Pers Ubiquit Comput (2014) 18:1485–1497
DOI 10.1007/s00779-013-0750-3

ORIGINAL ARTICLE

Smart objects to support the discrimination training of children with autism

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Received: 8 November 2012 / Accepted: 15 February 2013 / Published online: 9 November 2013

Abstract Teachers spend considerable amount of time keeping students with autism “on task” giving away prompts and rewards and maintaining a detailed record of students’ progress during the object discrimination training. We hypothesize that tangible computing, in particular smart objects, could help teachers cope with the problems faced during the object discrimination training of students with autism. In this paper, we describe design principles for smart objects to support the object discrimination training and present several example prototypes. First, we present the design and implementation of “Things that think” (T3), a smart device that converts traditional objects into smart objects that promote interactivity with a playful and engaging interaction, and are capable of the automatic recording of students’ progress. Then, we present four T3 smart objects assembled in a board. The results of a 7-week deployment study of the use of such smart objects in three classrooms of students with autism ($n = 25$, 7 teachers and 18 students with autism) demonstrate T3 smart objects reduce the workload of teachers, ease the record-keeping and increase its reliability, and reduce students’ behavioral problems while improving their cognitive efficacy. We close discussing directions for future work.

Keywords Tangible computing · Smart objects · Assistive technology · Autism · Child–computer interaction · Discrimination training

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1 Introduction

Autism is a neurological disorder affecting 1 in 88 children,[1] and it is associated with cognitive impairments in attention, information processing, social communication, and memory [20]. Due such cognitive impairments, individuals with autism, especially children, frequently exhibit behavior problems including lack of engagement, impatience when taking turns, and odd and repetitive behaviors. Behavior problems children with autism experience may interfere with their cognitive efficacy, socialization, health, safety, and quality of life [5].

Object discrimination training is a type of cognitive therapy, teachers use to empower children with autism cognitive learning [27] and engagement. Teaching discrimination skills to children with autism is a time-consuming and stressful task as children with autism present many behavioral issues and disruption. Furthermore, on each trial in every therapy, teachers need to maintain a detailed record of students’ achievements and behavior to

[1] CDC’s Autism and Developmental Disabilities Monitoring (ADDM) Network.

monitor their progress. As teachers often record this information manually, it is commonly inaccurate making assessment and scaffolding, unpredictable [19].

Most of the available tools used during the object discrimination training include real objects and paper-based visual supports (i.e., those things we see that enhance the communication process [6]) that along with prompts from teachers help students to match a real object to its corresponding visual support. Visual supports can ease the behavior and attention challenges children with autism faced by augmenting communication with visual cues. Paper-based visual supports (Fig. 1 right), however, hardly offer interactivity and their "cartoonish aspect" scarcely portray realism. Children with autism often find themselves confused and disengaged in the therapy.

Technological interventions that provide interactive visual supports (e.g., vSked [14], MOSOCO [9], see related work) help teachers to keep students "on task" [14]. However, these tools still lack some of the realism real objects have to help students generalize from the classroom to other environments (Fig. 1 left). Thus, a new type of interactive visual support capable of augmenting the physical form of a traditional object with digital and interactive information is needed to combine the benefits of both digital and physical supports.

By integrating the digital and physical world, smart objects can provide support for interactivity [17] and feedback for learners with autism and, at the same time, automatically track information about student progress. There is little work that explores the use of smart objects in this way, opening new research questions about ways smart objects can support the special needs of children with autism and help to reduce the workload of teachers who must track student progress manually when using traditional objects. The design of such smart objects presents several design and interaction challenges (see Sect. 2). In this paper, we explore the design space for developing "smart objects" to alleviate current challenges teachers face during the object discrimination training of children with autism

2 Related work

Over the last decade, ubiquitous technologies that use "visual supports" have mainly supported children with autism to manage their visual schedules [11] or remediate their speech and language disabilities [2], serving most of the time as an augmentative communication tools [2]. For example, some projects (e.g., vSked [14], MOSOCO [9, 26]) have researched the use interactive displays using visual schedules inside the classroom (e.g., vSked [14]) and mobile technology for the generalization of social skills (e.g., MOSOCO [9, 26]). The deployment studies of these applications have prove that ubiquitous solutions in support of students with autism reduces the quantity of educator-initiated prompts [9], encourages consistency [7] and enables skills generalization in real-life situations [9]. This work shows that there is great potential to use ubiquitous tools for "interactive visual supports" in support of the training of students with autism. However, leaves open questions as to how the benefits students gained when using digital visual supports (e.g., vSked [14], MOSOCO [9, 26]) could be obtained with real objects—often used during the discrimination training.

Research in tangible computing to support children mainly involves the use of smart objects to support learning and development. Smart objects have been designed to empower children self-reflection (e.g., SystemBlocks and Flowblocks [28]), engagement (e.g., CTI [1]), self-directed activity (e.g., Tap&Play [18]), and language (e.g., OnObject [15]). Most of these smart objects incorporate entertainment-based mechanisms to engage the child in the learning process (e.g., Augmented Knight Castle [13]).

Fig. 1 Paper-based visual supports used in the therapies of object discrimination training

Fig. 2 A student with autism attending to an object discrimination lesson during 1 day of observation (*left*). Teachers interacting with a mock-up prototype during the focus group (*right*)

Some of these solutions make use of technology that enables the integration of physical and digital media based in popular commercial devices (e.g., liveScribe[2] running Tap&Play [18]) or involve the development of self-crafted devices to provide more means of interaction (e.g., On-Object [15]). The experiences of these and similar projects have led designers to propose a set of design principles (e.g., [19]) to facilitate the design of smart objects for children. These projects show the applicability of smart objects to develop physical interactive learning systems in support of children and are relevant to us as we are interested in building smart objects to support the learning process of children as well. However, little has been said about how these solutions could support the challenges teachers face during the training of students with autism, as projects in tangible computing for children with autism are scarce.

In light of the related literature, this work has three contributions. First, we present a set of design principles that led to the development of a device that turns any traditional object into a smart object combining the benefits provided by physical and digital supports and shows their effectiveness as a guiding principle. Second, we present several smart objects that could be useful to other researchers interested in designing technology in support of the training of students with autism. Finally, we demonstrate that the "smart objects" following our principles positively impact both teachers and students with autism.

3 Research process

During 3 months, we conducted a qualitative study to investigate the role of physical objects during the object discrimination training of low-functioning students with autism. The study was conducted in Pasitos A.C.,[3] a specialized school clinic where 15 psychologist teachers attend to close to 50 low-functioning children with autism. During this time, we conducted 13 semi-structured interviews with 11 teachers working at this clinic. We complemented our interviews with 75 h of passive observation (Fig. 2 left).

Following an interactive user-centered design methodology and to supplement our understanding from our literature review, for the following 3 months, we used the results of the study to iteratively design 3 low-fidelity prototypes and a set of design scenarios that were presented to teachers in a mock-up form (Fig. 2 right). We conducted 3 participatory design sessions to discuss our prototypes and new design insights. We used the results of our participatory sessions to redesign our prototypes and to choose from the alternatives proposed from teachers.

Then for a period of 2 months and based on the uncovered design principles, we developed Things that think (T3), a device that transforms a traditional object into a smart object, and the T3Board, a board assembling several T3 objects.

Later the T3Board was deployed in three classrooms of Pasitos A.C., with 18 low-functioning students with autism (e.g., between the ages of 3 and 8 $m = 5.47$, $SD = 0.96$, 2 females) and 7 teachers[4] ($n = 25$, all of females). The evaluation study followed three conditions: *pre-deployment* (2 weeks), *deployment* (4 weeks), *and post-deployment* (1 week). During pre-deployment, students participated in a standard object discrimination therapy including direct instruction from teachers and the use of paper-based visual supports. Then researchers installed the T3Board and gave 2 training lessons to the students and their teachers participating in the study. During the deployment phase, students and teachers participated in the therapies using the T3Board (Fig. 7). Finally, in the post-deployment phase, participants returned to the first condition, using paper-

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

[3] http://www.pasitos.org.

[4] Although we were interested in understanding the impact of the T3Board on students and teachers, teachers were mainly interviewed as proxies [24]. Tang and McCorkle [24] to gather the information from non-verbal students with autism.

based visual supports during therapies. Participants were video recorded during therapies (Fig. 7). The total time of observation was just under 56 h. We conducted and recorded weekly interviews ($n = 36$) with the teachers across each study phase interviews (e.g., lasted about 40 min $m = 0{:}39{:}10$, SD $= 00{:}04{:}05$).

During pre-deployment, participants were asked about daily routines and general training practices. During deployment, participants were asked to discuss how the use of the system went during that particular week, comment on how T3 impacted their therapies, particularly attention, behavior, and engagement, and encouraged to tell stories and discuss what they found interesting, surprising, or different that week. At the end of the study, we asked about how things changed after we withdrew T3, especially if they perceived the practices better or worst. Recorded interviews and videos were transcribed.

Data analysis followed a mixed-method approach, including the use of qualitative techniques to derive grounded theory and affinity diagramming, and sequential analysis to quantify students' and teachers' behaviors. Our approach for the sequential analysis of the data involved the generation of a coding scheme for the systematic coding of the data. The coding scheme included the kind of activities that teacher does (i.e., prompt, reward, taking notes), engagement (e.g., "on task", "of-task"), behaviors and teachers' types of prompting. Inter-observer agreement (IOA) following our coding scheme for coding our videos was acceptable ($r = 0.92$). Using our coded video transcripts, we estimated, for each participant under each condition, the total and descriptive statistics of: the time students spent in different emotions and different types of attention. Finally, we used an ANOVA to compare the time students with autism and teachers remained on each condition.

4 Discrimination training in autism

It was until recently that Mexican law recognized autism as a developmental disability. For this reason, there is no physiological or clinical support in Mexican schools that educate children with autism. As a consequence, parents of children with autism seek for support from programs offered by private, often expensive, school clinics. To meet this need, the Mexican government has special programs that partially subsidize top-rated school clinics with high-quality school staff. Pasitos A.C. is a specialized clinic that provides support to students with autism through their high-quality faculty integrated by physiologists, including one with a PhD in neuroscience. This contrast with special education classrooms in other countries only supervised by teachers. The students who attend Pasitos A.C. are mostly from low-income families, and their resources are limited. Most of the children at Pasitos A.C. are subsided by the Mexican government. These children benefit from the cutting edge therapies and personalized psychology support by highly prepared staff at the school, with classrooms filled with specialized therapeutic tools, personalized to each child's needs.

Teachers at Pasitos A.C. conduct repetitive trials in which an object is presented with a cognitive goal to the student (e.g., identifying an object). A teacher considers a trial complete if the student successfully reaches the goal without the need of teacher-initiated prompts (e.g., a spoken instruction, pointing toward the correct answer). Teachers reinforce a completed trial with a reward (e.g., tickles, spoken congratulations). To support skills generalization, teachers frequently use real objects enriched with laminated "paper-based cards" to add content to the real object helping students reach their goal.

4.1 A prototypical lesson

To exemplify how teachers conduct an object discrimination lesson at Pasitos A.C., here we present an example scenario.

When the teacher Bella reviews the student file[5] *of Marley, a 6 year-old low-functioning child with autism who likes ducks and is exhibiting severe behavior problems and having trouble with colors, she realizes that Marley is learning how to discriminate the pink color. Bella starts the trial and places a green and a pink paper-based laminated card in the table in front of Marley (Fig. 2 left). Bella also places a duck to let Marley know that if he appropriately completes the trial he will have more time to play with the duck, as a reward. Then, Bella starts the first trial of 10 and asks Marley to grab the pink card. Marley grabs the green card instead and starts playing with it while looking around the classroom. During this time, Marley is "off task." So Bella prompts Marley saying, "Marley! Grab the pink card!" and points toward the pink card. Then, Bella annotates in the student file Marley's behavior. Bella takes Marley's hand to help him grab the pink card saying: "Marley! Grab the pink card!". Marley grabs the pink card and gives it to Bella. Bella rewards him by saying: "Good job!" and starts moving the duck around to play with Marley. Then, Bella annotates a sad face in the student file to mark the trial as incomplete, as Marley needed verbal, visual, and physical prompting. When Marley sees the sad face he gets mad and starts screaming at Bella. Bella tries to start a second trial, but Marley does not cooperate and they cannot complete the 10 trials for the day.*

[5] The student file is a record storing clinical and behavioral information about a particular child including his/her diagnosis, goals, and interests.

This scenario shows in one hand the workload teachers have during a discrimination lesson (e.g., giving away different kinds of prompts and rewards or adapting teaching materials to each child needs and preferences) and how much effort they have to invest in keeping the student “on task”, constantly prompting the student while maintaining a detailed record of the student’s interactions with objects. In the other hand, we can see in this scenario how students struggle to be engaged, resulting in having to early finish the therapy. The need of technological interventions to ease the work of teachers, and engage students toward the therapy when using physical objects and improve their behavior, is evident.

5 Design principles for smart objects

Based on our literature review and design study, we determined the following design principles for developing smart objects in support of the training of students with autism when using physical objects.

5.1 Automatic capture of trends and interaction gestures

Teachers regularly face the challenge of capturing behaviors during the training of students with autism [12, 14]. Much of this record-keeping is done manually, and as a consequence, the capturing of usage data can be “an arduous and a time-consuming task” [14]. This problem is exaggerated when teachers need to annotate and identify students’ interactions gestures when using physical objects, as in the case of the objects discrimination training.

Teachers need to correlate specific behaviors to later identify significant trends. Currently, teachers use all of their senses (i.e., sight, hearing, touch) to qualitatively perceive students’ behaviors and interaction gestures, to later associate them to quantitative data such as the number of students’ responses or educator-initiated prompts.

> … if [the student with autism] is on task, or cooperative or adequately using the object, or if suddenly does a mannerism while you are annotating [the number of educator-initiated prompts] fixated in your notebook, you don’t see it, and you can’t later evaluate the relationship between behavioral issues and prompts, … you have to use all of your senses, but sometimes is impossible to be 100 % on top of everything (Nadia, teacher)[6]

[6] Participants’ quotes were translated from Spanish to English, and some were adjusted to fit English grammar conventions.

To facilitate the record-keeping and the identification of “correlations” among the captured data, a smart object should be able to perceive the outside world, as the human brain does through the brain’s sensory system. Therefore, smart objects should have *vision, auditory, and somatic sensation* capabilities, to be able to see and hear students’ behaviors while quantifying students’ interactions when feeling the touch of a student.

The sensory system of a smart object should enable teachers to associate qualitative (e.g., a student laughing) and quantitative (e.g., number of educator-initiated prompts) data for trends identification.

Sight capabilities could be provided through an embedded camera with monitoring capabilities that will enable the automatic or selective archiving [10] of relevant observed behaviors (e.g., CareLog [10], Abaris [16], SenseCam [11]). *Hearing* capabilities could be provided through an embedded loudspeaker that will enable an object to hear students’ reactions or teachers’ prompts. Voice recognition could be used to identify relevant words (e.g., a prompt), as audio markers that could be used for the adequate audio segmentation.

To facilitate the detection of interaction gestures, a smart object should have *somatic sensation* capabilities that will enable a smart object to identify when the student touches it. *Haptic* technology (e.g., inTouch [4]) or sensors (e.g., accelerometers [15]) could also help to identify these and other type of interaction gestures such as “shaking”, “grabbing”, “swinging”, or “releasing” an object. The identification of students’ interactions will enable the automatic recording of students’ responses.

Data visualization must also be accessible in multiple ways combining visual representations of both the quantitative and qualitative captured data. Having multiple data visualizations are important for the appropriate assessment of students’ progress [7, 9, 14]. We build upon this research emphasizing that the proposed sensory system of smart objects will enable teachers to analyze trends beyond specific behaviors (e.g., a student positively reacts to the green color vs. number of student’s responses).

5.2 Mimic teachers’ practices for behavior management

Teachers frequently prompt students to help them achieve their goal and give away rewards to encourage students to stay “on task”, as behavior management strategies. The number of educator-initiated prompts should be faded out as the student executes the skill being taught without needing help from teachers.

> You as a teacher need to be alert to identify when you need to change the [number of educator-initiated

> prompts] because students don't need the same support, and that is the key (Nadia, teacher)

A smart object should be able to adapt its configuration as the student learns the skill reducing the number of given prompts according to each student's development. Indeed, most of the proposed design principles for developing technology in support of students with autism emphasize that the technology should be "flexible to meet students' interests and growth development [11]".

Another important aspect during the training of students with autism is the use of rewards. Rewards serve as behavior reinforcement and motivate students to finish their task as having the reward visually available contributes to student's engagement [7]. It is very important to timely give away the reward so the student understands why s/he is being rewarded.

> I give the student a reward when s/he is able to do what I am asking him/her to do … immediately, you do what I want, and [as a reward] I tickle you or hug you or give you a chip, immediately, you can't wait because you will lose the [reward's] purpose (Nadia, teacher)

To mimic current teachers practices of given prompts and rewards when appropriate, a smart object should be able to emit instructions, sounds, music, spoken congratulations or lights, as a new form of verbal and visual digital-based prompts or rewards. We envision this capability of a smart object as a sort of "skin" that it is added to the outer fabric of the object and that will change according to students' needs, like a chameleon.

Sound and light capabilities could be provided through a loudspeaker or an array of LEDS that with different level of intensity could provide verbal and visual digital prompts or rewards. Mimicking a physical reward or prompt will require a more complex type of technology such as robotics (e.g., [8]) and more advanced motor capabilities (e.g., topobo [22]).

5.3 Bringing objects into life

Current analog physical objects lack of interactivity and teachers need to envision playful ways to keep students "on task" [23], and more particularly engaged with the object used during the object discrimination training.

> We first teach students with a real object, so the child can touch it, and then we use laminated cards … with real objects it is easier and simpler for them but it is more difficult to maintain the student [on task]. Real objects are not interactive so we move them around a lot (Bella, teacher)

One strategy teachers use to promote interactivity is to move an object around to sort of bring such object into live, like a cartoon comes alive in an animated motion movie. Moving the object, as teachers explained, will not only redirect students' attention to the therapy but could also serve as a positional prompt or reward.

A smart object should have movement capabilities to enable a real object to move when needed. Movement capabilities could be achieved with an embedded motor that will enable an object to have basic motor skills: vibrate, spin, or move a determined distance.

5.4 Ease the configuration and personalization of smart objects

Current analog physical objects require a lot of manual configuration. Teachers self-craft the objects used during the object discrimination training as rewards (e.g., teddy bears) or tools (e.g., paper-based laminated cards, see prototypical lesson). Moreover, these objects should be personalized to students' interests demanding from teachers a lot of work [11, 14].

> Every child is different and every child needs a different reinforcement (Nadia, teacher)

To avoid adding an extra burden to teachers, a smart object should facilitate its configuration and personalization according to each student's needs. A smart object should have a memory to learn how a student and a teacher like to use a determined object and later use this knowledge to automatically configure such object.

Operations among smart objects to enable the configuration transfer making the use of today's most popular interaction models (e.g., bump[7]) are essential. For example, some projects on tangible computing mimic the popular "copy and paste" PC operation to enable the transfer of configured sounds and interaction gestures among smart objects (e.g., Tap&Play [18] and OnObject [15]). Current smart objects should take advantage of these solutions and build tools taking into account these interaction models to enable the configuration transfer.

6 The brain of "Things that think" (T3)

Using our design principles, we developed Things that think (T3, Fig. 3), a 1.2" plastic cube embedding an accelerometer, a loudspeaker, a motor, a multicolor led array, and a microphone.

T3 enables a traditional object to emit different "patterns" of:

[7] http://www.bu.mp.com.

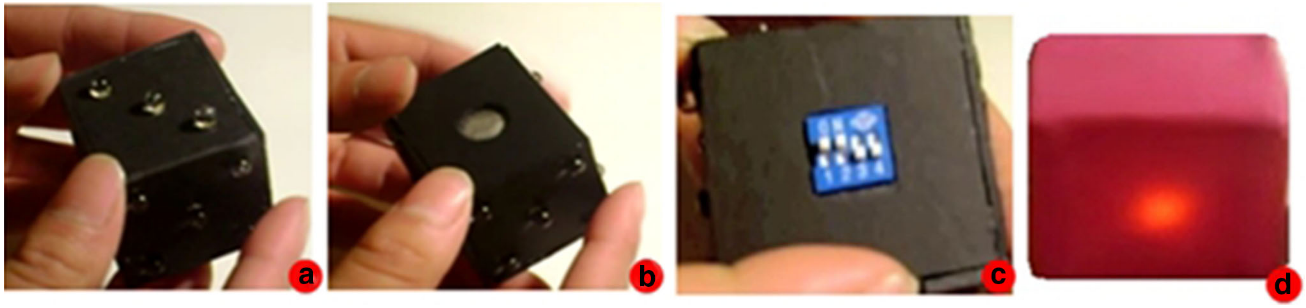

Fig. 3 The T3 cube integrating a led array (**a**), a loudspeaker (**b**) and a configuration panel (**c**). A T3 object embedding a T3 cube blinking to mimic a positional prompt (**d**)

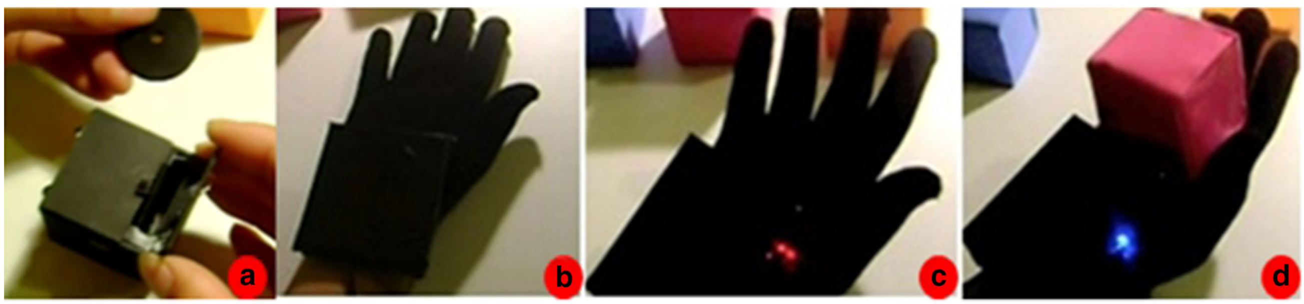

Fig. 4 A teacher placing an RFID tag inside the T3 cube's container (**a**). The RFID glove (**b**) turning its led on *red* when waiting for a response (**c**) and turning *blue* when reading an object (**d**) (color figure online)

- *sounds*, teachers choose a prerecorded sound, or use the microphone to record a sound, to be later played by the cube (e.g., "Marley, grab de pink card!");
- *illumination*, a cube can also "light on" or "blink" (Fig. 3d) in blue, yellow, or red or emit "fireworks" by jointly blinking in blue, yellow, and red; and
- *movement*, a cube can also "vibrate", "spin", or "move" a predetermined distance.

T3 has a configuration panel (Fig. 3c) available in one of the cube faces that enable teachers to activate or deactivate a 4-vector of T3 events (i.e., sound, sound, illumination, and movement); so, for example, a T3 object (i.e., a traditional object housing a T3 cube) mimicking a reward could say a spoken congratulation, sing, emit fireworks, and spin.

To measure students' interactions with a T3 object, a T3 cube uses an accelerometer to infer the user-interaction gestures of "grabbing", "releasing", and "shaking" [21]. A T3 cube works in pair with an RFID glove (Fig. 4b). The RFID glove is a common glove integrating an RFID reader that detects RFID tags storing the student's identity and the id of the T3 cube with which it is paired. Taking into consideration the object id, the RFID glove identifies if the object a student selected is correct. A T3 cube has a special container that optionally houses RFID tags (Fig. 4a). The RFID glove also integrates a two-color led that gives feedback to teachers about the state of the RFID glove. The led turns blue (Fig. 4d) when the RFID glove is "reading a response" and turns red when it is "waiting for a response" (Fig. 4c). The RFID glove interaction model mimics current practices teachers follow when asking a student to grab an object (see prototypical lesson scenario). All gestures detected by the accelerometer or the RFID glove are automatically logged, so teachers can later use this information to identify trends and monitor student progress.

7 Developing Things that think (T3) and the RFID glove

The architecture of T3 has six components: the T3 cube, the RFID glove, the communication interface between the T3 objects, and the gesture estimation algorithm (Fig. 5).

The *T3 cube* and the *RFID glove* were implemented using the phidgets sensors. The T3 cube integrates 3 modules supporting the events of illumination, sound, and movement and 2 modules triggering such events to recognizing the interaction gestures of grabbing, releasing, and shaking and to detect when the RFID glove is waiting for or reading a response. The RFID glove has an extra module activating an RFID reader to identify the RFID tag a T3 object houses.

The T3 cube and the RFID glove work in pair with their respective components. The *T3 component* manages a 4

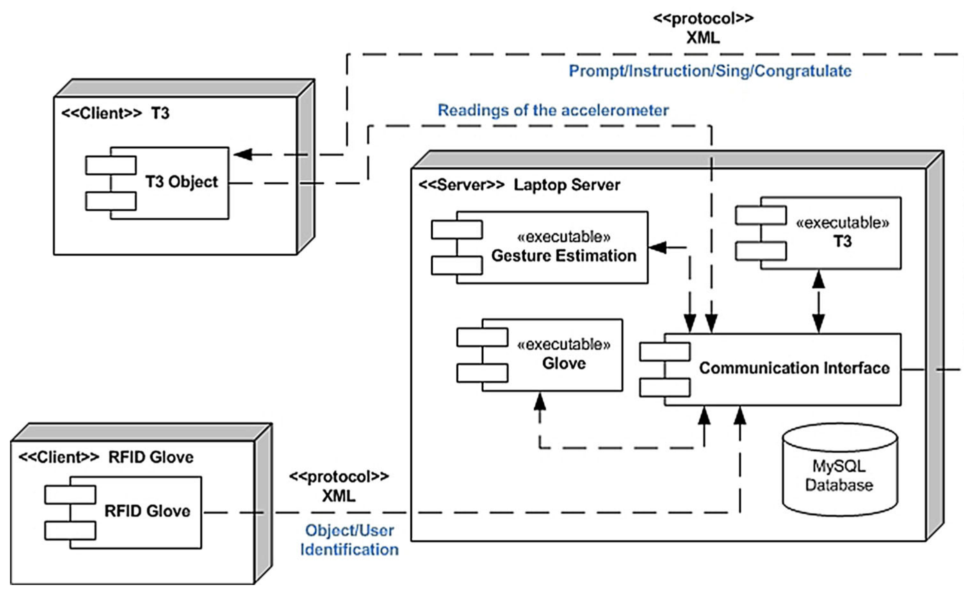

Fig. 5 The T3 architecture composed of six main components: the T3 object and the RFID glove as clients and in the server side: the communication interface, the gesture estimation algorithm, the RFID glove component, and the T3 component

event vector [<sound>, <sound>, <illumination>, <movement>] a user activates from the configuration panel enabling a cube to emit sounds, illuminate, and/or move. Each event portrays different "patterns" of sounds, illumination, or movement. Sounds events include four sounds patterns to enable a cube to give a "prompt", "a spoken instruction", "a congratulation phrase", or "sing". Such patterns are represented as configuration xml messages that store each user interests. This component stores a database of 10 sounds, 4 spoken congratulations, and 20 instructions. Alternatively, teachers may use the T3 microphone to record more sounds that will be associated with the activated event. The T3 component also controls a multicolor array of LEDS controlling three lighting patterns: "light on", "blink", or "fireworks". For movement, the T3 component controls a motor embedded in the device emitting the patters of "vibrating", "spinning", or "moving" a predetermined distance. Developers are responsible to linking a T3 cube to the available illumination, sound, and movement patterns.

The *Glove component* is responsible for the (1) user identification and (2) object recognition. To either identify an object or a user's identity, the teacher wearing RFID glove grabs a T3 object housing an RFID tag or an id RFID card. The RFID glove component receives the signal from the tag on the ≪client≫ and compares the stored id with the information stored in the database. Finally, it retrieves either the identity of the user or the description of the object.

The *Communication Interface*. The communication interface runs in a PC, and it is connected to a Phidget Interface Kit 8/8/8 to supply substantial battery power to the ≪clients≫. It includes an XML communication protocol that handles communication between the RFID glove and its paired T3 object, based on the communication model proposed in the SALSA middleware [25]. The Broker is an Instant Messaging (IM) server that stores the id of all of the T3 objects registered in the system. Each T3 object uses a Broker Proxy, which is an IM client that communicates with another T3 object via Broker. The Broker stores the state of each T3 object and notifies their changes to other T3 objects. The communication protocol includes four types of XML messages: "right answer", "wrong answer", "reading response", and "waiting response".

The *Gesture estimation algorithm* reads windows of 0.5 s containing 25 readings from the accelerometer. The algorithm utilizes the average, variance, and the RMS of these numerical readings and a linear sorter to detect 3 interactive gestures: grabbing, releasing, and shaking. The recognition accuracy is 87.08 %, on average [21].

To exemplify how teachers and students use T3 objects with the RFID glove and how the components of our architecture interact, here we revisit the presented scenario.

Bella personalizes two T3 cubes activating from each cube's panel an instruction (i.e., "Marley! Grab the pink cube!"), a prompt (i.e., "Marley! Give me the pink cube"), a blinking "illumination" pattern (i.e., as a positional prompt), and a vibrating "movement" pattern (i.e., as a physical prompt). Then, she attaches the configured T3 cubes to a green and a pink cube. Then, she grabs another T3 cube and activates from the panel a song (i.e., from the Looney Tunes cartoon), a congratulations phrase (i.e., "Good job! Marley!"), a fireworks "illumination" pattern, and a spinning "movement" pattern. She attaches the T3 cube to a duck that will sing, spin, and emit fireworks as a reward. Then, she places all the configured T3 objects (i.e., the green and the pink cube, and the duck) in front of Marley.

Next, Bella grabs the pink cube with the RFID glove to pair the glove with such cube. The RFID glove turns blue waiting from a response from the student. The RFID client sends via Broker a message to the T3 component of the pink cube. The T3 component retrieves from the database the adequate sound and sends it to the T3 component. The T3 component activates the loudspeaker of the pink T3-cube who reproduces the instruction, saying: "Marley! Grab the pink cube!". Then the T3 component activates the RFID glove. After a few seconds, the RFID glove does not detect a response and sends an instruction via Broker, to the array of LEDs and the motor, of the pink cube. The pink cube blinks and vibrates. When Marley perceives the blinking and the vibration, he grabs the pink cube and gives it to Bella. The RFID glove detects a response and turns on red. The RFID glove sends an instruction to the duck, which activates its loudspeaker, motor, and array of LEDs. The duck sings the 'Looney Tunes song' and also congratulates Marley saying: 'Good job! Marley', while spinning and emitting fireworks. Marley laughs.

8 Making "things" think

During our participatory design sessions and after presenting the T3 cube to teachers, teachers envisioned four types of T3 cubes they would like to have pre-configured during the object discrimination training.

The reward cube representing rewards

This cube could sing a popular cartoon theme song, say spoken congratulations phrases, spin, and emit fireworks, and it is defined by the following configuration vector: [**<singing>**, **<congratulating>**, **<emitting fireworks>**, **<spinning>**]. Teachers decide from the configuration panel which events they would like to activate. For example, if a teacher only activates the events of "singing" and "spinning", the T3 "reward" object will only sing and dance. Teachers take into consideration students' interests to decide which events activate. Cartoon theme songs and congratulations phrases are randomly retrieved from the database.

The marker cube giving feedback to students of their grades per trial

Teachers explained that most students recognize traditional scribbles used to grade students (e.g., happy/sad faces or thumbs up/down), and for most of the time, teachers observed that when students notice their grades, they are more engaged in the therapy. This strategy mimics some special education curriculums for autism promoting the practice of self-grading [3].

> … [students with autism] like to see how they did in a trial, so they lurk into my notes. The use of these 'markers' helps us to keep [the student] on task (Anna, Teacher)

Teachers asked for *a cube* that will let the student know the obtained grade per trial. So, we decided to pre-configured two kinds of cubes:

- one reacting with right answers that will light on "green" when the student correctly finishes the trial, defined by the following vector [**<null>**, **<null>**, **<lighting on green>**, **<null>**], and
- another one for wrong answers that will light on "red" [**<null>**, **<null>**, **<lighting on red>**, **<null>**].

The meter cube indicating the number of completed and remaining trials

Teachers also recognized that one positive side of the manual record-keeping is that they are aware of the number of completed trials. They use this information as a time-measurement metric to coordinate the classroom schedule. To mimic this practice, teachers asked for meters that will let them know the number of completed and remaining trials. This cube is inspired in the numerical meter and moves 0.5" each time a student completes a trial. This cube is defined by the following vector [**<null>**, **<null>**, **<null>**, **<moving 0.5>**].

The talking cube mimicking teachers' practices of giving instructions and prompts

Teachers asked for a T3 cube defined by the following vector: [**<instructing>**, **<prompting>**, **<blinking>**, **<vibrating>**] to give verbal (e.g., "Marley! grab the pink cube!") and positional prompt (i.e., the cube vibrates or blinks). Teachers take into consideration students' functioning level to decide how much prompting a student needs and use this information to decide which events activate from the configuration panel.

8.1 The T3Board: assembling several T3 pre-configured cubes in a board

After selecting the desired pre-configured T3 objects, we assemble all these objects in a board (Fig. 6 left) per teachers' request. The T3Board is a 22.06" × 12.21" × 4.14" wooden box assembling:

- four talking cubes (Fig. 6d left) that will give instructions and prompts to students;
- one meter cube that will advance 0.5 each time a student finishes a trial and will give teachers feedback on the number of completed trials (Fig. 6c left);
- two markers cubes embedded in a happy and a sad face-box (Fig. 6b left) that will light on green when the student correctly completes a trial and red, otherwise; and
- one reward cube (Fig. 6a left) that will sing the 'Looney Tunes song', spin, emit fireworks, and congratulate the student when the student successfully completes a trial.

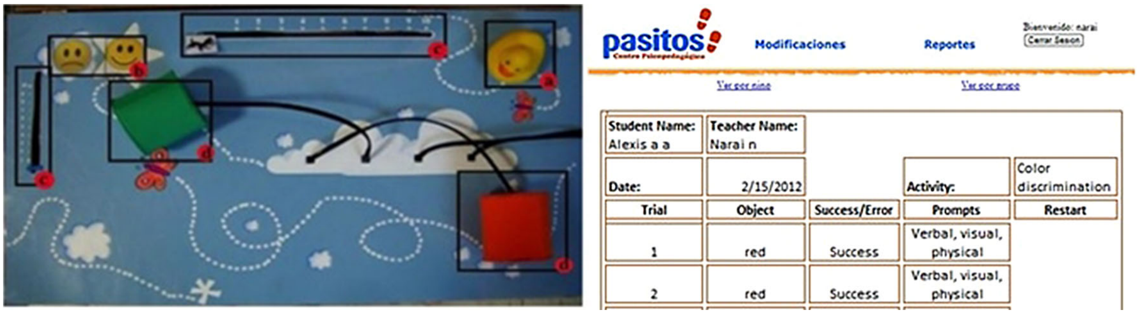

Fig. 6 The T3Board assembling, a reward (*a*), a sad face-box and a happy face-box markers (*b*) a meter (*c*) and four talking objects to give instructions and prompts when appropriate (*d*) (*left*). An example of the reports the system generates (*right*)

We extended our architecture adding one module to the RFID glove acting as a master table controlling all the objects in the T3Board. Whenever the RFID glove detects a "right answer" message, it will activate the adequate face-box, the meter, and the reward; in contrast, the RFID glove will activate the prompting configured in each T3 talking cube when student incorrectly selects an object or when no response is detected. All of these objects communicate via Broker.

One of the features of T3Board is automatic log generation. This log records activity data such as duration, prompt count, and rewards given. This data enables teachers to generate and distribute summarized progress reports (Fig. 6 right). The T3Board system allows the exploration of its logged data through a web application that, for information privacy purposes, requires a password. The teacher can access and review recorded data for a specific date or download a summary over a time period.

9 Results

Overall, the use of the T3Objects on the T3Board (Fig. 7) has a positive impact in teachers' workload helping teachers to keep students "on task", facilitating the record-keeping, and reducing the burden associated with giving instructions, prompts, and rewards. Also the T3Board helped students to stay engaged on the therapy and improve their cognitive efficacy.

9.1 Use and adoption

Participants found the T3Board "easy, fun, and engaging". Teachers and students rapidly learned how to use the T3Board with a few hours of training.

> I felt that [the students] immediately began to understand [how to use the T3Board] and worked quite well… (Bella, teacher)

> [The T3Board] works for me, it is something different but the most important thing is that [the T3Board] works for the students (Adriana, teacher)

These results demonstrate that "smart objects" are important and useful in classrooms and for therapies of students with autism. The results also imply that low-functioning students with autism are capable of using "smart objects" during therapies facilitating the work of teachers.

9.2 Burden and workload

We found that teachers reduced the time they spent capturing notes and maintaining the records when using T3

Fig. 7 Participants using the T3Board during the evaluation study. A teacher setting up the therapy (*left*) and a student using the T3Board when discriminating the *red color* (*right*) (color figure online)

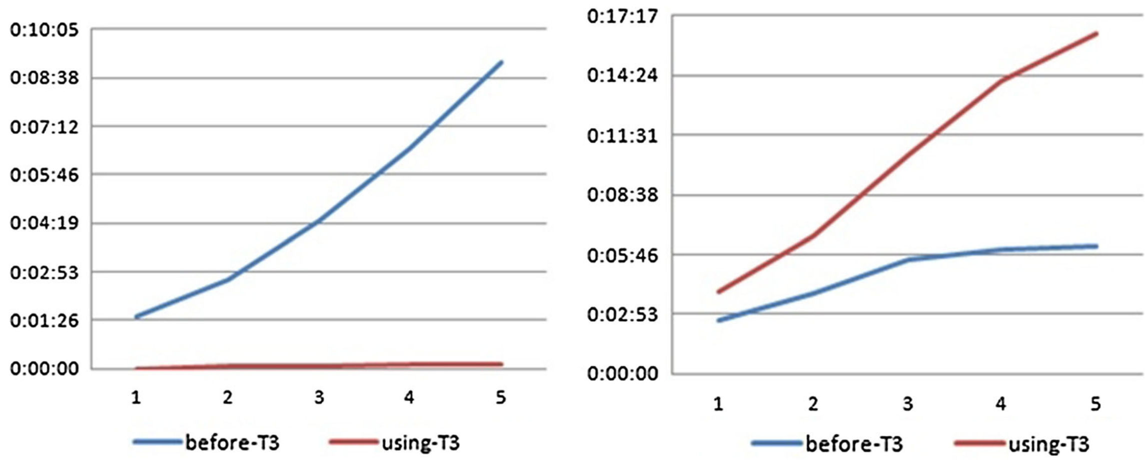

Fig. 8 Per week cumulative distribution comparing the average time teachers was taking notes, before and using-T3 (*left*). Per week cumulative distribution comparing the average time students was "on task", before and using-T3 (*right*)

than before (before-T3 00:03:19; using-T3 00:00:03; $p = 0.05$, Fig. 8 left).

> When we start using [the T3Board] I felt a little bit weird because I am used to take notes in every trial, but now [the T3Board] is [taking the notes] for me, and it's awesome because after using [the T3Board] when I'm taking notes I didn't realize what [the student] is doing (Anna, teacher)

> [The T3Board] helps us to take notes because most of the time, before the T3Board […], we used to keep the notes in our minds but when the therapy ends and we have to take the notes […] we didn't remember everything, we got lost! (Adriana, teacher)

Using the T3Board, teachers did not need to worry for remembering important events happening during the trials or to take notes during the therapy. These results indicate that smart objects may not only reduce the burden associated with maintaining the record-keeping, but also help teachers to stay focused on the student during the therapy.

> Now [using the T3Board], I do not annotate, I focus on what [the student] is doing, I like that, and now that I saw the reports, I like it more. I was shocked because I saw so much data I don't usually record (Nadia, teacher)

These results highlight the importance of using technologies to facilitate the record-keeping during the therapies of students with autism, as a design insight when designing smart objects. We found out that the automatic record-keeping enables teachers to be aware of students' performance and also teachers reported a reduction in the number of given instructions and prompts (before-T3 9; using-T3 5; $p = 0.09$) and rewards (before-T35.83; using-T3 4.93; $p = 0.14$) per therapy. Note that these results are not significant because we are quantifying the verbal prompts and rewards teachers gave to students. These results probe that verbal support was not reduced after the introduction of T3 indicating that support from teachers is still important and by no means replaced by the smart objects.

> Yes, I did less prompts, I saw the students more interested in participating [in the therapy] and in the work (Bella, teacher)

9.3 Cognitive efficacy and engagement

The students improved their behavior when using the T3Board during the therapy and when waiting for their turn, as they were more engaged with the teacher and in the therapy (before-T3 00:01:35; using-T3 00:03:25; $p = 0.001$, Fig. 8 right). Before the use of the T3Board, the students did not make visual contact with the teacher nor with the objects used during therapies. But this behavior changed when using the T3Board.

[The T3Board] engages students; there is a desire [from students] to use [the T3Board]. When using the [T3Board] students behave better (Carla, teacher)

> Before [using the T3Board] I used to prompt students to make eye contact, saying: 'Linda look at me' […] I often used physical prompts moving her head to make eye contact. Now using [the T3Board] I don't have to do that, because the student is looking at me, waiting for me, waiting to work (Anna, teacher)

These results highlight the importance of mimicking current teacher practices for behavior management when designing tangible technologies for students with autism. Such practices have a positive impact on the interaction and engagement of "smart objects" portraying a new type of interactivity.

Beyond the impact on behavior, we observed the T3Board positively impacted the performance of students, in terms of their cognitive skills.

> Using [The T3Board] I can see improvements in the students, also with just one session (Adriana, teacher)

> I feel students more independent, for example students were working alone, they are learning to discriminate (Bella, teacher)

The use of the T3Board improves not only the efficacy of the therapy in students, achieving faster results, and promoting better results. The T3Board allows students to perform the activity in a more independent way, with less prompts and instructions from the teacher.

10 Conclusions

In this paper, we show how appropriately designed "smart objects" can play a crucial role in alleviating the challenges teachers face during the object discrimination training of students with autism. Our results show that our design principles are useful for the development of appropriate "smart objects" that facilitate the record-keeping, reduce teachers' workload, and help teachers to keep students "on task".

The primary contribution of this work was to articulate the design space of "smart objects" for a specific population and explore how our design principles could be used as a framework to develop smart objects to support autism education.

Teachers were very interested in exploring how T3 objects help students to generalize the skills learned outside the classroom, opening new questions to explore the impact surrounding the use of "smart objects" in real-life situations, beyond the classroom environment. Furthermore, the levels of independence to be reached by individuals using these tools and the ways in which these "assisted-independency" is measured should be further interrogated.

As for future work, we plan to include more interactions gestures and patterns to the T3 cube to reach a much broader range of functionality and explore the use of the arduino sensor technology for enabling the wireless communication among our "smart objects". The lessons described here could be useful for people designing "smart objects" for children and for practitioners in special education looking for innovative ways to improve the care of students with autism.

Acknowledgments We thank to Pasitos A.C. for their support. This work was funded through Lizbeth Escobedo's and Catalina Ibarra's CONACYT fellowships and through the UCMexus Grant #634-237 and CONACYT Grant #10256.

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