Blended Reality Characters

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ABSTRACT
We present the idea and formative design of a blended reality character, a new class of character able to maintain visual and kinetic continuity between the fully physical and fully virtual. The interactive character's embodiment fluidly transitions from an animated character on-screen to a small, alphabet block-shaped mobile robot designed as a platform for informal learning through play. We present the design and results of our study with thirty-four children aged three and a half to seven conducted using non-reactive, unobtrusive observational methods and a validated evaluation instrument. Our claim is that young children have accepted the idea, persistence and continuity of blended reality characters. Furthermore, we found that children are more deeply engaged with blended reality characters and are more fully immersed in blended reality play as co-protagonists in the experience, in comparison to interactions with strictly screen-based representations. As substantiated through the use of quantitative and qualitative analysis of drawings and verbal utterances, the study shows that young children produce longer, detailed and more imaginative descriptions of their experiences following blended reality play. The desire to continue engaging in blended reality play as expressed by children's verbal requests to revisit and extend their play time with the character positively affirms the potential for the development of an informal learning platform with sustained appeal to young children.

Categories and Subject Descriptors
H.5.m [Miscellaneous]: Human robot interaction. – *information interfaces and presentation.*; I.2.9 [Robotics]; I.3.6[Computer Graphics]: methodology and techniques. –*interaction techniques.;* K.3.1 [Computer Uses in Education].

General Terms
Design, Experimentation, Human Factors, Theory.

Keywords
Human robot interaction; Blended reality character; interreality portal; robot hutch; informal learning.

1. INTRODUCTION
In this paper, we explore the creation of a developmentally-appropriate, technologically-mediated experience for young children between the ages of three and a half and seven. To compliment the vivid and active pretend play, critical to children's development, this technological platform computationally models a *blended reality* context for a new type of play that takes place both on screen and in the real world as a fused and continuous space. This singular play context serves as the springboard for imaginative play activities, blurring the boundaries between screen-based and tangible, robotic media.

The Alphabot, a *blended reality character*, appears to seamlessly move on and off the screen, fluidly transitioning from a computer graphics character on screen, to a mobile robot in physical reality. The character's transmediation is enabled through a physical robot hutch enclosure, acting as a metaphorical portal between the real and the virtual. Passing through the interreality portal, the *blended reality character* maintains continuity and carries with it any changes that happen as a result of interactions with participants in the physical space.

This new context for play blends all of the affordances of the real, physical world in which children naturally develop, with the extensible space and potential of the digital world, in an intuitively accepted spatial arrangement as demonstrated in user studies.

In the following pages, we will describe the concept and design of a blended reality character, and discuss how it's unique interaction context supports young children's play in an appealing and fun environment. The design will reveal the system's foundation is rooted in a generalized approach to robotics as the design of "living characters," with specific extensions to the system to support children's participation in robotic gaming platforms for immersive learning and imaginative play.

This work attempts to understand what the impact of providing such an environment is on preschool-aged children's imaginative play. Using a system theories approach to frame the formal, experiential and cultural dimensions of blended reality, the scope of this paper confines itself to exploring the experiential domain of this framework, focusing on the playful interaction between young children and Alphabot, a blended-reality character (see Table 1).

Table 1. Blended reality framework

	Formal	Experiential	Cultural
Objects	physical blended virtual	human participants robot participants	medium
Attributes	object properties rules system properties rules	human interaction human-robot interaction state of the system	how when why medium was created
Relationships	spatial behavioral (among objects)	social emotional educational playful	medium to culture
Environment	affects objects	context of play	culture

2. MOTIVATION

In our current, top-down media landscape, children often passively consume media produced by adult professionals. Early education specialist and founder of the influential Reggio Emilia approach to kindergarten, Loris Malaguzzi, claimed that *"each child has the right to be a protagonist."* [3] There is an urgent need to protect youth and empower them to shape their own media environments. The United Nations Convention on the Rights of the Child (CRC) adopted in 1989 confirmed this sentiment echoed by educators and media experts around the globe [21]. We hope the system presented in this paper and its evaluation can offer a perspective on what user-generated content by young children transcending cultural and linguistic boundaries might look like.

Alarming recent findings published in a 2009 report by Nielsen indicate the amount of screen time by kids aged two to five is on average more than 32 hours a week [16]. That's over an entire day a week that children are sitting sedentary in front of the television. Meanwhile, over the past three decades, childhood obesity rates in the United States have tripled. In 2010, First Lady Michelle Obama launched the Let's Move campaign stating, "the physical and emotional health of an entire generation and the economic health and security of our nation is at stake" [12]. This work seeks to address some of these issues by creating a novel context for imaginative play that transcends the limitations of current media and empowers children with the tools to physically engage with media both on and off the screen.

Nearly ¾ of American children play computer and video games [22]. Educational games offer a promising and untapped opportunity to leverage children's enthusiasm and help transform teaching and learning. Learning takes place best when children are engaged and enjoying themselves [21]. The literature on play is clear on the importance of creating opportunities for unstructured, imaginative play for preschool-aged children. Play is vital for the social, emotional, physical and cognitive development of young children [9]. If we want to create a future society of freethinking, tinkering problem-solvers we need to support our children's active creative exploration through playful, informal learning.

Inspired by the pioneering work of Joan Cooney, Gerald Lesser, Jim Henson and the Sesame Workshop folks who took charge and dedicated themselves to bringing their vision of accessible and fun education for all, it is our hope that this work plants the seed for an international effort to connect preschool aged children to each other through a playful, informal learning system built atop the foundations of a blended reality. The first step, and one of the core motivators of this work is to show that children have accepted blended reality as an extension of media, and are engaged with blended reality characters paving the way for fun and rewarding learning opportunities.

3. BACKGROUND AND RELATED WORK

3.1 Context for Robot Characters

The Personal Robots Group at the MIT Media Lab has long been driven by the vision to design sociable robots[1]. In an effort to create engaging robotic characters the group's researchers have drawn inspiration and critical insights from classic animation techniques [26]. If a robot were to be treated like a living character imbued with the illusion of life, and sustain an engaging interaction with a person, we playfully reasoned it would need a back-story, a context or world of its own. As one researcher jokingly asked: "Where do the robots go when the lights go out?" Based on the assumption that robotic characters, like animated characters, are perceived as more than the sum of their constituent parts, we imagined that providing them with their very own world might help people interacting with them move past constantly comparing robots to familiar life forms. Testing this fanciful hypothesis meant building a world for robots, a world that could blend into our own so that humans and robots could meet and play in a contextual middle-ground. We began by designing a home or robot hutch for our fluffy squash and stretch robot *Miso*. The idea of a robot hutch, however, dates back to 1950 when Grey Walter built a small home and recharging station for one of his famed analog Tortoise robots. He interchangeably referred to it as a kennel or robot hutch[7].

3.2 The Apple Yard

In [11], the authors advanced a definition of blended reality as the modeling of a "window," through which virtual objects enter the player's physical space. In the "Apple Yard" game prototype developed, a player used a wand to hit virtual apples metaphorically flying out of the screen. The unique features described included the ability for a player to interact directly with a virtual object in the physical world and the idea that the game's display screen is rendered as a "window" that connects the physical and virtual worlds. The potential benefits for health and fun were made apparent, due to the whole-body interaction capabilities of the single-player system designed.

This work also subscribes to a whole-body interaction design philosophy, but extends the definition of Blended Reality to include the user-perceived transmediation of phenomena from virtual to real, tangible objects able to move and interact with the user in physical space. Rather than designing experiences that orient the user towards the screen, our definition of blended reality also models a continuous environment, yet allows for further natural interaction that is not screen-dependent and is tactile and social. It incorporates the use of a metaphorical portal through which an embodied, appealing robotic character extends out of and onto the screen, providing a blended context for play that orients the multiple users towards each other and the mobile, robotic media in the physical interaction space.

3.3 Interactive spaces designed for children

In *Funky Forest,* Theodore Watson created a beautiful, immersive play space and invited children to tend to a digital ecosystem [25]. Projected images of water currents on the floor were affected through the manipulation of tangible plush logs used to direct or dam the water flow. Infrared cameras positioned to detect participant's movement in the space, measured participant's location and arm joint angle values to trigger the growth of trees and influence their branching angles. Our blended reality play context is inspired by a similar artistic and technical approach towards the production of these types of spaces. We agree with the author's emphasis on leaving ample room for children to explore. *Funky Forest's* characters, however, remain on the screen (in the forest). In contrast, the Alphabot, a blended reality character, is able to move off of the screen into physical reality. As a result, we expected to see differences in engagement and collaborative play with the character.

Walt Disney's *Living Characters* initiative is a long-term project combining multiple technologies to create new levels of guest interaction with Disney (and Pixar) characters in their various theme parks [Wal08]. For example, In *Turtle Talk*, Pixar Animation studio's *Finding Nemo* character, Crush (a surfer dude turtle) is brought to life in what looks like a fish tank. The quality of the rendered image is similar to what children see in early Pixar movies, however, the character is rendered live and able to interact directly with children, answering questions to their delight. Although these efforts take talented teams of 40 or more, multiple years and millions of dollars to produce, the results are amazing and seem magical to Disney's guests. These experiences comprise some of the top attractions across the board in the entire Disney theme park system. Blended reality play uses a subset of these techniques with highly simplified characters, but extends the experience seamlessly off the screen as the character transits through the interreality portal. Moving beyond a screen-based interaction, the child is empowered to use all his/her senses to both interact with the blended reality character and affect the media on and off-screen.

3.4 Mixed reality robot gaming

With the goal of blurring the boundary between physical and virtual reality in order to provide a fused context for play, the authors of [19] implemented an interactive, mixed reality (MR) robot gaming platform. Procedurally animated, real-time computer graphics were synthesized live and displayed on a floor-mounted screen serving as a window into the robot character's 3D fantasy world as well as projected into the interaction space shared by both the human player and the robot. A virtual beach ball with the unique ability to transmediate between the floor space and the space in the screen seamlessly negotiated the interreality boundary and provided the main focus for a simple game of pong. Rather than control a character on-screen like in a traditional video game, the user's joystick tele-operated Miso, a tangible, physically embodied robot character as it played with its virtual companions. Special emphasis was placed on the importance of maintaining perceptual continuity by closely coupling the simulated world's physical laws to our material reality. This preliminary work set forth the technical underpinnings of modeling a singular, fused reality and documented the design considerations. At the time, it became clear that although the graphical representation of a ball was smoothly moving between both spaces, the next logical step would be to make the physical robot character appear to move between both spaces.

Figure 1. A Blended reality play space for HRI

4. BLENDED REALITY

Paul Milgram and Fumio Kishino defined Mixed Reality (MR) as "anywhere between the extrema of the *virtuality continuum*" [14]. In practice, the term refers to the merging of the real and virtual worlds to produce new environments where physical and digital objects co-exist and interact in real time.

Blended reality extends mixed reality, enabling the fluid movement of *blended reality characters* between the fully virtual and the fully physical.

This new, kinetically and visually continuous extension of media off the screen and into a mobile and interactive robotic character, is made possible through the use of the *interreality portal* which also doubles as a robot hutch. Motorized doors open on command and close automatically, concealing the robot character as it transits across the interreality boundary. This unique ability maintains the persistent illusion of life for a transmediating character.

The blended reality play environment extends media typically restricted to being screen-based, into the physical world where it can be interacted with in a naturally intuitive and tangible way. The resulting singular, fused context of play encourages whole body movement and collaborative face-to-face social play. It supports an immersive experience without requiring special equipment like head-mounted displays.

4.1 The physical (instrumented) space

The physical play space, measuring approximately 150 square feet provides ample room for up to three children to naturally and actively move through. The floor is cushioned by 42 white foam tiles which constitute a large floor screen. An aluminum truss system framing the space holds the projectors and Phasespace motion capture cameras used to track objects in the space [17]. Three large, sand-blasted acrylic panels make up the main rear-projection screen which measures 12 feet by 8 feet, providing an immersive display with an aspect ratio of 1.5:1. Three ultra short throw projectors mounted and aligned behind each one of the panels project a bright, stitched and cohesive image. Four short-throw projectors hung from the truss system and oriented downwards towards the white floor mats project the ground image. In addition, custom made wooden platforms attached to the truss hold four audio speakers that distribute sound through the space.

4.2 The digital space

The digital world is rendered in real-time on two dedicated graphics computers. The graphics system renders a total of approximately 7 million pixels (7,077,888) at interactive rates on two computers serving nine screens. One of the computers is allocated to rendering a 2304 x 1024 image stream for the main back wall screen while the other renders four 1024 x 768 image streams properly stitched and projected on to the floor. The remaining two additional outputs are used by the system operator to monitor and make live programming adjustments to the environment. The system makes extensive use of Graphics Processing Unit (GPU) accelerated methods to synthesize the resulting experience.

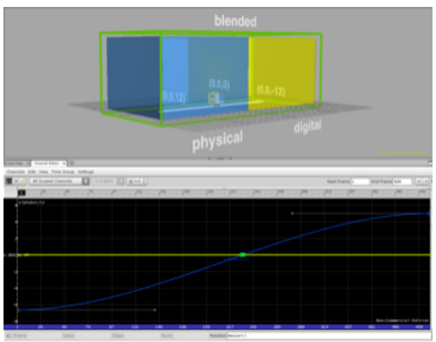


Figure 2. Internal representation of Blended Reality

4.3 Unified coordinate space

Blended reality remaps user interactions in the physical subspace (recorded by the Phasespace motion capture system) into a unified coordinate space, computationally modeled as a superstructure including both the digital and physical spaces. The unified, blended reality coordinate space plots the Z or depth axis so that the zero-crossing matches the threshold point between physical and digital reality. This method clearly delineates the spaces yet permits an animator to smoothly interpolate an animated movement which begins in the digital space and ends in the physical space (and vice-versa) as one continuous movement. The animation curve for the blended reality character's translate Z parameter is shown in Figure 2 with visual emphasis placed on the cross-over point. The system automatically detects the cross-over point and uses it to dynamically control either the digital, computer graphics character or the physical robot. This unified spatial definition further enables the computation of a superphysics model that takes into account the velocity and trajectory of the blended reality character, matching it's speed (incoming or outgoing through the portal) across the boundary in order to maintain kinetic continuity [6]. Techniques from [19] are extensively used and extended including the matching of ground planes across spaces.

4.4 Engineering integrated experience

Providing an integrated experience requires the thoughtful assembly of an experimental media pipeline able to deliver a broad range of cross-modal experiences.

The system is engineered primarily with accessible, off-the-shelf software tools with a bias towards live programming environments that circumvent the more traditional and linear code and compile models. The core system programming is done in real-time with the results directly accessible and visible at all times. This coding *mise-en-scène* enables the designer to receive immediate feedback by tinkering with the "always on" world.

The system's media pipeline integrates an assortment of modules engineered to generate and oversee audio-visual and mobile robotic interactive media.

The system's synthesized graphics, event choreography, signal processing flow, and inter-application communication hub runs in a constantly evolving and experimental Touch project file. Touch is a highly capable, advanced visual programming environment situated at the core of and integral to the execution of this work. The blended reality environment control software provides the necessary animation for the blended reality character and conditions incoming sensor data, mapping it to fit various internal and external uses. Additionally, the software project hosts a scripted, internal logic responsive to event-based, environmental triggers and human interaction with the robot and the space itself.

A private, local network with static IP addresses enables communication between application modules running on separate computers. To ensure the robot can roam unfettered, the system communicates with the robot over a bi-directional XBEE series2 radio transceiver.
The Open Sound Control protocol was chosen as the main inter-application "glue" due to its widespread acceptance as a standard for connecting the most popular digital content creation applications. Both sound software packages (Ableton LIVE, Max/MSP) and the system's control hub, Touch Designer, communicate with each other over OSC.

5. BLENDED REALITY CHARACTER

A Blended reality character is designed to maintain visual and kinetic continuity between the fully virtual and the fully physical. The character is persistent in that it can only exist in one location (or subspace) at a time.

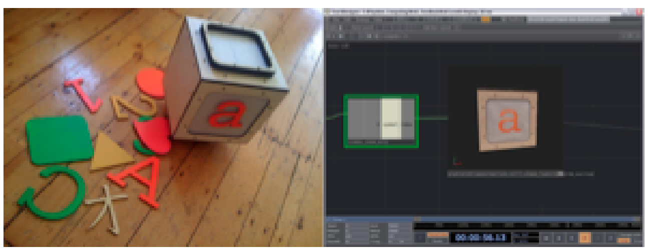
All appearance, movement, actions and attitudes must consistently build towards the character's style or personality. This essence must be maintained across the blended reality context of interaction in order to trigger a social response. Research shows a character doesn't have to look like a real person to give and receive real social responses [18]. Information about personality can come from anywhere. Inconsistencies in the presentation of characters, however, will diminish the purity of personality and thereby contribute to confusion and even dislike. The internal consistency of the character is doubly complicated by it's dual representation in blended reality. A strong, consistent personality embodied in a simple form helps reduce complexity and deliver on expectations. By design, interactions with a blended reality character should be simple and causality must be clearly shown or it will fail. The approach used in designing this blended reality character took as its departure point the concept that children should be able to use what comes naturally as situated learners in the real world with real developmental needs and an insatiable appetite for play.

5.1 The Alphabot

Over three-hundred years ago, English philosopher John Locke in 1693 made one of the first references to alphabet nursery blocks "dice and playthings, with letters on them to teach children the alphabet *by playing*" (emphasis added) [13]. In the early 1700s, Friedrich Wilhelm August Froebel, the pioneer of the kindergarten movement introduced alphabet blocks and in 2003 the alphabet block was inducted into the National Toy Hall of Fame [2][15].

Alphabet blocks were one of the first educational toys for children. They are a mainstay of early learning and nearly every child has spent at least some time playing with alphabet blocks building critical social, creative, cognitive, motor and literacy skills. Moreover, inter-generational play between adults and children with these time-honored blocks has served to deepen family bonds, providing a link between generations. For over three centuries, block play has been providing the whole child with fun developmentally-rich opportunities. Traditionally, the tactile, tangible letter cut into the side of a block is a shape that can be traced by the finger of the child to form cross-sensory, multi-modal memories of the symbol.

Alphabot, an instance of a blended reality character, fashioned after a familiar wooden letter block was designed to be fun, safe and have a modular front face that could accept any symbol reacting to user input both on and off-screen.



5.1.1 *Physical Alphabot*

The physical embodiment of the Alphabot blended reality character is a 12 inch cubed robot designed to resemble an alphabet block. The wooden robot is proportionally smaller than the youngest, standing child and moves predictably and slowly thus portraying a non-threatening demeanor. It enables interactions of many different kinds in the physical environment and can motivate specific play actions through immediate feedback. The top face is as an open tray, left experimentally ambiguous as white space in the design, inviting children's suggested use. Around the outside of the robot are four, small active-IR LEDs used in conjunction with the Phasespace motion capture system to localize the robot in space. The robot is tele-operated by an adult caretaker observing the child-robot interactions. The front velcro face of the robot, structurally supported by a thin sheet of clear acrylic, motivates specific action. Children can experiment with attaching and detaching wooden symbols with embedded RFID tags recognized by the robot and communicated wirelessly to the blended reality media system.

5.1.2 *Alphabot symbol token accesories*

Alphabot's collection of tangible symbol tokens are laser-cut out of the same, high-quality Baltic Birch wood that the robot's body is made with. Serifa, a beautiful serifed font created by prominent Swiss typeface designer Adrian Frutiger in 1967, was chosen for its highly legible quality. Formative research by the Children's Television Workshop on *Ghostwriter,* pointed to the importance of resisting creative and unusual letter shapes and non-standard orientations when presenting text to children [5]. As Alphabot's symbols are intended to exist both in the real world as tangible letter forms as well as animated on-screen, research-validated best-practices are employed to ensure the system is effective at clearly conveying information to children [4].

The system's symbols are a subset of numbers, shapes and letters including international characters. Following fabrication, each symbol is sanded down to smooth out the contours and coated with bright, non-toxic paint. Strips of adhesive velcro on the back provide an easy way to affix and detach the symbols from the robot's front face. Care was taken to design the symbols in a way that makes holding them a pleasure. The intention is to provide children with an opportunity to explore, manipulate and reflect upon the use of artifacts and their possible effects in blended reality play. Two blank square symbols coated with chalkboard paint invite customizations. Children of all ages have enjoyed using chalk to draw faces or anything at all and affixing their creations to Alphabot.

RFID tags

To couple the symbols to the blended reality play experience, 16mm thumbnail-sized RFID button tags are inserted into the back face of each symbol. Each tag comes with a unique 32-bit ID code and is not reprogrammable. The carrier frequency of the tags is 125kHz which works well with the RFID reader (ID Innovations' ID-20) internally mounted inside the robot behind it's front face. The range for the RFID reader to correctly identify the button tags is approximately two inches. The reader can read tags through various materials including wood. In this case, the RFID reader correctly identifies tags through the acrylic and velcro layers on the robot's front face.

Identified symbols immediately trigger the robot's LED to light up Alphabot's face. This lets the child know that the robot has recognized their input. The identified symbol is also sent wirelessly to the main environment control computer which distributes this information to various sub-systems, triggering visible and audible responses.

5.1.3 *Digital Alphabot*

Alphabot's virtual representation is designed to be as consistent as possible with the physical robot version of the character.

5.1.3.1 *3D geometry*

A simple geometric primitive box is all that's needed to represent Alphabot on the screen. This makes the geometry component of Alphabot's digital representation extremely lightweight and easy to render in real-time. In addition to leaving room for other important computations, keeping Alphabot geometrically simple creates opportunities for future migration of the blended reality character onto mobile platforms and other devices lacking 3D graphics prowess.

5.1.3.2 *Surface appearance*

Digital Alphabot's surface appearance leverages a common environment mapping technique known as cube mapping optimized for real-time rendering [8]. To match the appearance of the robot in physical reality, photographs of the physical character wearing each symbol are used as the source for the cube maps. A straight-forward, stock OpenGL Shading Language (GLSL) shader running on the graphics processing unit (GPU) permits the character's surface appearance to adapt to changing lighting conditions in the world, further integrating digital Alphabot into the final blended reality rendered scene [20].

In order to maintain character visual continuity throughout the blended reality play context the digital version of Alphabot's face displays the current symbol placed on the physical robot. To accomplish this, the robot's embedded software program continuously polls the RFID reader and wirelessly transmits a symbol ID to the robot control computer which forwards it on as an OSC message to the main graphics and environment control computer rendering digital Alphabot. Upon receipt, the value is used to switch between all of the possible cube maps depicting the various symbols in the set. The newly selected map is sent to the GLSL shader and the digital Alphabot's face updates, displaying the new symbol. There is no noticeable latency as this process happens at faster than interactive rates.

5.1.4 Animating Blended Reality characters

Alphabot, an instance of a blended reality character, able to fluidly move across the entire span of Milgram's Virtuality Continuum, is animated using traditional keyframed animation as input into a procedural blending subsystem coupled with real-time procedural motion synthesis and performance animation techniques. Animation clips created in industry-standard, 3D animation content creation applications (e.g. Autodesk's Maya) are exported as FBX files, a platform-independent 3D data interchange format and fed into a real-time procedural animation blending engine. This method allows for the integration of hand-crafted 3D animation clip playback, sequencing and event-triggered blending.

5.1.5 Limits of current system

The inexpensive hall-effector's sensors mounted to the back of the robot were unable to provide a stable quadrature signal in the current version of the robot. This restricted the possibility for making the robot autonomous. During the play test studies with children, however, the choice to have a research assistant tele-operate the robot helped acquiesce any parental concerns about the robot's safety around children. As the robot is currently being localized through the motion capture system, a location vector as well as an orientation (heading) quaternion are given, enabling future development of semi-autonomous behavior.

6. INTERACTION DESIGN GUIDELINES

As in traditional animation practice, everything starts with a story. The design of Alphabot's world went through various white board iterations until a consistent story could be told about the three hills. We imagined these hills to exist on the outskirts of Alphabot city. The curved shape of the hills enhance the dramatic effect of having Alphabot come out and play- moving from screen space representation to its mobile robot embodiment.

Despite the flexibility of the authoring environment and the endless affordances of the digital world, the physical interaction space does present some practical constraints. As part of the design philosophy we ensure that the core experience is designed for the appropriate number of child users. Leaving enough space for active, healthy children, we limit our interaction design and experience to a maximum of three children concurrently in the space.

Overall, safety is of utmost concern in all aspects of the work. The robot's motor speeds and thus movement are constrained and checked for safety at two different levels. The physical interaction space is outfitted with soft, padded flooring.

When creating visual media for the system we ensure all contributions remain in cannon with the overall aesthetic design. The rendering style and visual appearance of the world is designed to appear simple and sparse. By foregoing the use of a photorealistic style we author a naif, painterly world with plenty of white space for both the children's imaginations and the possible future inclusion of their own drawings and content.

7. EVALUATION

The study's goal was to evaluate the continuity of the blended reality character and its potential to engage young children in imaginative play scenarios. The design of the study was based on a classic comparison model.

7.1 Experimental conditions

Condition 1: A blended reality scenario in which the child plays with Alphabot (blended reality character) in its environment by exploring the causal effects of placing one of six tangible symbols on the robot and having it physically move into its hutch and watching its virtual representation continue up a hill on the screen in digital space. In this condition we tested 17 children: 11 boys and 6 girls between the ages of 3.5 to 7.

Condition 2: A video-game, virtual scenario of blended reality play with the Alphabot in which the child sits at a desktop computer and plays a symbol-placing game with the Alphabot (screen only) character using a mouse as input. In this condition we tested 17 children: 11 boys and 6 girls between the ages of 3.5 to 7.

The tasks in both conditions were analogous.

7.2 Observational methods

Unobtrusive audio/video recording observational methods were used to document each play test. A three camera setup was used to record: 1. a wide-angle, rear shot, from the point-of-view of the child that framed the entire play scenario 2. a close-up, front shot of the child to enable observation of the child's face and 3. a master shot of the child during the post-play test interview.

7.3 Participants

We play tested 34 children three and a half years old to seven years of age. The development of imaginative play in children begins around two and reaches its peak between the ages of five and seven. We therefore designed the study's blended reality play scenario to be age-appropriate for children in that age range [21].

Seventeen children in each condition play tested the system. The age and gender distribution were evenly matched across both conditions. Children tested in one of the conditions were not permitted to play test the other condition.

7.4 Pre-play test protocol

Upon arrival of the child and their adult guardian or parent to the lab, a research assistant would greet them in the lobby and describe the play test to the parent. Parents were invited to observe the whole experiment but requested to pretend they were busy reading a magazine, in an effort to avoid having the child check in with them or seek their approval during the play test.

7.5 Play test scenario

Each play test lasted approximately ten minutes. During the play test a research assistant would begin by introducing the child to the Alphabot character on-screen (in digital space). The children were then invited to tickle the character by touching the character on the screen with their hands (Condition 1) or with the mouse-pointer (Condition 2). The researcher would model this interaction by tickling the on-screen character causing it to spin around or hop up and down. Following a verbal request for Alphabot to "come out and play," the character would appear to descend down the virtual hill in the on-screen, digital space and would promptly emerge into the physical space (Condition 1) or the virtual physical space (Condition 2), through the hutch or interreality portal. The character would then move around freely in the physical space stopping in front of the child and symbols spread out on the floor (Condition 1) or on-screen (Condition 2).

The researcher would proceed by demonstrating the process of changing the symbol on the character's face. In turn, the character would react by moving towards the hutch, the doors would open allowing the character to pass through and the character's virtual representation would be seen moving up the hill in digital space. Arriving at the top, the character's symbol would be displayed on its face where the child placed it, and express itself clearly, establishing causality. Throughout the main portion of the play test the child was given the autonomy to play freely and choose any symbol in any order or sequence, imagining the possible outcomes.

As the play test came to an end the sky in the digital space would darken simulating a sunset. The blended reality character would return to the hutch and move up to the hill and the child would be informed that the Alphabot was going to take a nap.

7.6 Interview protocol

Immediately following the end of the play test, a research assistant would ask the child if they wouldn't mind answering a couple questions. They would then escort the child out of the space to a separate area with a child-sized table and chairs. The interview questions were structured to be brief, to the point and made use of age-appropriate language.

We also presented the child with a simplistic diagram of the blended reality play space depicting the screen, hutch and physical play space, including the framing of the screen and physical space. Children were asked to point to the location on the diagram in response to various questions. The interviewer coded the children's responses using a consistent nomenclature scheme across both conditions.

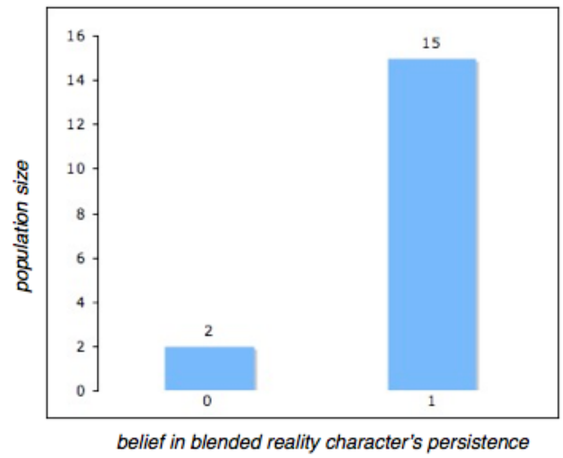
In addition, we asked each child if they wanted to give us any suggestions on how to improve Alphabot. This question also helped us determine their level of engagement and belief in the character.

Finally, we asked them to draw a picture for Alphabot and suggested that we could give it to him. We gave each child space to freely associate and tell us a story (reflecting on their experience).

7.7 Validated evaluation instrument

To help children understand what was expected of them, response options were presented to them in picture form using a Likert-type scale. For our study, we found that the Smiley Face Assessment Scale (SFAS) was a useful, validated evaluation instrument that removed confusion for the child. Explaining the 5-point continuum to the child by pointing at each face and describing them as "very happy, happy... sad," helped but was often not a requirement to get a clear answer. Hopkins and Stanley have shown that pictorial response scales are sometimes more effective for assessing attitudes, especially for children [10].

7.8 Results



7.9.1 Acceptance of Blended Reality character

Based on experimental results, our findings show that children aged three and a half to seven have accepted the idea of a blended reality character. To assess the character's continuity from physical space to digital space we asked children to identify the total number of Alphabot characters. Children who believed in the character's persistence across the blended reality play context were assigned a value of one, whereas those who identified the incorrect number of characters were assigned a zero value. Positive affirmation of the blended reality character's continuity across multiple forms of media (screen and robotic), also indicates belief in its world as the two are inextricably tied together.

7.9.2 Impact on character engagement and play

To uncover the core differences we studied the post-play test video interviews and tallied the number of children's responses to the question: "What would you want Alphabot to do?" This helped give us an indication of how deeply engaged they were with the blended-reality character.

Based on the large number of imaginative suggestions received from the children who participated in the blended reality play experience (condition 1) in comparison to the low number of answers in condition 2, we found that the blended reality play experience had a significant impact on children's post-play test verbal utterances and imaginative suggestions.

Following play tests in the first condition (blended reality play) 87% of the children tested made detailed suggestions on what they would want Alphabot to do, while 13% did not respond. In comparison, only 3 out of 17 children or 18% of the children who play tested condition 2 (virtual blended reality) replied with imaginative suggestions. Eighty-two percent of the children who did not experience blended reality play with Alphabot abstained from answering the question: "What would you want Alphabot to do?" showing a marked decrease in interest and engagement with the character when confined to the screen.

These results suggest that for the population tested, blended reality play experiences lead to a deeper engagement with a character able to transmediate between a screen and physical reality in the form of a mobile robot in comparison to a strictly screen-based character. Furthermore, providing a blended reality play experience for children between the ages of three and a half and seven results in a notable increase in the number of post-play imaginative suggestions and creative ideation. Additionally, the study revealed a noticeable difference in the imaginative quality of the suggestions in both cases. In the control experiment (condition 2), children suggested that Alphabot should be able to dance and jump more. In condition 1 (blended reality) children also wished that Alphabot could dance and jump, as well as fly, play soccer, be a wind-up jack-in-the-box toy and go upside down. These qualitative differences also indicate deeper engagement with the blended reality character.

7.9.3 Situating the character

One of the compelling results the study uncovered in connection with the acceptance of the blended reality character was the children's views on where the blended reality character lived and played.

Asked to point to a spot in a diagram depicting the entire blended reality play context including the physical space, hutch and digital space, 65% of the children in condition 1 (blended reality) replied that the character lived in digital space and 35% replied that it lived in the hutch. None of the children replied that the character lived in physical space, despite playing with and touching the physical robot.

It is difficult to say whether the children conceived of the hutch as part of physical reality or as a distinct, liminal space between physical reality and the digital space on screen. Interestingly, the responses varied by gender, with the majority of boys (82%) asserting the character lived in digital space whereas the majority of girls (67%) replied that the blended reality character lived in the hutch.

Although almost two-thirds of the children in condition 1 thought the character lived in digital space, fifty percent replied that it played in physical space (with them). The second most common response (31% of the children) held that the character played in digital space. None of the children answered that it played in the hutch. Three of the girls did not answer making a gender comparison in this case difficult.

In the control experiment (condition 2: virtual blended reality video game), 65% of the children replied that the character played in digital space while 29% asserted that it played in virtual physical reality. Nine percent answered that it played in the hutch.

One of the boys in condition 2, got up from his chair and looked behind the flat-screen computer monitor when Alphabot went into the digital (screen space) in the game.

Results from this part of the study may prompt further investigation together with a deeper consideration of children's spatial reasoning abilities in light of their age and individual developmental stage. Given the unique spatial arrangement that blended reality affords, it may prove fruitful as a medium to explore what Dr. Howard Gardner, founder of the multiple intelligences theory, terms *spatial intelligence* as it emerges in young children [Gar83].

7.9.4 Interreality transit

The trend in providing richer detail and more imaginative responses in post-play test interviews of children who experienced blended reality play, in contrast to those who play tested the virtual version (condition 2), prevailed as evidenced by responses to the question: "What happens when Alphabot goes from "here" (pointing at the physical space in the diagram) to "there" (pointing at the digital space)?

In condition 2, children offered unvarnished, factual responses like, "It's triggered by a symbol" and "He changes himself". By contrast, blended reality play testers (in condition 1) came up with unexpected and imaginative explanations like, "He takes a train to get from here to there." Another explained that Alphabot had jumped through and yet another child simply answered, "Noise." Suffice it to say that making sense of these answers is challenging at best. What is apparent is the change in tonality between the more realistic answers given in condition 2 compared to the more inventive descriptions offered by children who engaged in blended reality play.

7.9.5 Symbol use

As an initial step towards a pedagogic use of Alphabot's symbol system to guide children's informal learning, we asked them to recall the effect of placing a symbol on the character in both conditions. Sixty-four percent of the interviewed children in both conditions verbally recalled a symbol. Some of the children that did not verbally recall a particular symbol during the interview, drew them when they were given time alone to reflect and draw freely. One child drew the Japanese symbol on Alphabot and added jet packs as well as two letter "P"s, a symbol not found in the play test set. Several children drew alphabots with hearts. Another child drew Alphabot with the number three and yet another with the letter "a". A four year old girl told us "I hope Alphabot gets to see my picture, I'm drawing alphabets."

The most commonly recalled symbol in condition 1 (as recorded during the interview) was the mustache. This was likely due to its ability to trigger a world scene change, transporting them to a cafe in France. In virtual blended reality, the most commonly recalled symbol was the heart, likely due to the visual magnitude of its on-screen effect (an explosive outpour of hearts).

7.9.6 Sustained appeal of blended reality play

Despite the relatively short (ten minute) duration of the blended reality scenario tested, several children expressed a desire to continue engaging in the experience. "I want to come back and play with Alphabot," one child mentioned. Another stated, "I want to play with Alphabot's friend in Japan". Children in the control experiment did not express similar wishes. They did not ask to replay the condition 2 video game of virtual blended reality. In comparison, a condition 1 play tester grew impatient with the interview process and asked, "Can we play with Alphabot now?"

The long-term appeal of blended reality play is yet to be determined. Initial evidence, however, points towards children's desire to revisit and extend their play time with Alphabot in blended reality.

7.9.7 Children's drawings

Overall, children drew more pictures following their play experience in condition 1 (blended reality) than after condition 2 (virtual blended reality). In condition 1, children drew the blended reality environment often depicting themselves and the character together. In contrast, in condition 2 children drew the Alphabot character alone and did not draw themselves.

One of the interesting themes that emerged from children's drawings after experiencing condition 1 was the apparent switch or blending of spaces in their illustrations. Hills and flowers that they experienced existing strictly in the digital world were drawn in the representation of the physical space. In one case, a five year old boy drew the whole blended reality context seemingly from the inside out.

One boy impressively recalled the Japanese character, added symbols not found in the play set and gave the Alphabot jet packs. These drawings do call for further analysis by an expert in the field. It is important to note, however, that these drawings should be respected for their own artistic merit and caution should be used when making interpretive assumptions.

8. CONCLUSION

The play test study's findings unequivocally demonstrate that young children (3.5 to 7 years old) have accepted blended reality characters. Results show that young children believe in the continuity and persistence of a blended reality character across multiple forms of media.

As indicated through interviews and drawings, the play tests reveal significant qualitative and quantitative differences in children's engagement with blended reality characters over strictly screen-based characters. Deeper engagement is indicated by the length of verbal utterances, the more descriptive and imaginative qualities of children's responses to interview questions and the number of drawings produced.

In blended reality, children experience a deeper sense of immersion. The difference in the number of post-play test drawings in which children depicted themselves playing with the character in its blended reality world suggests that children see themselves as co-protagonists, immersed in blended reality play. Belief in the continuity and persistence of the blended reality character seems to be inextricably tied to belief in the persistence of the character's world.

The desire to continue engaging in blended reality play as expressed by children's verbal requests to revisit and extend their play time with the character shows the potential for development of an informal learning platform with sustained appeal to young children.

9. ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Personal Robots Group and the MIT Media Lab community. Special thanks go to Adam Setapen for designing and fabricating the robot hutch and collaborating with Natalie Freed on the robot control software and embedded code. Natalie Freed was also instrumental in designing the robot's electronics. Fardad Faridi graced our environment with appealing visual imagery- Thank you. The play test eval team comprised of a generous and talented mix of Harvard Graduate School of Education and MIT students along with volunteers were integral to conducting the evaluation.

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