e-MoBo, a Low-Cost, "Robo-Mediator" Helping Therapists Teach Children How to Express Emotions: Insights from Field Testing

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***Abstract*— Parental estrangement can cause long-term harm to socio-emotional skills, mental health and wellbeing. This is pronounced for children who experienced trauma. "Robo-Therapists" have been used to train children to express emotions, but such robots are often "human replacements" and tend to be too costly to deploy widely. We propose *e-MoBo*, a low-cost, non-humanoid "Robo-Mediator" of our own design to train children's socio-emotional skills towards creating stronger relationships with others. We report on the developing *e-MoBo* and results of a field study with the current prototype and 14 neurotypical children, ages 5-9, as we prepare to deploy *e-MoBo* in a residential center with traumatized children. Our results suggest that *e-MoBo,* compared to a control, helps children express emotions, offering the promise of a low-cost, non-anthropomorphic, Robo-Mediator meeting children's needs.**

I. Introduction

The bond formed between parent and child is the most crucial attachment for a child's growth and development [1]. Attachment Theory holds that children have a natural tendency to seek out social interactions with primary caregivers to form lasting, attachment relationships [2]. When a child experiences abrupt separation from a primary caregiver, or when caregivers are not present or responsive enough, the child often suffer deficits in social and emotional functioning, short- and long-term, and diminished mental health and wellness, among other detrimental effects [1].

The impact of neglectful caregivers is especially pronounced in children who experienced early childhood trauma, causing emotional dysregulation. These children are often assigned by the State or caregivers to live in, or attend school and treatment at a trauma-care center [3]. Typically, the center's therapists aim to strengthen the child's capacity to recognize, express and regulate emotions in accordance with specific social contexts. The success of such a strategy is, however, dependent on the training performed at trauma-care centers which, in the US, oftentimes suffer from staff shortages, staff turnover, insufficient training, and a high ratio of children per staff member – all of which may lead to significant, acute delays in a child's physiological, cognitive, and socio-emotional development [4, 5].

In the field of social robotics, research that aims to investigate the effects of robot-assisted therapy is growing [6]. In this paper, our interdisciplinary research team presents "*e-MoBo*" – a robotic device of our own design that, with participation of a caregiver (e.g., a therapist, teacher, or staff member), helps children express emotions – one of the biggest obstacles in a child's "social-emotional learning" (SEL).

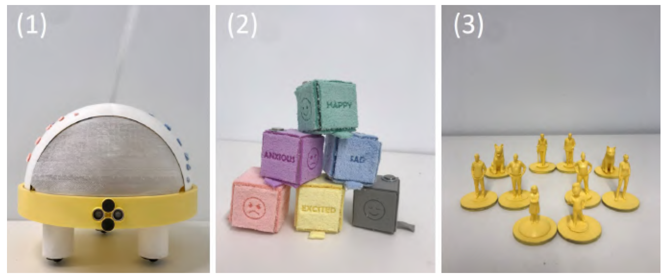

Figure 1: e-MoBo: new prototype.

In this paper, we report on field studies with three early e-MoBo prototypes (introduced in [7]), present a new design integrating their most promising aspects (Fig. 1), and report results from a field study with the new e-MoBo design, engaging fourteen neurotypical children from a local pre/after-school to inform the readiness of e-MoBo for field studies with children who experienced trauma. We close this paper with a consideration of a significant design advancement we implemented in the e-MoBo design informed by the field study at the school, discuss the larger promise of this kind of research for child-robot interaction, and present our plan for bringing e-MoBo to traumatized children at the Hillside Residential Center (Rochester, NY).

II. State of the Art: Emotional Robots for Children

This research can be characterized as "robotic psychology," a subfield of HRI which explores how robots could be used in psychological science and therapy [8]. Technological interventions like e-MoBo have excellent potential for children's socio-emotional learning in therapy which can translate to real-world situations, helping children recognize, express, self-regulate, and control emotions [3]. Robots displaying suitable behaviors can act as a source of encouragement, fostering proactive engagement in, and facilitating shared focus between child and a peer or adult [6].

Some approaches to studying socio-emotional learning using robots include: capturing motion data from children to study play patterns and analyzing how these relate to affective responses [10]; exploring how robotic assistants might help to improve verbal communication in children with different disabilities [11]; exploring the ability of children to understand emotions exhibited by a robot with only movement as

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feedback [12]; investigating the potential to help children learn basic psychosocial skills from interactions with robots [13]; testing robots and their social benefits in the context of collaborative play [14]; exploring how robots could recognize a child's intent during play [15]; investigating how robots could be used to train turn-taking skills through robot-child interaction [16]; and aiming to improve social behaviors through HRI [17]. The field study conducted by our group, reported here, falls under "behavior studies" – how a child´s behavior (expressing emotion) and cognition (awareness of emotions) change when a robot is or was present.

As part of our research, our team undertook a targeted review of state-of-the-art robots previously developed for improving socio-emotional skills in children. Some of the robots found in the literature have been developed to detect emotions in users through behavioral reading and provide feedback according to the acquired data [18]. Most of these robots focus on regulating the emotions of children. Other robots have been developed to exhibit emotions to the child through multimodal stimuli to improve skills related to empathy [10], [12]. As positive reinforcement, such robots typically use visual stimuli (in the form of lights and visuals presented by screen), auditory stimuli (in the form of sounds and music), and tactile stimuli (in the form of movement, vibrations, and even smell). Many robots effectively apply behavioral recognition through cameras, microphones, heartbeat sensors, temperature sensors, and other sensors dedicated to behavioral capture [18]. One of the most widely tested robots for this purpose is the NAO humanoid robot [9]. For our research, the standard means for behavioral recognition (cameras, microphones, on-body sensors) may be too intrusive for the targeted population, raising ethical issues and logistical challenges for staff, therapists, and caregivers. Moreover, many of the robots cited from the literature are prohibitively costly for public, residential institutions like Hillside. Less costly, less intrusive, e-MoBo has the potential to help adults teach children how to express their emotions without the robot generating assumptions about the child.

According to Daniel et al. [19], social robots in psychological therapy are either "Robo-Therapists" or "Robo-Mediators" Most robots found in the literature cited here are Robo-Therapists that are designed to replace adult humans – therapists, staff, teachers, and caregivers. But as the literature suggests (e.g., [20]), best therapeutic practice is to balance a child's interaction with robots and humans. As such, our research aims to develop a Robo-Mediator, *e-MoBo*, that helps children express emotions to therapists, staff, teachers, and caregivers while at least one of these adults is present and active.

III. DESIGN PROCESS: PREVIOUS WORK AND LEARNINGS

The research reported here follows from three early e-MoBo prototypes: "*e*", *Mo*", and "*Bo*" that we introduced in [7]. Practically, *e-MoBo* aims to help children engage and connect with their inner emotional world as they handle and touch a child-centric robot, observe how the robot responds to their actions, and express their emotions to adults through words and gestures, thereby improving conversational and overall interpersonal skills. Co-designing e-MoBo with Hillside therapists and staff will continue to provide insights on how to promote safety and efficacy in research sessions with traumatized children by employing strategies that closely resemble clinical and routine interactions with children [3].

e, *Mo*, and *Bo*, our three early prototypes, were introduced in a first meeting with Hillside therapists and staff, and to children, ages 4-13, at the Sciencenter in Ithaca, New York. Our findings are presented in Table I-1. Two main gaps were identified: (1) *Lack of conversational aspects* (lacking a continuation of multimodal, children-robot conversation); and (2) *Lack of transition from child-robot interaction to child-adult interaction* (the adult should be part of the interaction from an early stage to ease the transition from interactions with a robot to the same with an adult). At this stage, our team conducted an ideation session to combine and integrate the most promising aspects of the early prototypes into one *e-MoBo* design, the focus of a second meeting with Hillside (Table I-2). During this second visit to Hillside, we were introduced to the therapy rooms and tools that are currently used for emotional learning, which helped inform our design with the goal of enhancing the therapy experience.

TABLE I. LEARNINGS FROM PARTNERS

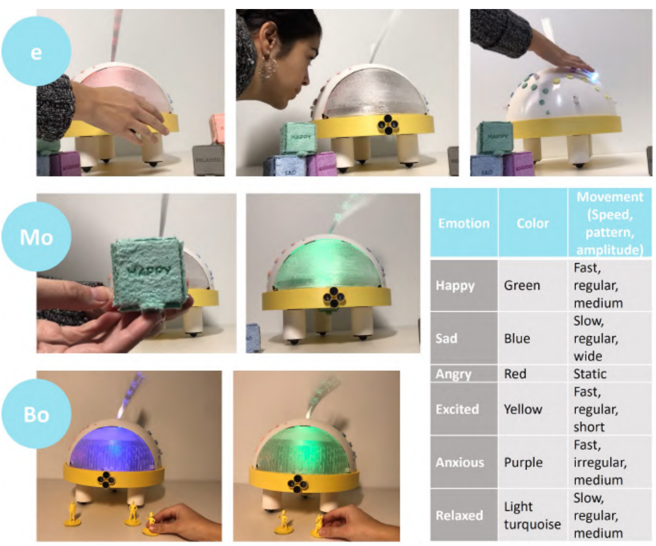
(1) First meeting with Hillside and Science center
• Responses to the user's emotions for empathy training. • Diverse responses for each modality (sound, visual, tactile). • Emphasis on tactile interaction. • Wireless functionality. • Figures beyond humans, such as pets. • Avoid replacement of therapists. • Data collection to track the progress.
(2) Second meeting with Hillside
• Children as leaders of the therapy session. • Endorse storytelling for understanding & expressing emotions. • Tactile stimulation for relaxation. • Permit children to interact with the robot on their own. • Approach: comforting, stable entity that "welcomes" children when they return from their visits home. • Age range: from 4 to 14.

IV. DESIGN: E-MOBO

The design of the new e-MoBo system (Fig. 1) includes three main elements: (1) the *Robot* featuring a 3D-printed, semispherical structure supported by three legs with casters to allow for movement, topped by optical fibers extending upwards; (2) *Emotion Cubes*: wooden cubes embedded with a conductive magnet and covered by felt, where the word and emoji for one emotion is engraved into the felt; and (3) *Figures*: 3D-printed figures that represent people and pets familiar to the child. The new e-MoBo robot incorporates three behavioral dimensions necessary for cultivating effective interpersonal relationships: *Trust and openness* (from the early "e" prototype); *Understanding and expressing emotions* (from "*Mo*"); and *Communication and relations* (from "*Bo*"). These three modes are each explained as follows.

The "*e*-mode" includes three different types of interactions (see Fig. 2-e) aiming to cultivate trust and openness through: (1) *proximity*, an index of a healthy exchange [14] (e-MoBo 'wakes up' and shows a light following a heartbeat pattern); (2) *speech*, a skill for initiating interactions (e-MoBo reacts to sound by moving its fiber optic filaments, signaling the start of the next interaction); and (3) *gamification*, shown to assist in motivating children in behavioral therapy [18] (in a game-like activity, "Follow the Light," e-MoBo lights up an LED, and the child covers it by touching the photoresistor neighboring it. The robot will then play a sound, turn off the LED, and light up a different LED). The "*e*-mode" engages children in an interactive experience through touch and a conversation-like activity – the pragmatic understanding of "taking turns" essential to healthy conversation [11].

The "*Mo*-mode" is dedicated to understanding and expressing emotions. It involves the e-MoBo robot and the Emotion Cubes (see Fig. 2-*Mo*). The child places an Emotional Cube in the cavity below the hemisphere of e-MoBo, located at the center point of the yellow ring, where it is held in-place by conductive magnets. The emotion chosen by the child will be expressed through a unique display of light and movement of the fibrous filaments in the robot so that the child can "see" the emotion in e-MoBo. This activity aims to help children become aware of and express emotions. The emotions (Happy, Sad, Angry, Excited, Anxious, and Relaxed) and colors selected for each cube are those used currently in behavioral therapy according to the literature [1], our own prior empirical work, and by Hillside therapists. The specific behavior for each emotion is described in Fig. 2.



Emotion	Color	Movement (Speed, pattern, amplitude)
Happy	Green	Fast, regular, medium
Sad	Blue	Slow, regular, wide
Angry	Red	Static
Excited	Yellow	Fast, regular, short
Anxious	Purple	Fast, irregular, medium
Relaxed	Light turquoise	Slow, regular, medium

Figure 2: '*e*', '*Mo*', and '*Bo*' modes and behaviors.

The *"Bo*-mode" is dedicated to developing conversational skills and forging personal bonds (see Fig. 2-*Bo*). Starting from the emotion selected by children and expressed by the robot, children are asked to tell a story that leads them to feel this way (e.g., angry), making use of the 3D-printed figures (Fig. 1). This activity is deeply rooted in the concept of reflection to gain self-knowledge. Technology has been proven very beneficial in supporting human reflection [21]. One of the most effective techniques for this is storytelling, which is rooted in personal reflection towards expressing emotions and empathy and building relationships. Our plastic figures were based on Furman and Buhrmester (2009) key personal bonds for children: parents, grandparents, teachers, and friends. In conversations with Hillside, however, we determined that our figures were too restrictive. Consequently, our 3D-printed figures are: 2 women, 2 men, separate figures for grandparents, a girl, a boy, a nuclear family (neutral), a dog, and a cat – together, these figures open more possibilities and narratives for children.

Following Hillside's advice to make surfaces softer to enhance tactile stimulation, e-MoBo features a pattern of multicolored felt circles that form a path. Finger-tracing is one of the most common techniques to calm children [22].

Previous studies [10] have argued that robots do not necessarily need language, facial expressions, or body postures to elicit an emotional situation. As such, e-MoBo was designed with the premise that a social robot should be designed for a few specific behaviors that promote quick understanding and engagement. Additionally, studies [10] suggest that robot designs characterized by abstraction rather than figuration (e.g., human-like and pet-like) allow children to discover their own rapport with the robot during interaction. Accordingly, the eyes that were a key feature in the early *Bo* were conscientiously not embodied in the new e-MoBo design. Likewise, to avoid anthropomorphism, the ultrasonic sensor, often "read" by users as eyes, was disguised (Fig. 3). Accordingly, the new e-MoBo evokes emotional states exclusively through movement, lights, rhythm, and sounds (without verbal feedback). Lastly, for e-MoBo, the incorporation of any kind of display was also avoided, as tangible technologies have been shown to provide more effective paths for self-expression, leading to greater agency [6]. All the design decisions considered here resulted in the non-anthropomorphic e-MoBo robot serving as mediator between child and adult, avoiding both "replacement" of adults and a dependency of children on the robot.

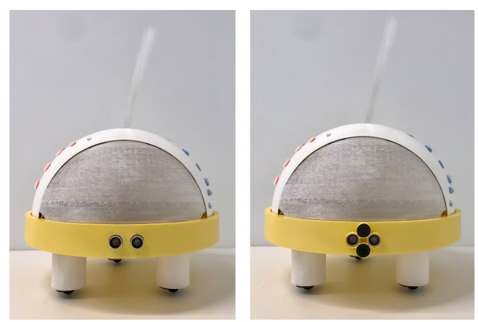


Figure 3: Redesigning e-MoBo as a non-anthropofmorphic robot.

V. STUDY

We tested fourteen neurotypical children (7 boys and 7 girls), ages 5-9 (Mean age 6; Median age 7) at the IC3 pre/after school in Ithaca, New York. Experimental and control groups were balanced in age, gender, and number. Two researchers occupied a small meeting room at IC3: one researcher played the role of a therapist, while the other took notes on a laptop using software designed to consistently capture durations and numbers of behaviors while ensuring the camera was capturing video for subsequent coding. The main goal of the study was to establish whether children in the experimental group, interacting with e-MoBo, would be more willing to express emotions with an unfamiliar adult than children in the control group who were only provided the cubes and figures (the e-MoBo robot was not present). Results were expected to build confidence in our design and inform a next iteration worthy of testing safely with children who had experienced trauma and are treated at Hillside.

For both groups, the Emotion Cubes and 3D-printed figures were arranged randomly in a row on the table. In the experimental group, where the children interacted with also the e-MoBo robot, three activities (here, "A") were carried out (corresponding to the design explained in Section IV):

A1. Introduction to e-MoBo via the Light Game. The child is encouraged by the experimenter to get close to e-MoBo which then presents a light pattern. Next, the child is asked to speak to the robot, to which e-MoBo responds by moving its fiber optic filaments. Following these introductory steps, the "Light Game" begins: the child is asked to touch the LED that e-MoBo lights. When the child touches proximate to the lit LED, that LED turns off, a sound is played, and an LED at a new location is lit. This trajectory repeats for 10 "Lights."

A2. Emotion Cubes. In this activity, the researcher offers the child the first cube on the left and asks the child to search the cube's faces to find the word inscribed for one of the six emotions. The cube is then placed in the cavity on the underside of e-MoBo, which then actuates an evocation of that emotion through colored lights and physical movement of the filaments. Children are then asked to identify the emotion portrayed by e-MoBo. The process is repeated for all six cubes, each cube inscribed with one emotion-word, picked hereafter by the child in random order.

A3. Storytelling. The researcher asks the child to select the cube that represents that emotion that best characterizes how the child felt earlier that day or in recent days. The child then inserts that Emotional Cube into e-MoBo, which portrays that emotion. The researcher then asks the child to tell a story that provoked that child-selected emotion using the 3D-printed figures (if the child wishes to use them). The prompt is given: "*Can you tell a story that made you feel [emotion]? You can use the figures to help you if you'd like*."

In the control group (the group *without* the e-MoBo robot), children were provided the Emotion Cubes, the 3D-printed figures, and wooden disks that replicated the "Light Game" activity but without interactive lighting. To mimic Activity 1 in the experimental group, five wooden discs with engraved stars on one face were set randomly on the table with the stars facing down – replacing the interactive electronics. Three activities akin to the three activities for the experimental group were carried out as follows:

A1. The Path Tracing Game. The researcher turns a wooden disc upside down, and the child is asked to flip it back over. This path-tracing game was repeated 10 times as for the experimental group.

A2. Emotion Cubes. The researcher hands the child the first cube on the left and asks the child to search the cube's faces to find the word inscribed for one of the six emotions. This process is repeated for all six cubes, randomly picked one-by-one by the child. As there is no e-MoBo for the control group, each cube is simply set aside after it's examined.

A3. Storytelling. The researcher asks the child to select the cube that represents that emotion that best characterizes how that child felt, earlier that day or in recent days. As for the experimental group and with the same prompt, the researcher then asks the child to tell a story that provoked that child-selected emotion, using the 3D-printed figures.

Our partners at Hillside were very clear that children are never left alone in the therapy room. Moreover, according to the critical position against "human replacement," while the robot can play an important role in therapy sessions, the therapist must also be present and guide the interaction to facilitate emotional expression. (e-MoBo has been designed, however, to be useable by children without an adult present.)

The study was video-recorded, and the videos were coded. To assess children's expression of emotions while interacting with an adult, we employed measures from the literature, divided into *behavioral* and *verbal* [11, 13]. Behavioral metrics relied on the visual behavior of the child. We documented the number and duration of time the child looked at the robot and compared that to the number and duration of time in which the child looked at the 'therapist'. In addition, children's facial expressions were analyzed to identify the number and duration of time the children expressed an emotion, positive or negative. Regarding the verbal aspects of the child-adult interaction, both quantitative and qualitative factors were considered: (1) the number of words per session expressing emotion; (2) the semantic content of the child's story when asked about a feeling they had (e.g., the extent to which children offered details when describing their emotion); (3) an estimation of the extent to which children felt safe enough to share their emotions with the 'therapist' (e.g., whether they shared anything personal/emotional).

VI. RESULTS

A. Behavioral metrics

Children in the experimental group displayed considerably more emotions than the control group (Fig. 4). The Mean percentage of time children expressed emotions through gestures during the session was 12.33% for the experimental group and 5.47% for the control group. The interaction with e-MoBo brought about different positive emotionality: Laughter (P4), wiggling (P4), "thumbs up" (P3), and descriptive words ("cool!" P1; "This is fun!" P3) (Fig. 5-P). Similarly, when e-MoBo displayed negative emotions, the experimental group expressed negative emotions: frowning (P3, P4, P5) and lowering their voices (P3, P4) – what seemed to be empathy with e-MoBo (Fig. 5-N). In contrast, the control group was emotionally neutral. This suggests e-MoBo's capacity to elicit emotional expressions solely by lights, movements, and sounds.

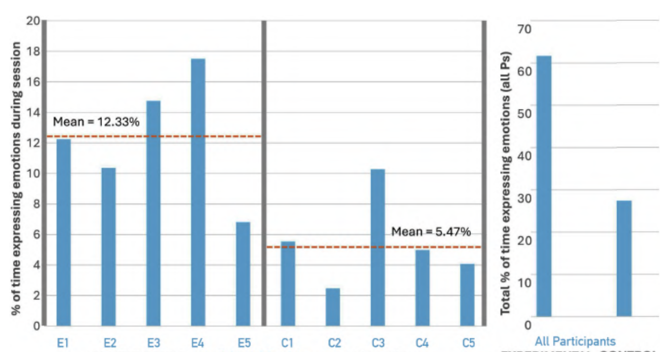


Figure 4: Children in the experimental group displayed considerably more emotions than participants in the control group.

Figure 5: Children in the experimental group expressing emotions.

B. Language and Communication

The child's age significantly impacted the results of our semantic analysis. In *Activity 2. Emotion Cubes*, older participants (ages 8 and 9), with more developed language (reading and speech) skills were able to read the emotions on the cubes, while younger children (ages 5-7) had difficulty. The cubes that posed greater difficulty were "anxious" (P4-P7, P11-P14), and "relaxed" (P2-P6, P11, P12, P14). The "angry", "excited" and "happy" cubes were also sometimes interchanged (P3, P5, P6, P11, P12). This suggests that, with younger children, the faces of the Emotion Cubes could be improved to depict feelings in a more precise manner. When emotions were identified incorrectly, the researcher continued with the activity using the emotions that the child identified. When the child answered, "*I don´t know*.", the researcher provided the correct emotion. In this case, it was observed that when the child in the experimental group put the cube inside e-MoBo and the researcher asked them how the robot felt, the child made an effort to remember the emotion that the researcher clarified before, suggesting that e-MoBo enables the learning of unfamiliar emotions (P1, P2, P4, P5).

Figure 6: Children in the experimental group interacting with the figures.

In *Activity 3. Storytelling*, regardless of the group, older participants expressed themselves in more detail (using more words), whereas younger children were more reserved or did not want to make the effort. In comparison with children in the control group, children in the experimental group referenced more concrete incidents from their lives associated with the emotions they selected, involving personal stories (P1 and P13), specific people (P3, P14), actions (P3, P4, P13, and P14), and objects or things (P3, P4, P5, P13). The 3D-printed figures of Activity 3 proved beneficial in getting participants to express emotional experiences (Fig. 6). Children could identify their family members, teachers and themselves in these figures. However, participants P3, P9, and P10 stated that the collection of figures could use more children.

C. Post Reflection

Table II presents some key findings from our study at IC3.

TABLE II. FINDINGS FROM THE STUDY

Positive aspects in the design
• e-MoBo: Effective and enjoyable • Favorite elements: cubes (texture) and filaments (movement). • Filaments: due to their movements and position towards eye-level, facilitated eye contact between child and adult. • Light game: enjoyable, intuitive, and helped engage those who were shy (P1, P4, P5).
Reactions and new ways of playing (see Fig. 7)
• Positive reactions to the movements of the filaments through smiles (all Ps), placing their hand next to the fibers (P2, P4, P14), wiggling (P4), and verbal annunciations (P4, P13, P4). • Placing the soft felt cubes close to the face (P3). • Stacking the cubes; separating positive and neative emotions (P6). • Placing figures under the robot (P2, P5) and on top of it (P5).

Figure 7: Children in the experimental group interacting with the moving, filaments and soft cubes (caregivers consented to use faces in all figures).

VII. DISCUSSION AND FUTURE WORK

We reported on three early designs and a more current design of e-MoBo, an assistive robot to help train traumatized children to express their emotions. Our exploratory user study with neurotypical children suggests that e-MoBo is a promising tool for helping children learn, understand, and express emotions to others. Through interactive experiences with e-MoBo, children in the experimental group were engaged, enjoyed the activity, expressed emotions, and were empathetic to the robot. When asked to rate the experience using a graphical 5-point Likert scale ("1" for *unhappy*, "5" for *very happy*) children in the experimental group all rated their experience with e-MoBo "5, *very happy*" versus a mean of "3.6" from the control group. More importantly, these interactive experiences with e-MoBo enabled children to express their emotions with an adult (Fig. 4).

In our field study, we observed that children treated the figures as distinct from the robot. We since iterated our design so that children could place the figures on an integral, transparent "stage for storytelling." The small holes in "stage" allow light to pass through, illuminating the figures in colors corresponding to the emotions they choose (See Fig. 8).

Figure 8. e-MoBo's new feature: integrating the figures with the robot.

This design feature promises to dissolve the barrier between e-MoBo and the figures we observed. In the future, we will cautiously explore the incorporation of language processing, enabling the robot to recognize specific words uttered by the child and respond accordingly. Additionally, future smart capabilities might record proximity of the child, frequency of emotion selection, and instances of emotional words expressed. This data could then be compiled to create a record of the child's emotional states for productive use.

VIII. Limitations

Our iterated e-MoBo will be deployed in a user study with children at the residential facility in a real therapy context involving professional staff. Inviting children who experienced trauma to interact with a lesser prototype would be irresponsible. We followed a design mandate to only expose vulnerable populations to systems that were sufficiently developed to minimize potential for the design failing or causing undue harm or complications. The studies reported here with neurotypical children were planned as anticipatory for the study of the iterated e-MoBo prototype for reasonable deployment with a larger sample of traumatized children at Hillside. Upon returning to Hillside to work with its population of children, we plan to compare e-MoBo with the NAO robot to compare the efficacy of our design with a state-of-the-art.

IX. Conclusions

Our field study results suggest that e-MoBo was effective in facilitating neurotypical children's learning, understanding, and expression of emotions such that we can confidently use it with children who experienced trauma. This work represents a design exemplar of a low-cost, nonhumanoid “Mediator” that promises to enable vulnerable and neurotypical populations.

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