DEMONSTRATION

RainbowForest: A Playful Educational Tool to Engage Children with ASD in Learning through Play in Classrooms

KEZHUO WANG, Southern University of Science and Technology, Shenzhen, Guangdong, China

RUI QI, Southern University of Science and Technology, Shenzhen, Guangdong, China

YAFEI GE, Southern University of Science and Technology, Shenzhen, Guangdong, China

PENGCHENG AN, Southern University of Science and Technology, Shenzhen, Guangdong, China

XUELIANG LI, Southern University of Science and Technology, Shenzhen, Guangdong, China

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Kezhuo Wang
School of Design
Southern University of Science and Technology
Shenzhen, Guangdong, China
12333213@mail.sustech.edu.cn

Rui Qi
Southern University of Science and Technology
school of design
Shenzhen, China
12433270@mail.sustech.edu.cn

Yafei Ge
School of Design
Southern University of Science and Technology
Shenzhen, China
12112141@mail.sustech.edu.cn

Pengcheng An
School of Design
Southern University of Science and Technology
Shenzhen, China
anpc@sustech.edu.cn

Xueliang Li*
School of Design
Southern University of Science and Technology
Shenzhen, Guangdong, China
lixl6@sustech.edu.cn

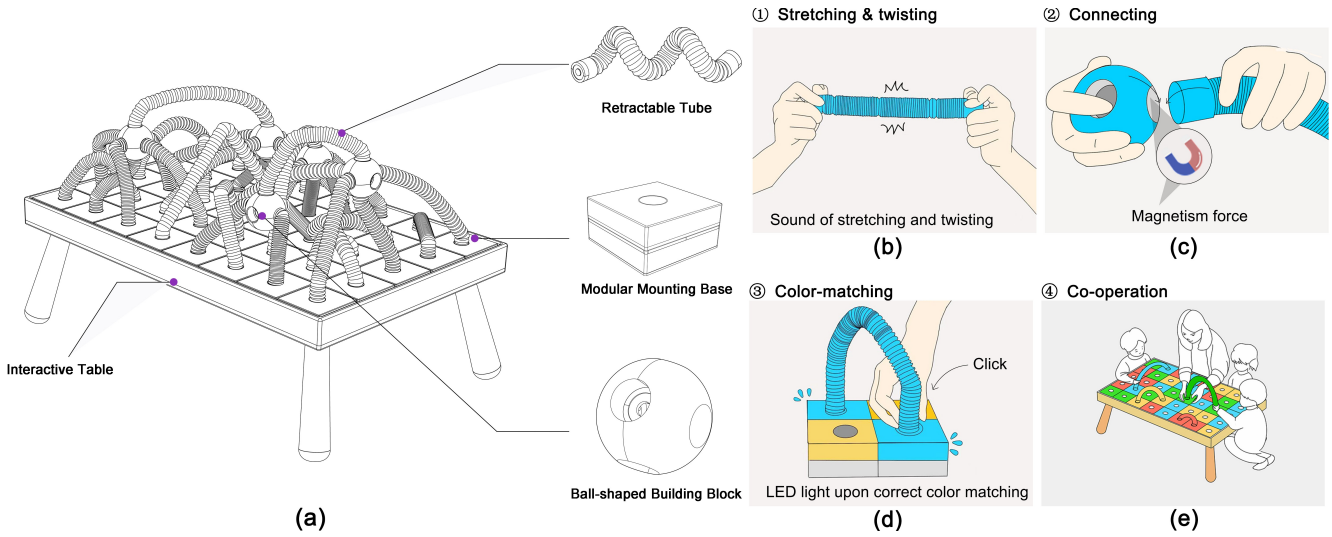

Figure 1: RainbowForest (a) is a playful educational tool designed to engage children with autism in learning through play. It features modular mounting bases, ball-shaped building blocks, and retractable tubes. The design encourages sensory exploration of the modular objects (b), color-matching activities through connecting the tubes with the blocks and mounting bases (c, d), and social play as children collaborate with peers and teachers to build various structures (e).

Abstract

Increasing tangible technologies have been developed to support children on the autism spectrum develop their gross motor and communicative skills through play activities. However, most research focuses on one-on-one interactions between the children and the objects with adult participants. Few designs can be readily integrated into classroom settings where dynamic child-child and child-teacher interactions are essential to the children's play and learning experiences. We design RainbowForest, a playful educational tool that can engage children on the autism spectrum in learning through play. The design idea emerged from a preliminary investigation of existing educational toys commonly used in special education and therapies for children with autism. RainbowForest can engage the children in the structured play of color-matching games as well as the open-ended play of block-building. Our design also serves as a teaching tool, enabling educators to set play rules aligned with specific learning objectives.

*Corresponding Author

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CCS Concepts

• **Human-centered computing → Interaction design theory, concepts and paradigms**.

Keywords

Autism, Children, Tangible, Play, Modalities, Minimally-Verbal

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1 Introduction

Learning through play, also known as play-based learning [2], playful learning [6], and purposeful play[1], is an approach commonly used to promote children's engagement and holistic skills development in learning. While this approach has been widely adopted in child-computer interaction (CCI) [4], challenges exist to include neurodiverse children, especially children with autism spectrum disorder (ASD).

Compared to their typically developing peers, children on the spectrum often exhibit unique behavioral characteristics in play. First, research [13, 14] shows that in familiar, home environments, children with ASD often engage in solitary and self-directed play that they feel comfortable and in control, which might further hinder their development in social behaviors, such as turn-taking, sharing, and cooperation. In addition, children on the spectrum often seek proprioceptive feedback using their bodies as probes to help themselves make sense of their surroundings through movements such as sweeping, bobbing, or flapping [15]. This is also exhibited in their free play as they are exposed to unfamiliar objects[5]. They often choose unconventional play objects such as bottle caps and rubber bands[12]– some researchers refer to this play behavior as "junk object play" [12]–where their interest is mostly attracted by the sensory properties of these items such as their smell, texture, sound, and visual effects[5]. Furthermore, their play often displays a lack of imagination which is often observed in their typically developing peers [10, 11]. Research [8] reveals that compared to "constructive" and "exploratory play", where creative strategies and imagination are employed, children with ASD exhibited a stronger interest in "functional play" driven by the direct purpose denoted by an object.

Human-computer interaction (HCI) technologies are increasingly developed to support children with ASD in holistic skills development through engaging them in physical and social play. For example, Wu et al. [16] introduced SqueeBall, a sensory-rich interactive playground designed for children with low-functioning autism. By incorporating features such as light and sound into softballs, the system encourages group-based play activities, such as sharing and imitation, fostering social connections among participants. Similarly, Wilson et al. [15], through a series of co-design activities, developed ExpressiBall, which is a tangible technology prototype designed to support self-expression in minimally-verbal children on the autism spectrum. Huang et al. developed StarRescue, a collaborative tablet game, that embeds turn-taking mechanics into a modified Pong-like gameplay, to engage preschool children with high-functioning autism in social interactions with positive feedback from both teachers and parents [9]. However, most of these designs are situated in one-on-one interactions between the child and the object with adult participants (e.g., researchers, parents and teachers) peripherally involved, providing feedback or prompts. Few designs exist that address the special needs of autistic children in real-world classrooms where dynamic child-child and child-teacher interactions are interwoven with their play and learning experiences.

To engage children with autism in learning through play in natural classroom settings, we design RainbowForest. This design is inspired by the use of playful objects in rehabilitation and special education for children on the spectrum. Taking a metaphoric approach, RainbowForest contains the elements of sandplay, block-building, sensory and social play. Composed of mounting bases (with color sensors and LEDs built in), ball-shaped building blocks, and retractable tubes, it provides multisensory and interactive experiences in play. RainbowForest can engage the children in the structured play of color-matching games as well as open-ended and social play of block-building. Our design may also serve as a teaching tool, enabling educators to set play rules aligned with specific learning objectives.

2 Design rationale and inspiration

To gain an initial understanding of how playful objects are currently applied to support children with ASD in playful learning, we conducted interviews with 15 professionals (including 3 therapists and 12 special education teachers) and field observations in three autism-specific rehabilitation centers. Our questions for the interviews focused on the professionals' therapeutic and pedagogic approaches in support children with ASD to learn through play, and what and how playful objects are used in their practices. Figure 2 shows the collection of the playful objects (serving as educational toys) from our field observations. Notably, all of these toys were chosen by professionals from the market based on their requirements in practice. None were specifically designed for educational purposes for children with ASD. Through a thematic analysis of the interviews and observations[3], we identified common characteristics shared by these toys, which also align with the literature on autism .

Sensory stimulation. We noticed that the professionals tended to choose toys that provide strong sensory feedback in physical play. For example, the plastic retractable tubes (Fig. 2a) are among the children's favorites, as noted by the professionals. These objects offer multi-sensory feedback, including vibrant colors, tactile stimulation from their textured surface, and engaging sounds produced when they are stretched, compressed, or twisted. Other similar toys, including the Magnetic alphabet board (Fig. 2b) and Rotating toy tower (Fig. 2c), were also favored by professionals for their diverse sensory properties and appeal to children with autism.

Versatility and modularity. According to the professionals, they valued the multifunctionality and the broad range of ways children could interact with them when selecting the objects. Toys with modular features, such as LEGOs (Fig. 2d) were preferred

for this purpose. Another example is the building blocks (Fig. 2e) that allow for the children to engage in a range of creative and imaginative play.

Social interactivity. Social interaction is a key learning objective for children with ASD in rehabilitation and special education [7]. Sandplay (Fig. 2f) has been commonly used as a way to foster the children in self-expression and engage in social communication with others. It also allows children to engage with basic geometric shapes without needing to assign meaning, facilitating independent interaction without professional guidance.

3 Design of RainbowForest

Informed by our previous work as mentioned above, we propose the design of RainbowForest (as introduced in Figure 1). Following the design rationale of *sensory stimulation*, *social interactivity* and *versatility*, it takes inspiration from the sandplay, building blocks and the sensory toys that are commonly seen in therapeutic and educational practice for children with ASD. The design of RainbowForest follows an iterative process driven by our hands-on experiences of making and the immediate feedback of the professionals and children with autism. Below we present the development of two versions of the prototypes that demonstrate this process.

3.1 Design iteration 1

Our design exploration begins with the building blocks and tubes. We aim to ensure the materials, shapes, and connection mechanisms provide an engaging experience for children with autism in terms of *sensory stimulation* and *versatility*. The plastic retractable tubes (Fig. 3a) were chosen as the tube components, directly inspired by our field observations (as mentioned in Section 2). Building blocks of different shapes and placements of connection slots were printed (Fig. 3b), and tested with the tubes to evaluate their compatibility and potential for constructing diverse structures (Fig. 3c).

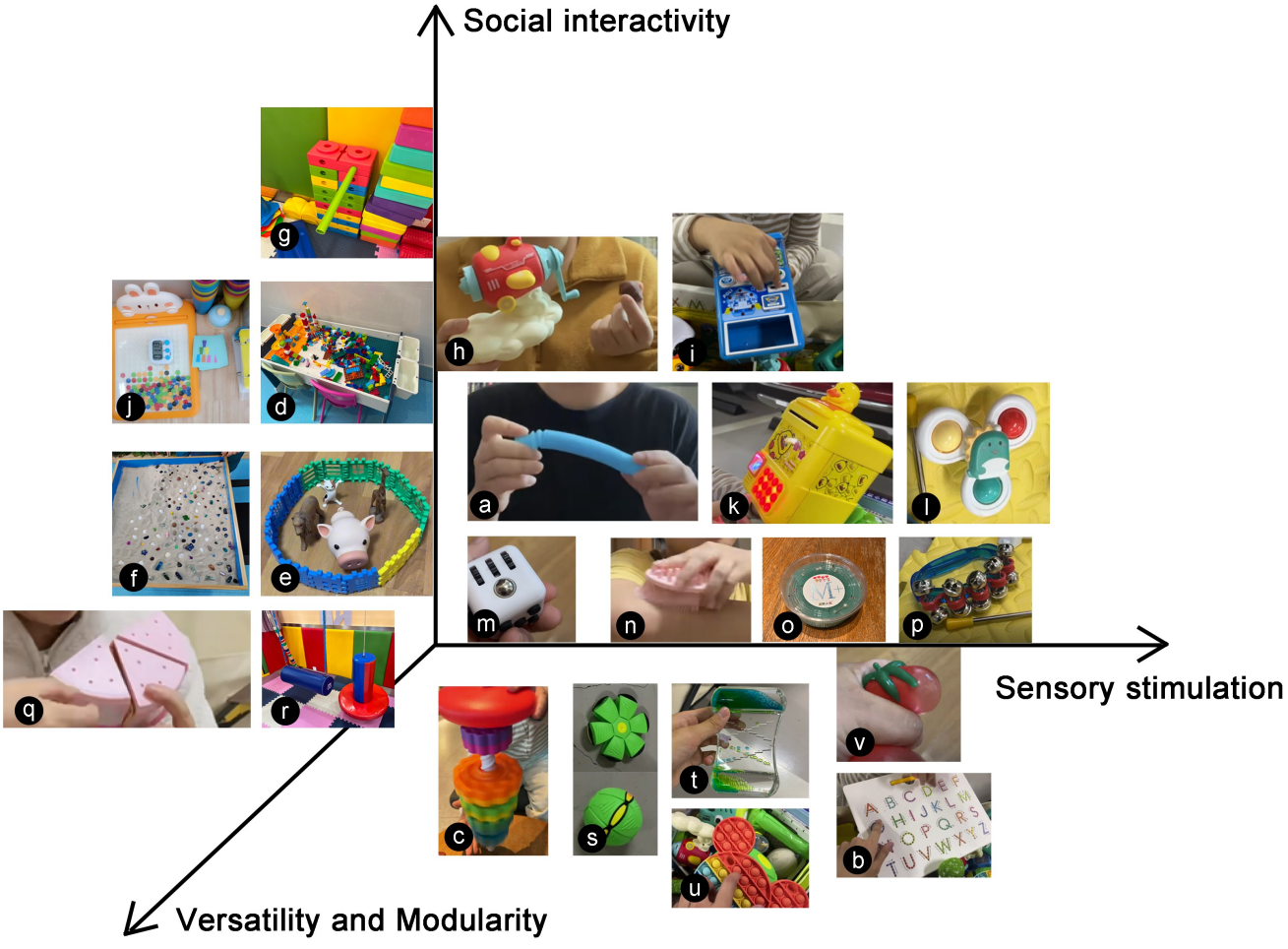

Figure 2: Categorization of playful objects utilized to promote playful learning for children with autism from the field observation

Additionally, the researcher (first author) brought the building blocks and tubes to a rehabilitation center, where they were tested in free play with two children with autism (6 year old, male; 7 year old, male). Before the session, the therapist in rehabilitation center was consulted about the objects to ensure their safety. The session was conducted under the supervision of both the therapist and the researcher, who were available to provide support or guidance as needed. During the session, we observed that the children were interested in these objects and were able to build simple structures with the blocks and tubes (Fig. 3d). We also found that these items could engage the children in collaborative play as one helped the other in connecting the tubes to a three-slotted block (Fig. 3e).

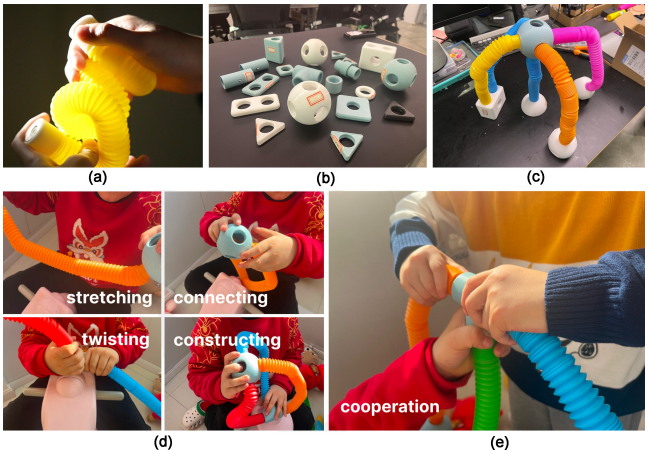

Figure 3: 3D-printed components (a,b,c) and initial testing with two autistic children to explore the possibilities of play

Figure 4: The initial prototype of Rainbowforest (a, b, c) and a discussion session with the special education teachers to receive their feedback (d)

As the result of the first design iteration, we developed the initial prototype of RainbowForest (Fig. 4a, 4b, 4c). Inspired by the concept of sandplay, we made a table (82 cm x 56 cm x 50 cm) as the platform for the children to connect and build with the blocks. The table featured modular cubes made from laser-cut plywood, which served as the mounting bases. These cubes, labeled with different colors and secured to the table using Velcro fasteners, could be rearranged to create various color patterns for the bases. We added magnets to both ends of the tubes, as well as to the slots of the building blocks and mounting bases, to ensure a smooth and secure connection when inserting the tubes into the blocks and bases. We demonstrated this prototype to a group of special education teachers (n=13) on the occasion of an academic event (Fig. 4d). The design received positive feedback from the teachers, indicating its potential to be integrated into real-world classroom settings.

3.2 Design iteration 2

At this stage, we collaborated with a special education primary school and introduced our design as an open-ended playful probe into their daily educational activities. Over the course of five days, 8 special education teachers and 30 children (including 29 children on the autism spectrum and one child with Down Syndrome, aged 7–13) interacted with the design in classroom settings. During the process, the teachers were encouraged to redefine the rules of play according to their experiences and the teaching objectives. Field observation and post-interviews with the teachers were conducted to help us understand how children with ASD engaged with our design during open-ended play, and how the special teachers adopted our design as a resource in creating learning opportunities for the children. Through the user test (Fig. 5), we found that RainbowForest was well adopted by the children in creative open-ended play and by the teachers setting up structured play with specific learning objectives integrated. This field study was approved by the ethics committee of the responsible institution (Approval Number:20240213)

Based on feedback from the field test, we further developed our design. The major improvements focus on enhancing its multisensory feedback and interactivity by integrating electronics into the design. We used a ESP32 Supermini microcontroller, a TCS34725 color sensor, a WS2812b LED strip, a mini power module, and a mini speaker module to initiate automatic recognition of the color matching and provide sound-light feedback (Fig. 6a). Figure 6b shows the state-machine diagram indicating how the different electronics are controlled and communicating with each other. Each mounting base, equipped with a built-in LED and speaker, has two states when powered on: a blinking light to indicate idle status or incorrect color matching, and a steady light and a beep sound to signify correct color matching. We also adjusted the height of the table (40 cm) and size of the modular mounting base (10 cm x 10 cm x 8 cm), to make it more accessible for the children to reach and interact with.

4 Conclusion

In this paper, we present the design of RainbowForest, an playful educational tool that engages children with autism in learning through play in classroom environments. The design concept is informed by a preliminary study including expert interviews with the autism professionals and field observations in the rehabilitation centers. We followed an iterative process to develop two prototypes,

Figure 5: Children interacting with Rainbowforest in Classroom settings

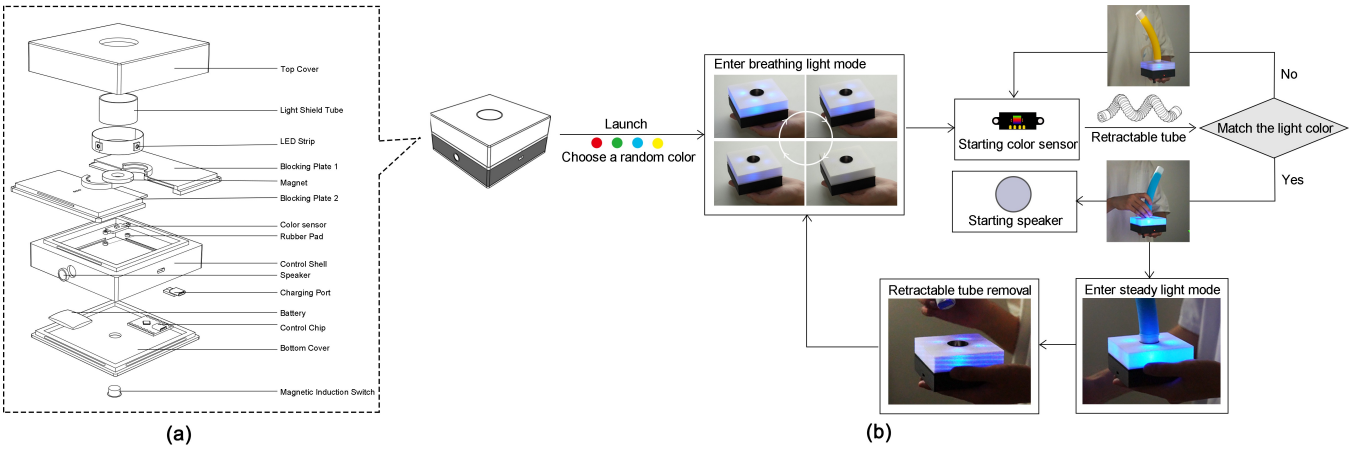

Figure 6: Electronic components (a) and state-machine diagram (b) of the final design of RainbowForest

gaining first-hand feedback from the children with autism and the professionals, and exploring its potential for integration into real-world classroom settings. We contend that our work presents a promising design case for real-world deployment and provides guidence for designers aiming to promote engagement of children with special needs in learning through play.

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