so that the children can learn to integrate them. This is a challenge, we argue, where tangible and embodied interaction, and BoostBeans in particular, can be helpful and even excel.

In summary, we opted for an open-ended toy like BoostBeans as we soon found out that designing a toy, which all children of our study would accept or even cherish was nearly impossible. Children can have very particular flavors when it comes to toys, and this might be the reason why there are so many "contextual" [15] toys in the collection of the EIS (i.e., toys for one particular purpose). BoostBeans, on the contrary, constitutes an unadorned set of modular components that do not define or even suggest a particular way to be played with.

This leads to our final considerations in this paper regarding open-endedness in therapeutic toy design.

On open-endedness in therapeutic toy design

During the review of related work we found that a number of researchers offered broad options for customizing their designs to meet user needs (e.g., [21]). In a way, BoostBeans depicts a similar yet different mode for customization. In our case, the EIS did not reconfigure the shape or application, but they used BoostBeans to (re-)arrange therapeutic exercises in a meaningful way.

Seeing these 're-appropriations' by the EIS poses some interesting questions for further research. These questions center around how far we can 'push the envelope' in creating therapeutic toys and devices that are "open to interpretations" [18]. It is widely acknowledged that "designing a technical object also typically entails designing, or prescribing, its use" [16, p.411]. In designing BoostBeans, we tried to avoid prescribing a specific way of how to use them. Still, at some point we had to make a number of very specific design decisions regarding their forms and functions. For a future research agenda, it might be interesting to look into research that consistently elaborates open-ended design (e.g., [15]) and investigate the boundaries of creating open-ended therapeutic toy design.

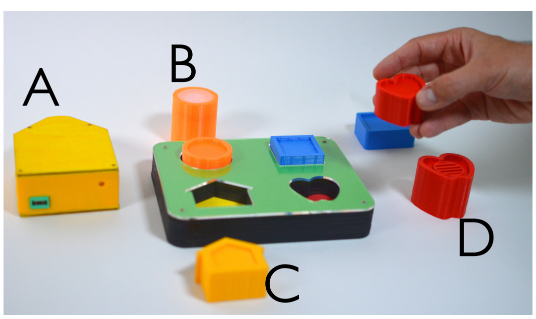

Figure 7. Redesign of the puzzle remote control. PowerBean (A) was added as a fourth actuator element. B: LightBean. C: puzzle button for PowerBean. D: SoundBean.

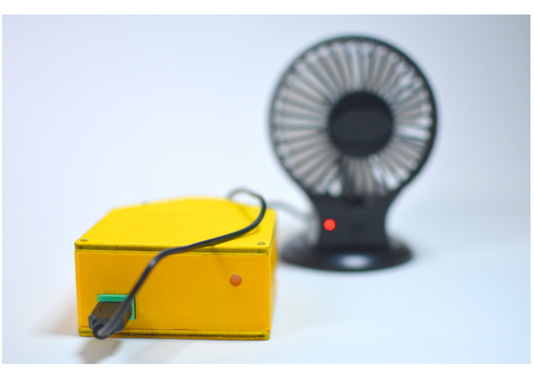

Figure 8. PowerBean with connected USB gadget (fan).

Limitations

The present work constitutes the description of the design case of BoostBeans. The prototype was created in a co-design process with a small number of therapists and children. In this paper, we don't aim to generalize findings. Its purpose is to describe the design process, to explain design decisions, and to show how the BoostBeans were used.

Further research is needed to evaluate the benefits of BoostBeans and map out different ways for using it. With respect to open-ended designs which have multiple interpretations, Sengers and Gaver suggest that "[…] systems might best be evaluated by gathering and presenting a variety of assessments from a diverse population of interpreters, allowing outsiders to get a rich and layered view of how the system is used, the roles it plays, and the cultural implications it suggests." [18, p.106] We agree with this evaluation strategy and plan to observe more participants interacting with BoostBeans in additional situations to be able to unpack a rich description of its use. Moreover, we want contrast observations of the EIS' use of conventional toys with that of BoostBeans.

CONCLUSION

We created BoostBeans in the course of a six months research endeavor involving four EIS and nine children. The prototype is a result of a co-design process, which revealed a potential for interactive and playful technology during early intervention programs with disabled children. BoostBeans constitutes a design case study where rather simple interaction mechanisms (controlling actions and reactions) could create valuable experiences by drawing on tangible and embodied interaction.

Through its open-endedness and tangibility, BoostBeans features a number of attributes that can be utilized in different ways. The system can be used *stand-alone*, but it can also be used *together with existing objects*, for example, toys. In this case, BoostBeans can be used to *augment* the toy or to *modify* it. Certain stimuli or characteristics of the toy could be *enhanced* or *reduced*. BoostBeans was also created to *inspire* or *enable* new exercises or (therapeutic) play activities. Finally, BoostBeans supports making the practices of early intervention even more *flexible* when responding to the children's needs.

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