

Using Augmented Reality to Help Children with Autism Stay Focused

Using the Mobile Object Identification System, which lets teachers superimpose digital content on physical objects, the authors study how augmented reality can increase the selective and sustained attention of children with autism during object discrimination therapies and elicit more positive emotions.

Autism is associated with impairments in attention management, information processing, and memory.¹ According to Kathleen Quill of the Autism Institute, “children with autism display a wide range of attentional disabilities and deficits across the many domains of attention function, including selective and sustained operations.”¹ *Selective attention* refers to the ability of children with autism to stay on task, even when a distraction is present, and *sustained attention* refers to their ability to focus for an extended period of time during continuous or repetitive activity. Children with autism also experience difficulties recognizing and expressing emotions, and most educators and psychologists agree that children’s emotions can affect

with autism find task repetition boring and frustrating, and the objects used don’t appeal to them. Consequently, children with autism often spend a lot of time off task and have difficulty sustaining their selective attention.

Caregivers use a variety of strategies to help such children stay on task and have a more positive experience, such as annotating text on top of physical objects,³ using verbal and physical prompts, and offering rewards. Here, we explore how augmented reality might help redirect the attention of children with autism to the objects used during therapy by bridging the gap between the physical and digital worlds. Using the Mobile Object Identification System (Mobis), a mobile augmented reality application we developed to let teachers superimpose digital content on top of physical objects, we investigate whether augmented reality elicits positive emotions and increases selective and sustained attention among children with autism during therapy.

their ability to focus on a task.¹

Therapeutic interventions for autism heavily rely on *discrete trial teaching*, a method that breaks down tasks into smaller components called *trials*, and *stimulus-response-reward techniques* that use physical objects to teach basic skills such as attention management, compliance, and imitation.² However, most children

Exploiting Digital Labels

Work on pervasive computing has explored a variety of technologies—including livescribe (www.livescribe.com/en-us), near-field communication, and RFID—for creating “digital labels” by tagging physical objects with digital information to integrate the physical and the

Lizbeth Escobedo
Autonomous University of
Baja California

Mónica Tentori, Eduardo
Quintana, Jesus Favela,
and Daniel Garcia-Rosas
Center for Scientific Research
and Higher Education



Figure 1. Participants across study phases. (a) A student with autism attending to an object discrimination lesson, (b) Pasitos staff during a participatory design session, and (d) children with autism using our technology during a deployment study.

TABLE 1
Summary of the data collected across study phases.

	Qualitative study (2010)	Participatory design sessions (2010–2011)	Evaluation (2012)	Total
Interviews with teachers	13	2	16	31
Total of hours of observation	75	—	54	129

virtual world (examples include Touch Counters,⁴ Memory Spot,⁵ and Tap & Play⁶). According to Tim Kindberg and his colleagues, digital label acts as a “bridge between the physical and virtual worlds [connecting] objects to services and applications. Labels are realized through tags—physical entities attached to or integrated with objects.”⁷

Other projects have researched how to create and manipulate interactive digital labels to help children with autism remediate their speech and language disabilities (such as Mocotos³), improve their social skills (such as Mosoco⁸), and manage their schedules (such as vSked³). These works raise questions about how we might integrate such interactive digital labels with the real objects and digital content that children with autism use during therapies.

A recent trend in creating digital labels to integrate the physical and digital world involves letting people use their smartphones as a “visor” to discover digital information embedded in

a physical object (sentient visors,⁵ for example). This type of augmented reality has been successfully used with children with autism (for example, with Mosoco⁸ and Arve⁹). However, to our knowledge, the efficacy of such applications has yet to be tested, and open questions remain as to how augmented reality could combine the benefits of both physical objects and interactive digital information to support real-time structured lessons for educational interventions.

Understanding Attention Management

For three months, we conducted a qualitative study to understand the attention management strategies that teachers use during therapies for autism (see Figure 1a). As Table 1 shows, we conducted 75 hours of passive observation and 13 semi structured interviews with 11 teachers working at Pasitos—a specialized clinic in Tijuana, Mexico, where 15 psychologist teachers care for close to 50 low-functioning children with autism.

Teachers at Pasitos use the *combined blocking procedure* to teach students how to discriminate between different objects.¹⁰ This method involves having students conduct trials in which they repeat a particular task. Each trial involves discriminating between two or more objects. Consider the following example scenario with a Pasitos teacher, Bella, and a five-year-old low-functioning student, Marley. Bella is trying to teach Marley how to identify a glass.

Bella starts by placing a glass and fork on the table in front of Marley. Then, Bella starts the first of 10 trials, asking Marley to grab the glass. Marley shakes his hands and moves his head from side to side, looking around the classroom instead of at the objects. During this time, Marley is off task. Bella physically redirects Marley’s attention, turning his head toward the objects, pointing to the glass, and saying, “Marley! Grab the glass!” Marley grabs the fork instead. Bella grabs Marley’s hand and places it on the glass, saying, “Marley! Grab the glass!” Marley grabs the glass and gives it to Bella. Bella rewards him by giving him a piece of cookie and saying, “Good job, Marley!” Then, Bella takes notes on the first trial, drawing a sad face to mark the trial as incomplete, because Marley needed many prompts. When Marley sees the sad face in his notebook, he gets angry and screams at Bella.

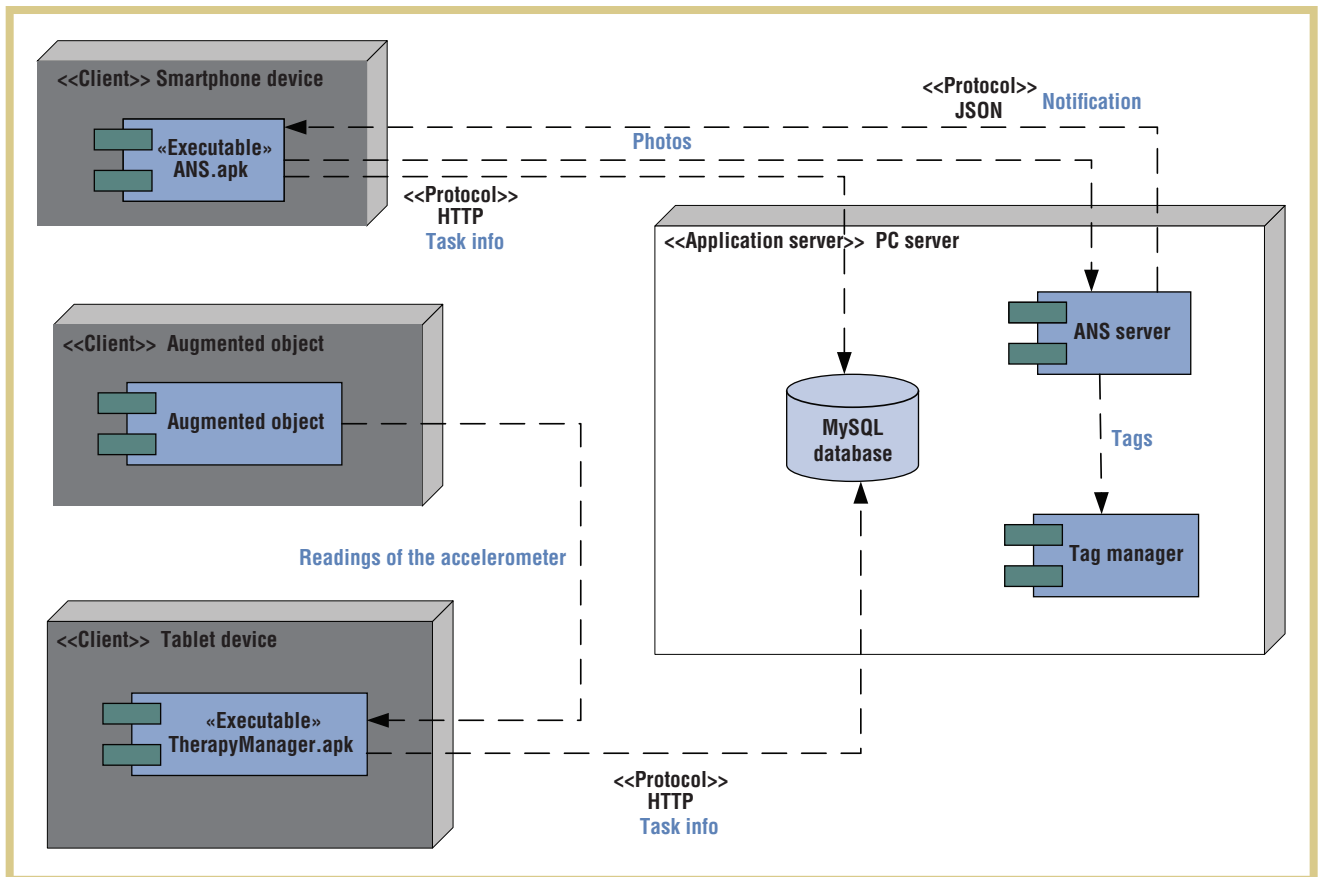


Figure 2. The Mobile Object Identification System (Mobis) architecture: the tag manager running on a PC, the Ambient Notification System (ANS) running on an Android smartphone, the therapy manager running on an Android tablet, and the augmented object embedded in the physical object.

The Mobile Object Identification System

Following our observations, we designed and implemented Mobis.

Design's Methodology

We used an interactive user-centered design methodology and spent the next 12 months iteratively designing two low-fidelity prototypes to present to the teachers (see Figure 1b). We conducted two participatory design sessions to discuss our prototypes and uncover new design insights. Using the results from these sessions, we selected one prototype to redesign and deploy.

We spent another two months developing Mobis from the selected prototype. Teachers chose the Mobis design because it accommodated both mobile

computing and augmented reality. The teachers needed a tool to potentially help students identify objects integrated into the environment, so being able to directly annotate digital content on physical objects while also allowing students to move away from the desktop was useful.

Architecture and Functionality

Mobis enables the direct annotation of digital content, including text, audio-recorded messages, and visual shapes (such as circles) on top of physical objects. Its architecture includes four main subsystems (see Figure 2):

- the therapy manager,
- an extended version of the Ambient Notification System (ANS),¹¹

- the tag manager, and
- accelerometers used to augment objects.

The therapy manager personalizes the therapy for each trial. Then, when the accelerometer detects an event, it tells the ANS which object the student is manipulating. The ANS captures a photo of the object and sends it to the ANS server. Then, the ANS server extracts the appropriate features from the received image and identifies the object. The ANS server stores the context associated with the students' performance (such as the time, object used, required prompts, and rewards). Together, all these subsystems provide the following functionality.

Intelligent Personalization

Incorporating intelligence into pervasive computing is becoming increasingly important, although most pervasive applications don't currently offer intelligent services. This vision of intelligence will greatly contribute to the creation of a smart world filled with a variety of embedded intelligence, letting pervasive applications adapt to users' needs.

Mobis lets teachers manually specify the level of prompting each child needs, but it continuously detects each child's progress to automatically decide how to fade out or increase the level and amount of prompting in real time. Algorithms running in the therapy manager continuously learn from users and automatically adapt the amount and type of prompting the system provides. These algorithms use a set of predefined thresholds to decide when to increase or remove prompting. Teachers can manually override this functionality if a student can't complete the task with the level of prompting automatically set by the system. These types of prompts are provided in the form of audio and text messages, vibration, and visual geometric shapes.

Automatic Object Recognition

Most available solutions for automatic object recognition use physical tags (such as RFID tags, accelerometers, or stickers) that alter the fabric of the object or use complex algorithms that heavily depend on environmental conditions (such as vision-based techniques). Mobis combines both to improve accuracy. We used physical tags with accelerometers attached to the objects of interest to detect students' interaction with the object, and we used vision-based techniques to identify the object.

To recognize objects, we used the Speeded-Up Robust Features (SURF) algorithm to extract features as interest points (IPs) from images.¹² This algorithm keeps a knowledge database, storing a set of images that will be later

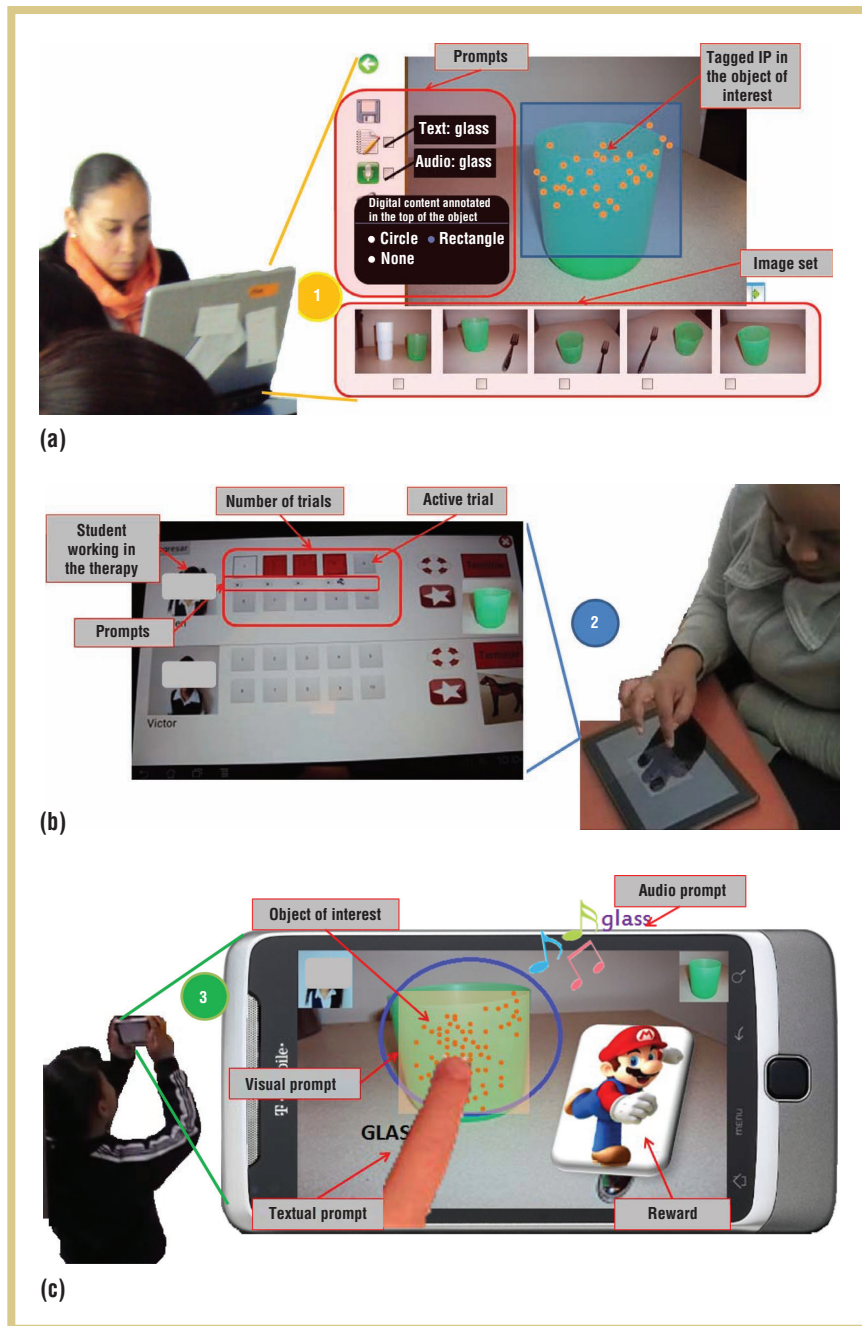


Figure 3. Using Mobis: (a) a teacher uploading photographs and tagging objects, (b) a teacher monitoring an ongoing trial, and (c) a student receiving prompts and rewards during a therapy.

used to compare against the source image. Teachers use the tag manager to create a database of images, uploading photos of the objects used during therapies. They associate tags with these images and associate the tagged images with the related therapy or classroom.

To create a tag, the tag manager subsystem shows teachers the images stored in its database. Teachers then select the object of interest—that is, the object they want the student to identify (see Figure 3a). The teachers then select one cover image to represent a set of

photos of the object of interest. Then, for each cover image, teachers annotate the digital content (for example, selecting the shape and adding a related audio or text message).

Mobis will later display this digital content as a prompt superimposed over the object of interest, using the ANS subsystem. The ANS server uses the SURF algorithm to select the IPs from the source image and compare them against the IPs stored in each of the tags available in the database for the object of interest.

To recognize when a student manipulates objects, we used accelerometers to augment the objects of interest and help teachers capture students' interactions. The approach for gesture recognition uses windows of 0.5 seconds, containing 25 accelerometer readings from which we extract the mean, variance, and root mean square as features to feed a linear classifier, detecting the interaction gestures of grabbing, shaking, and releasing an object with 90 percent accuracy.¹³

Labeled Physical Objects

There's renewed interest in using augmented reality to label the world, given that smartphones with cameras and a variety of readers or sensors are now in the hands of millions—soon perhaps billions—of people. Smartphones thus have the potential to help define appropriate interactions for augmented reality services.

We deployed the Mobis ANS subsystem on a smartphone. The ANS superimposes digital content (such as audio, text, and visual prompts) on the image captured from the smartphone camera. The students use the ANS as a “visor” (see Figure 3c) to uncover the digital content to help them identify objects in a visual plane during the object discrimination therapies. Digital content could be in the form of text annotations, sound, or predefined geometric shapes, which teachers select from the therapy manager.

Cloud Connectivity

Flexibility and performance are important when developing mobile and augmented reality systems. The ability to automatically upload information to the cloud improves flexibility, because updates can be easily shared. Furthermore, this helps protect smartphone resources by running resource-demanding services in the cloud. However, having devices connected to the cloud, constantly exchanging information and heavily depending on the communication channel, might jeopardize performance.

To balance this trade-off, the smartphone extracts features and captures images, while it's the server's responsibility to recognize the context. Also, to lighten the data-transfer load, we used contextual information to determine what to share. For example, at the end of each trial, the ANS sends an “update request” message to the ANS server to monitor changes in the images available for the corresponding classroom using the tag manager. Even though this decision sometimes slightly delayed object recognition (by approximately 3 seconds), we got an average performance time of approximately 0.5 seconds, which is sufficient to support this therapy in real time.¹³

Evaluation Methods

We deployed Mobis in three Pasitos classrooms (see Figure 1c) with seven teachers working with 12 low-functioning children with autism. The children were between the ages of 3 and 8—the mean age (*m*) was 5.08, and the standard deviation (*SD*) was 0.9. We followed a single subject design, with three conditions: pre-deployment (two weeks), deployment (five weeks), and post-deployment (one week). We wouldn't move from one condition to the next until a follow-up pattern emerged (that is, we got the same results for each variable measured).¹⁴ Researchers video recorded all of the therapies and conducted weekly interviews with teachers across each study

phase (we recorded the interviews, each of which lasted approximately 30 minutes; *m* = 0:43:10; *SD* = 01:10:05). We interviewed teachers as proxies¹⁵ for students' needs and reactions, because only three of the 12 students participating in the study could pronounce some words. The total time of observation was just under 54 hours.

For our data analysis, we followed a mixed-method approach. We used grounded theory and affinity diagramming techniques to analyze the qualitative data, and we applied sequential analysis to quantify students' video-recorded behaviors. During deployment, we used the affinity diagramming techniques to better understand the effect of Mobis, and we used this knowledge when developing our interview questions. At the end of the study, we complimented our affinity diagramming with techniques to derive ground theory using open coding. Our coding scheme for the systematic video-coding involved codes describing selective and sustained attention, the ability of students to conduct the therapy (on-task versus off task), positive and negative emotions (such as happy or mad), and teachers' types of prompting (such as verbal or visual).

Ten researchers, trained in the use of our coding scheme, coded the videos, generating a new timestamp whenever a student changed activity. The interobserver agreement was acceptable (*r* = 0.907). Using our coded video transcripts, we estimated, for each participant during each condition, the total and descriptive statistics of the time students spent experiencing different emotions and exhibiting different attention spans. Finally, we used an analysis of variance to compare these statistics for each condition.

Interacting with a Labeled World

To better understand how Mobis increased the selective and sustained attention of students with autism during object discrimination therapies while

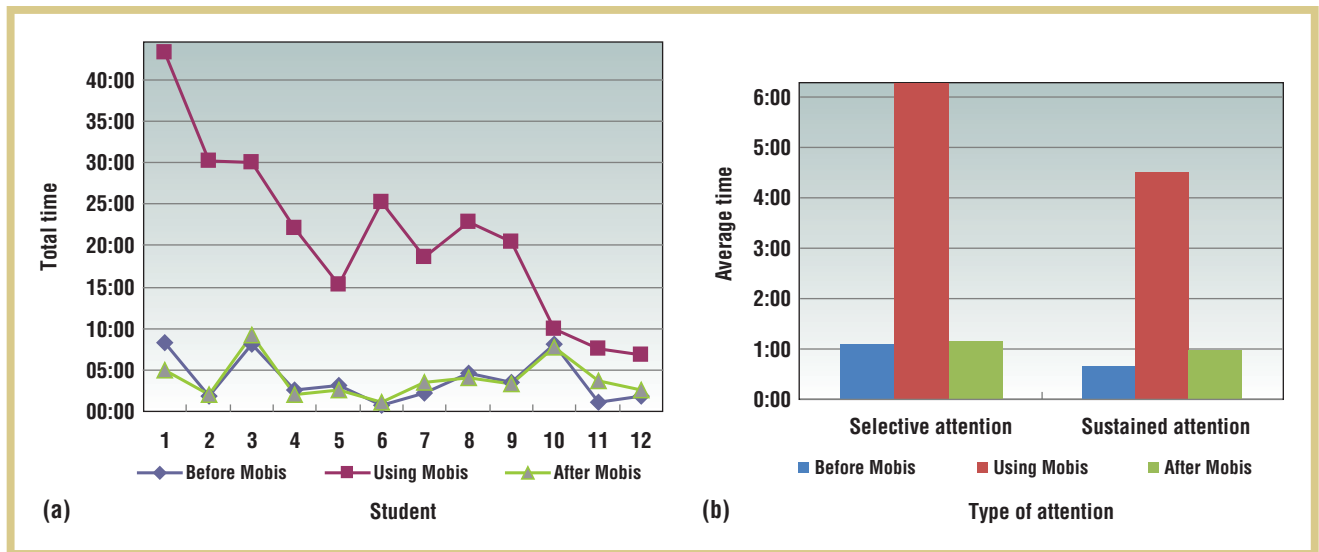


Figure 4. Mobis increased the time students remained on task. (a) Per student distribution comparing the total time students were “on task” before, during, and after Mobis use. (b) Total average time of students maintained selective and sustained attention before, during, and after Mobis use.

inciting positive emotions, consider how the following example differs from the earlier scenario.

Bella selects from the therapy manager an audio message and a circle as prompts to help Marley identify the glass. Then, Bella selects a brief video clip of Mario Bros. as a reward and activates the first of 10 trials. Bella hands Marley the smartphone, running ANS, and asks him to grab the glass. When Marley grabs the smartphone, it emits a sound and vibrates, showing the image of the glass on the top-right of the screen to remind Marley of the object he needs to grab. Marley grabs a fork augmented with accelerometers and Mobis makes a sound and superimposes a circle on top of the glass saying: “Marley! Grab the glass!” Marley sees the prompts and grabs the glass. As a reward, Mobis shows Marley a short video of Mario Bros dancing. Marley laughs.

Adoption and Use

Participants reported that Mobis was “useful, exciting, and easy to use.” Students learned to use Mobis with two days of training—an hour each day—and with minimal support from teachers.

Our results indicate that low-functioning students with autism can use augmented reality technology and a mobile device as a visor to uncover digital content. Although teachers helped students when manipulating the smartphone running Mobis (for example, helping students focus the camera or hold the smartphone), teachers explained that, surprisingly, students rapidly learned how to manipulate the smartphone. As one teacher noted (participants’ quotes were translated from Spanish to English),

Students experienced some problems when handling the smartphone [as a visor], but they got used to it. They got used to the smartphone’s weight and figured out how to hold it.

In addition to the traditional way of performing the therapy (one-on-one, sitting face to face), students used Mobis to discover their environment, walking through the classroom to identify objects painted on walls as well as outside of the classroom (such as in corridors near the classroom).

Mobis helped students discriminate between and identify new objects. As one teacher explained,

By listening to and looking at the object at the same time, [the students] can learn more.

These results highlight the importance of using this technology for students with autism, enhancing therapy goals with easy interaction, and potentially moving the therapy away from the desk to the environment where students live and interact—and, more importantly, without the help of teachers.

Impact on Attention

Mobis increased the time students remained on task by 20 percent while using Mobis (see Figure 4a). Students were on task for 17:15 minutes before using Mobis, for 3:12:47 hours while using Mobis, and for 20:55 minutes after using Mobis ($p = 0.003$). Students were more motivated during the therapy session when using Mobis—particularly when using it “on the move” to discover objects in the environment. As one teacher, Caroline, said,

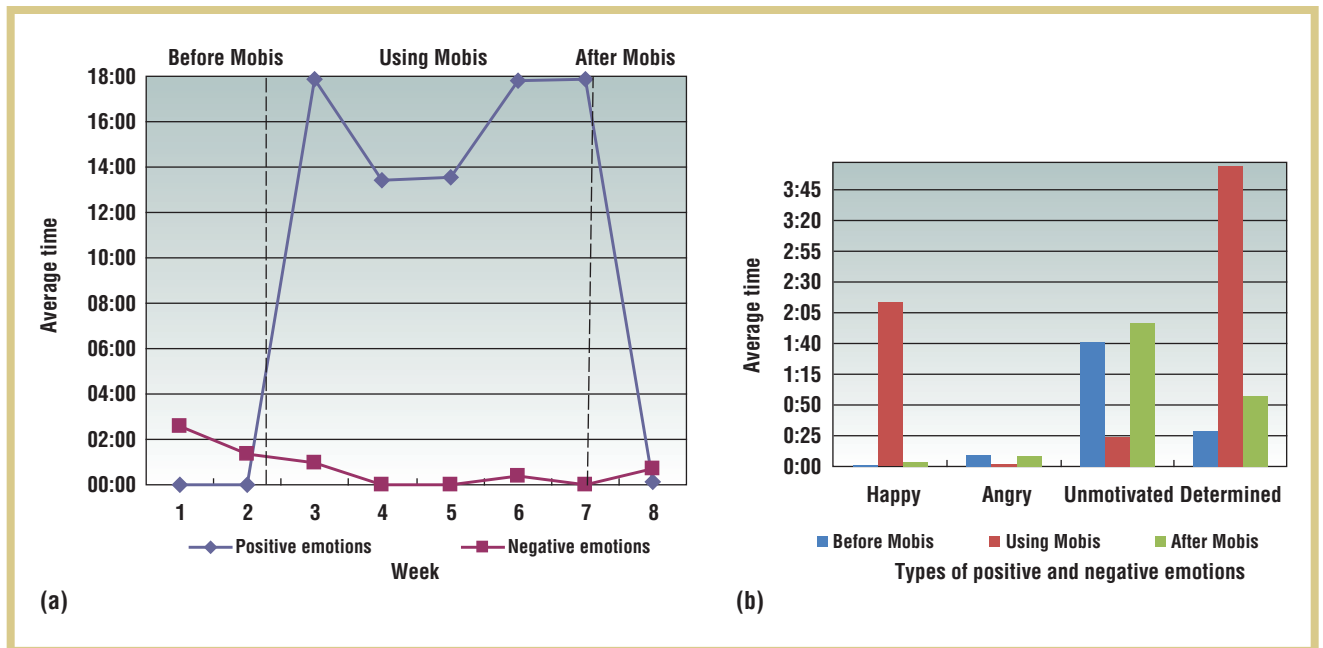


Figure 5. The effect of Mobis on emotion: (a) per-student distribution, comparing the average time students exhibited positive or negative emotions before, during, and after Mobis use; and (b) the total average time of students experiencing different emotions before, during, and after Mobis use.

Students now enjoy the therapy. They used to be apprehensive [before Mobis], but now they are more proactive and engaged in the therapy.

Rather than distracting the students and increasing errors during the therapy, Mobis helped increase student engagement with people and objects, which were the main problems the teachers were encountering. Mobis improved both the selective and sustained attention of children with autism (see Figure 4b).

Students improved their selective attention by 62 percent while using Mobis (before Mobis stayed attentive for 01:05 minutes; using Mobis this increased to 06:18; and after Mobis it lowered again, to 58 seconds; $p = 0.0002$), because they were engaged in the therapy (see Figure 4b), even when something could potentially distract them (such as other noises in the environment). Another teacher, Adriana, said,

Students were not distracted trying to get something near them, or seeing what happens to a classmate, or arranging the objects, or attending to some random noise. Students just [got Mobis] and start[ed] to focus on the therapy.

This finding demonstrates how augmented reality is a useful tool for promoting engagement during therapies for children with autism.

We also found that Mobis improved sustained attention, increasing the time students remained consecutively on task by 45 percent while using Mobis ($p = 0.005$) (see Figure 4b). As Bella explained,

Before [Mobis], some students would not even listen to us, even though we repeatedly called out their names. Now, because of the smartphone, the system, the sounds, [and] the visual stimulus, they are more engaged in the therapy and [spend] more time on task.

Overall, Mobis caught students' attention in a simple and effective way, with the ambiguous role of presenting unobtrusive stimulus (visual and audio prompts) due the capabilities of augmented reality technology, which proved effective for attention management—especially for children with autism. These results highlight the importance of mimicking current practices for attention management (such as the use of prompts and rewards) as features when designing augmented reality technologies.

Altogether, these results demonstrate that students increased their engagement during therapies, making therapies more effective. These kinds of tools can also be useful in traditional schools, which also have disruption problems during classroom activities.

Inciting Positive Emotions

As Figure 5 shows, Mobis incited more positive emotions among students during therapies—a 24 percent increase (0:01 before, 2:13 during, and 0:07 after Mobis use— $p = 0.004$). Caroline,

recalling one student “smiling and dancing,” said Mobis “motivates [the students] a lot!”

In addition to eliciting positive emotions, Mobis taught students positive behavior skills, such as how to be tolerant of others. For example, students learned when another student was doing the therapy, because Mobis made them more alert to classroom activities as they watched what their peers were doing and waited their turn. This implies a change in student behavior, because students were less stressed during the time spent in the classroom—they were more relaxed and patient. Positive changes in behavior increase the likelihood of children with autism being able to act in a socially acceptable manner, helping them better fit into society and integrate into social groups. One teacher, Adriana, said

Students are improving their patience. They didn't get frustrated doing the therapy, and they didn't start flapping their hands...in general, [there were fewer] behavioral issues.

Simple Tools for a Complicated Labeled World

One of the most important decisions when developing augmented reality services is to enhance a real experience while keeping the interaction model as simple and natural as possible. The use of Mobis leads to open questions about how to create a more suitable “augmented reality visor” to help individuals with cognitive impairments manipulate and discover augmented reality services.

One reason we chose to use a smartphone as the augmented reality visor for Mobis was to let students use the services while “on the move,” without needing to equip the classroom. However, children struggled (for a couple of days) to focus on the smartphone, and teachers spent significant time prompting students on how to use the smartphone. We observed



Lizbeth Escobedo is a PhD student in computer science at the Autonomous University of Baja California, Mexico. Her research interests include ubiquitous computing, HCI, and assistive technologies. Escobedo received her MSc from the Center for Scientific Research and Higher Education (CICESE). She's a student member of the ACM. Contact her at lizbeth.escobedo@gmail.com.



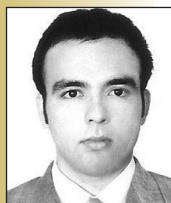
Mónica Tentori is an assistant professor in the Computer Science Department at the Center for Scientific Research and Higher Education (CICESE), where she investigates the human experience of ubiquitous computing to inform the design of ubiquitous environments that effectively enhance humans' interactions with their world. Her research intersecting HCI and ubiquitous computing particularly focuses on designing, developing, and evaluating natural user interfaces, self-reflection capture tools, and new interaction models for ubiquitous computing. Tentori received the Microsoft Research Fellowship in 2013 for her research work. Contact her at mtentori@cicese.mx.



Eduardo Quintana is a research assistant in the Computer Science Department at the Center for Scientific Research and Higher Education (CICESE). His research interests are ubiquitous and mobile computing, augmented reality, HCI, and social mobile applications. Quintana received his MSc in computer science from CICESE. Contact him at equintan@cicese.edu.mx.



Jesus Favela is a full professor of computer science at the Center for Scientific Research and Higher Education (CICESE), where he leads the Mobile and Ubiquitous Healthcare Laboratory. His research interests include ubiquitous computing, medical informatics, and HCI. Favela received his PhD in computer science from the Massachusetts Institute of Technology. He's a member of the ACM and of the Sociedad Mexicana de Ciencia de la Computación. Contact him at favela@cicese.mx.



Daniel Garcia-Rosas is an MSc student in computer science at the Center for Scientific Research and Higher Education (CICESE). His research interests include ubiquitous computing, HCI, and pattern recognition. Garcia-Rosas received his BS in computer science. Contact him at jdgarci@cicese.edu.mx.

that having the visor as a tangible device uncovered other uses. For example, children used the smartphone to “physically tap” on the image, portraying a new interaction model based on the metaphor of “tap and play.”⁶

In this regard, it will be interesting to design a new device that let users physically tap on or point to objects to discover digital content. Another solution is to take advantage of available wearable devices for augmented reality, such as Google glasses. In this case, the trade-off will be in deciding how long the user will be willing to wear the

device instead of carrying it around, given that some populations won't tolerate contact with the device.

Overall, when selecting the most simple and accurate tool to provide augmented reality services, it's important to consider the characteristics of the user and the effort required to set up evaluations in real conditions.

Mobis could be integrated with other pervasive technologies appropriate for use inside the

classroom, especially with capture-and-access tools, to help identify when a student with autism is on or off task during therapy. Such an environment might also help teachers automatically capture contextual information relevant to attention to evaluate children's progress. In this regard, it would be useful to design algorithms for the automatic recognition of attention.

The novelty of the augmented reality system clearly affected student engagement, but it's not clear from our five-week deployment whether this effect wore off. In future work, we'll analyze the effect of Mobis on the teachers' workload and the system's longer-term effect on students. ■

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